IEC 60099-8

Edition 2.0 2017-11
REDLINE VERSION

INTERNATIONAL STANDARD

colour inside

Surge arresters –
Part 8: Metal-oxide surge arresters with external series gap (EGLA) for overhead transmission and distribution lines of a.c. systems above 1 kV

IEC 60099-8:2017-11 RLV(en)

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CONTENTS

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SURGE ARRESTERS –

Part 8: Metal-oxide surge arresters with external series gap (EGLA) for overhead transmission and distribution lines of a.c. systems above 1 kV

FOREWORD

This redline version of the official IEC Standard allows the user to identify the changes made to the previous edition. A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text.

International Standard IEC 60099-8 has been prepared by IEC technical committee 37: Surge arresters.

This second edition cancels and replaces the first edition published in 2011. This edition constitutes a technical revision.

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

a) The Lightning discharge capability test has been completely re-written and re-named to Test to verify the repetitive charge transfer rating, Qrs with lightning discharges to reflect changes introduced in IEC 60099-4 Ed. 3 (2014) regarding new methods for rating the energy and charge handling capability of metal-oxide arresters. In addition to testing to evaluate the performance of the MO resistors, procedures for evaluating the performance of the EGLA series gaps have been introduced.
b) Omissions from Ed. 1 of this standard have been included, notably an RIV test and a means for determining the thermal time constant of the SUV portion of the EGLA.
c) Definitions for new terms have been added
d) A number of NOTES in Ed. 1 have been converted to normative requirements

A number of editorial changes have been made throughout the document to improve grammar and general flow of information.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
37/436/FDIS	37/438/RVD

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

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

A list of all parts of IEC 60098 series, under the general title *Surge arresters*, can be found on the IEC website.

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

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

A bilingual version of this publication may be issued at a later date.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

This part of IEC 60099 applies to the externally gapped line arrester (EGLA)

This type of surge arrester is connected directly in parallel with an insulator assembly. It comprises a series varistor unit (SVU), made up from non-linear metal-oxide resistors encapsulated in a polymer or porcelain housing, and an external series gap (see Figure 1).

The purpose of an EGLA is to protect the parallel-connected insulator assembly from lightning-caused over-voltages. The external series gap, therefore, should spark over only due to fast-front over-voltages. The gap should withstand all power-frequency and slow-front over-voltages occurring on the system.

In the event of SVU failure, the external series gap should be able to isolate the SVU from the system.

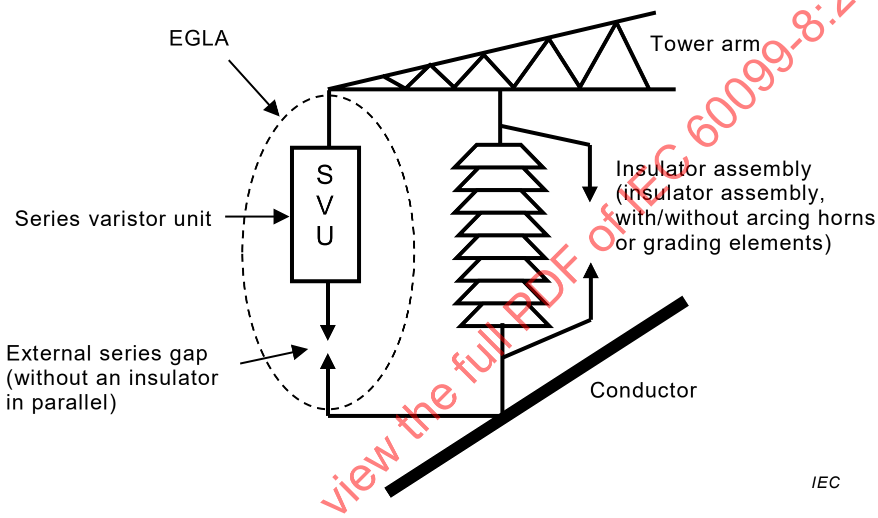


Figure 1 – Configuration of an EGLA with insulator and arcing horn

SURGE ARRESTERS –

Part 8: Metal-oxide surge arresters with external series gap (EGLA) for overhead transmission and distribution lines of a.c. systems above 1 kV

1 Scope

This part of IEC 60099 covers metal-oxide surge arresters with external series gap (externally gapped line arresters (EGLA)) that are applied on overhead transmission and distribution lines, only to protect insulator assemblies from lightning-caused flashovers.

This document defines surge arresters to protect the insulator assembly from lightning-caused over-voltages only. Therefore, and since metal-oxide resistors are not permanently connected to the line, the following items are not considered for this document:

- switching impulse spark-over voltage;
- residual voltage at steep current and switching current impulse;
- thermal stability;
- long-duration current impulse withstand duty;
- power-frequency voltage versus time characteristics of an arrester;
- disconnector test;
- aging duties by power-frequency voltage.

Considering the particular design concept and the special application on overhead transmission and distribution lines, some unique requirements and tests are introduced, such as the verification test for coordination between insulator withstand and EGLA protective level, the follow current interrupting test, mechanical load tests, etc.

Designs with the EGLA's external series gap installed in parallel to an insulator are not covered by this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60060-1:~~1989~~ 2010, *High-voltage test techniques – Part 1: General definitions and test requirements*

IEC 60060-2:~~1994~~ 2010, *High-voltage test techniques – Part 2: Measuring systems*

IEC 60068-2-11:1981, *Basic environmental testing procedures – Part 2-11: Tests – Test Ka: Salt mist*

IEC 60068-2-14:2009, *Environmental testing – Part 2-14: Tests – Test N: Change of temperature*

IEC 60099-4:~~2009~~ 2014, *Surge arresters – Part 4: Metal-oxide surge arresters without gaps for a.c. systems*

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

IEC 60507:~~1991~~ 2013, *Artificial pollution tests on high-voltage ceramic and glass insulators to be used on a.c. systems*

IEC TS 60815-1:2008, *Selection and dimensioning of high-voltage insulators intended for use in polluted conditions – Part 1: Definitions, information and general principles*

IEC 62217:~~2005~~ 2012, *Polymeric HV insulators for indoor and outdoor use ~~with a nominal voltage > 1 000 V~~ – General definitions, test methods and acceptance criteria*

~~ISO 3274, *Geometric product specifications (GPS) – Surface texture: Profile method – Nominal characteristics of contact (stylus) instruments*~~

ISO 4287, *Geometrical Product Specifications (GPS) – Surface texture: Profile method – Terms, definitions and surface texture parameters*

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 sources*

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

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
externally gapped line arrester
EGLA
arrester designed for installation on overhead lines to protect an insulator assembly from lightning-caused fast-front over-voltages only

Note 1 to entry: This is accomplished by raising the spark-over level of the external series gap to a level that isolates the arrester from power-frequency over-voltages and from the worst case slow-front over-voltages due to switching and fault events expected on the line to which it is applied.

3.2
series varistor unit
SVU
non-linear metal-oxide resistor part, contained in a housing, which must be connected with an external series gap to construct the complete arrester

Note 1 to entry: The series varistor unit may include several units.

3.3
section of an EGLA
complete, suitably assembled part of a complete EGLA necessary to represent the behaviour of a complete EGLA with respect to a particular test

3.4
section of an SVU
complete, suitably assembled part of an SVU unit necessary to represent the behaviour of an SVU with respect to a particular test

3.5
unit of an SVU
completely housed part of an SVU which may be connected in series and/or in parallel with other units of an SVU to construct, in combination with the external series gap, an EGLA of higher voltage and/or current rating

3.6
rated voltage of an EGLA
U_r
maximum permissible r.m.s. value of power-frequency voltage that can be applied continuously between the EGLA terminals, and at which it is designed to operate correctly

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

Note 2 to entry: ~~Different to the rated voltage of gapless (line) arresters,~~ The rated voltage of an EGLA is ~~a voltage that may be applied continuously~~ comparable to Uc of all other types of MO-arresters.

3.7
reference voltage of an SVU
U_{ref}
peak value of power-frequency voltage divided by √2, which should be applied to the SVU to obtain the reference current

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

3.8
reference current of an SVU
I_{ref}
peak value (the higher peak value of the two polarities if the current is asymmetrical) of the resistive component of a power-frequency current used to determine the reference voltage of the SVU

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 SVU units negligible. It is to be specified by the manufacturer.

Note 2 to entry: Depending on the nominal discharge current of the EGLA, the reference current will be typically in the range of 0,05 mA to 1,0 mA per square centimetre of metal-oxide resistor area for a single column SVU.

3.9
rated short-circuit current of an SVU
I_s
r.m.s. value of the highest short-circuit current under which the SUV will not fail in a manner that causes violent shattering of the housing and under which self-extinguishing of open flames (if any) will occur within a defined period of time

3.10
residual voltage of an EGLA
peak value of voltage that appears across the terminal-to-terminal length of the EGLA including series gap and connection leads during the passage of discharge current

3.11
residual voltage of an SVU
peak value of voltage that appears between the terminals of the SVU during the passage of discharge current

3.12
surface leakage current of an SVU
current that flows on the surface of the SVU

3.13
follow current
I_{follow}
the current immediately following an impulse through an EGLA with the power-frequency voltage as the source

3.14
specified long-term load of an SVU
SLL
mechanical force perpendicular to the longitudinal axis of an SVU, allowed to be continuously applied during service without causing any mechanical damage to the SVU

3.15
specified short-term load of an SVU
SSL
greatest mechanical force perpendicular to the longitudinal axis of an SVU, 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 SVU

3.16
mean breaking load of an SVU
MBL
average breaking load for porcelain or cast resin-housed SVUs determined from tests

3.17
high current impulse
peak value of discharge current having a 4/10 or 2/20 impulse shape, which is used to test the withstand capability of the SVU on extreme lightning occasions

3.18
salt deposit density
SDD
amount of salt in the deposit on a given surface of the SVU housing, divided by the area of this surface; generally expressed in mg/cm^2

3.19
verification test for coordination between insulator withstand and EGLA protective level
test used to verify that the EGLA will exhibit correct sparkover operation and clamp the overvoltage caused by lightning considerably lower than the flashover voltage of the parallel-connected insulator assembly

3.20
vibration withstand test
test to verify that the SVU and its connectors can withstand the specified mechanical vibration levels

3.21
lightning impulse discharge
approximately sine half-wave current impulse having a time duration within 200 μs to 230 μs during which the instantaneous value of the impulse current is between 5 % and 100 % of its peak value

3.22
repetitive charge transfer rating
Q_{rs}
maximum specified charge transfer capability of an EGLA, in the form of a single event or group of surges that may be transferred through an EGLA without causing mechanical failure or unacceptable electrical degradation to the MO resistors

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.

4 Identification and classification

4.1 EGLA identification

An EGLA shall be identified by the following minimum information, which shall appear on a nameplate permanently attached to the arrester:

- rated voltage U_r in kV;
- rated frequency in Hz, only if it is less than 48 Hz or larger than 62 Hz;
- classification series information (examples: "X1", "Y2");
- rated short-circuit current I_s in kA;
- manufacturer’s name or trade mark;
- year of manufacture;
- serial number (at least for arresters for ~~U_m~~ U_s > 52 kV);
- lightning discharge capability (only charge value) in C; example: "~~8~~ 0.4 C".

Information on required gap spacing including tolerances shall be given in an appropriate way, for example in the manual.

4.2 EGLA classification

EGLAs are classified by their nominal discharge currents and their high current impulse withstand capabilities as per Table 1, and they shall meet at least the test requirements and performance characteristics specified in Table 3. These arresters have no operating duties for slow-front surges and power-frequency over-voltages.

Table 1 – EGLA classification – "Series X" and "Series Y"

Series X					Series Y				
Class name	X1	X2	X3	X4	Class name	Y1	Y2	Y3	Y4
Nominal discharge current (kA), 8/20	5	5	10	20	Nominal discharge current (kA), 2/20	5	10	15	20
High current impulse (kA), 4/10	40	65	100	100	High current impulse (kA), 2/20	10	25	40	65

~~NOTE 1~~ "Series X" corresponds to the classification used in IEC 60099-4. A nominal discharge current of 8/20 wave shape and a high current impulse of 4/10 wave shape are used in IEC and in IEEE standards. "Series Y" corresponds to the classification applied e.g. in Japan on shielded line applications. Specification of wave shape 2/20 both for the nominal discharge current and for the high current impulse is based on this special application.

~~NOTE 2~~ According to service conditions, other high current impulse values than those specified in this table may be applied.

5 Standard ratings and service conditions

5.1 Standard rated voltages

Standard values of rated voltages (r.m.s. values) are specified in Table 2 in equal voltage steps within specified voltage ranges.

Table 2 – Steps of rated voltages (r.m.s. values)

Range of rated voltages (kV)	**Steps of rated voltage** (kV)
3 to 30	1
> 30 to 54	3
> 54 to 96	6
> 96 to 288	12
> 288 to 396	18
> 396	24

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

5.2 Standard rated frequencies

The standard rated frequencies are 48 Hz to 62 Hz.

5.3 Standard nominal discharge currents

The standard nominal discharge currents for 8/20 or 2/20 shapes are: 5 kA, 10 kA, 15 kA and 20 kA.

5.4 Service conditions

5.4.1 Normal service conditions

EGLAs which conform to this document shall be suitable for normal operation under the following normal service conditions:

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

b) altitude not exceeding 1000 m;

c) frequency of the a.c. power supply not less than 48 Hz and not more than 62 Hz;

d) power-frequency voltage applied continuously between the terminals of the EGLA not exceeding its rated voltage;

e) mechanical conditions: not specified (see NOTE);

f) wind speed: not specified (see NOTE);

g) pollution conditions: pollution by dust, smoke, corrosive gases, vapours or salt may occur; pollution does not exceed “heavy” as defined in IEC TS 60815-1.

NOTE It is recognized that mechanical and environmental issues are important for service, but due to the large variety of possible installation configurations it is not possible to provide standard values for items e) and f).

5.4.2 ~~Abnormal~~ Special 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 document in case of ~~abnormal~~ special service conditions ~~shall be~~ is subject to agreement between the manufacturer and the purchaser. A list of possible special service conditions is given in Annex C.

6 Requirements

6.1 Insulation withstand of the SVU and the complete EGLA

6.1.1 Insulation withstand of the housing of the SVU

The housing of the SVU shall withstand a lightning impulse voltage of

a) for "Series X": 1,4 times the residual voltage at the nominal discharge current

b) for "Series Y": 1,13 times the residual voltage at high current impulse, but not less than 1,3 times the residual voltage at nominal discharge current

NOTE The factor of 1,4 in case a) covers variations in atmospheric conditions up to 1 000m altitude and discharge currents up to three times the nominal discharge current.

6.1.2 Insulation withstand of EGLA with shorted (failed) SVU

The EGLA shall have the following insulation withstand performance:

a) the EGLA shall withstand the specified switching impulse withstand voltage level of the system even if the SVU has been shorted due to overloading (failure);

b) the EGLA shall be able to withstand the maximum temporary over-voltages phase to ground for their maximum durations even if the SVU has been shorted due to overloading (failure).

6.2 Residual voltages

The purpose of the measurement of residual voltages is to obtain the maximum residual voltages for a given design for all specified currents and 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 EGLA design for any current and wave shape is calculated from the residual voltage of SVU sections tested during type tests multiplied by a specific scale factor plus a calculated inductive voltage drop across the SVU, the gap and connection leads. The 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.

The value of the residual voltage of the EGLA at nominal discharge current and at high current impulse, respectively, multiplied by a factor as given in 6.1.1, shall be lower than the minimum flashover voltage of the insulator assembly to be protected.

6.3 High current duty

The capability of the SVU for discharging operations shall be demonstrated by injecting two high current impulses.

6.4 Lightning discharge capability

The capability of the metal-oxide resistors including the series gap of the EGLA to withstand lightning discharges having current waveforms with durations of several tens of microseconds for arresters applied on shielded lines and several hundreds of microseconds for arresters on unshielded lines shall be demonstrated. The related test also covers effects of multiple lightning strikes.

6.5 Short-circuit performance of the SVU

The manufacturer shall claim a short-circuit rating of the SVU. The short-circuit currents according to this rating shall not cause violent shattering of the SVU, and any open flames shall self-extinguish in a given time.

~~NOTE~~ The gap is not subject of the short-circuit tests on the SVU, and its short-circuit performance ~~should~~ is recommended to be verified separately. The gap should be able to maintain its mechanical integrity after having been subjected to the rated short-circuit current of the EGLA, and its spark-over voltage should not be decreased.

6.6 Mechanical performance

For the EGLA to be mounted on transmission towers or poles, mechanical performance to withstand tensile, bending and/or vibration loads due to wind pressure, conductor vibration abnormal load during installation work and moisture ingress shall be demonstrated.

The applicable values of tensile and bending loads shall be agreed between the manufacturer and the purchaser.

The SVU shall be able to withstand the vibration load to be expected in service.

~~NOTE~~ The complete EGLA including gap assembly and mounting structure should be able to withstand at least the same mechanical stress.

6.7 Weather aging of SVU

The SVU must be able to withstand the environmental stress expected in service. Environmental tests demonstrate by accelerated test procedures that the sealing mechanism and the exposed metal combinations of the SVU are not impaired by environmental conditions. For SVUs with polymer (composite and cast resin) housings, resistance to UV radiation has to be demonstrated in addition.

~~NOTE A revision of the UV test is currently under consideration by Cigré WG D1.14.~~

6.8 Reference voltage of the SVU

The reference voltage (U_{ref}) of the SVU shall be measured at the reference current on sections and units when required. The measurement shall be performed at an ambient temperature of 20 °C ± 15 K, and the actual temperature shall be recorded.

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

6.9 Internal partial discharges

The level of internal partial discharges in the SVU in the tests according to 9.1 and 10.3 shall not exceed 10 pC.

6.10 Coordination between insulator withstand and EGLA protective level

The correct coordination between flashover characteristics of the insulator assembly, the spark-over voltage of the EGLA with front-of-wave and standard lightning impulses and the residual voltage of the EGLA at nominal discharge current and, for “Series Y” arresters, at high current impulse shall be demonstrated.

Any spark-over operation for lightning impulse voltage shall occur in the external series gap of the EGLA, without causing any flashover of the insulator assembly to be protected.

The value of

- for "Series X": 1,4 times the residual voltage at the nominal discharge current according to Table 1 and 8.3.3;
- for "Series Y": 1,13 times the residual voltage at high current impulse, but not less than 1,3 times the residual voltage at nominal discharge current according to Table 1 and 8.3.3 and 8.3.4.

must be lower than $U_{50,\ \mathrm{Insulator}}$ minus X times the standard deviation, ($U_{50,\ \mathrm{Insulator}} - X \times \sigma$), of the insulator assembly to be protected, where σ = 0,03 and X is to be agreed upon between manufacturer and user, a recommended value being X = 2,5.

6.11 Follow current interrupting

Follow current interrupting operation of the EGLA under wet and polluted conditions shall be demonstrated by a test procedure which takes these operating conditions into account. Performing a follow current interrupting test is mandatory, either as a type test according to 8.8 or as an acceptance test according to 10.6.

6.12 Electromagnetic compatibility

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

In normal working operating conditions, the EGLA shall not emit significant disturbances. A radio interference voltage test (RIV) shall be applied as an acceptance test to the complete EGLA (see 10.4). The maximum radio interference level of the EGLA energized at the maximum continuous phase to ground system voltage ($U_s/\sqrt{3}$) shall not exceed 2 500 µV.

6.13 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.

7 General testing procedure

7.1 Measuring equipment and ~~accuracy~~ uncertainty

The measuring equipment shall meet the requirements of IEC 60060-2 and IEC 60099-4. The values obtained shall be accepted as ~~accurate~~ uncertainty 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.

7.2 Test samples

Unless otherwise specified, for each test item, the complete test sequence shall be carried out on the same test sample. The number of test samples is given in Table 3. The test samples shall be new, clean, completely assembled and arranged to simulate the condition in service.

When tests are made on sections or units, the following shall be fulfilled:

a) The ratio between rated voltage of the complete EGLA to the rated voltage of the section or unit is defined as n.

b) 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 EGLA divided by n.

c) The reference voltage U_{ref} of the SVU of the test section should be equal to the minimum reference voltage of the SVU of the EGLA divided by n. If the reference voltage of the SVU of the test section is greater than the minimum reference voltage of the SVU of the complete EGLA divided by n, the factor n shall be reduced correspondingly. If the reference voltage of the SVU of the test section is less than the minimum reference voltage of the SVU of the complete EGLA divided by n, the test section is not allowed to be used.

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

8 Type tests

8.1 General

Table 3 identifies the type tests that shall be performed on the complete EGLA or on components of the EGLA.

Table 3 – Type tests (all tests to be performed with or without insulator assembly; by manufacturer's decision)

Test item	Number of test samples	EGLA	Section of EGLA	Unit of SVU	Section of SVU	Clause number
Insulation withstand tests						
1.1 Housing withstand test of SVU	1			Test		8.2.2
1.2 EGLA withstand test with failed SVU	1	Test				8.2.3
2. Residual voltage tests	3				Test	8.3
3. Standard lightning impulse sparkover test a)	1	Test				8.4
4. High current impulse withstand test	3				Test	8.5
~~5 Lightning discharge capability test~~	~~3~~				~~Test~~	~~8.6~~
5. Test to verify the repetitive charge transfer rating, Q_{rs} with lightning discharges: MO resistors	10 (20)				Test	8.6.1
6. Test to verify the repetitive charge transfer rating, Q_{rs} with lightning discharges Series gap	1				Test	8.6.2
7. Short-circuit tests	4 or 5			Test		8.7
8. Follow current interrupting test b)	1	Test c)	Test c)			8.8
9. Bending test	3 or 6			Test		8.9.2
10. Vibration test d)	1			Test e)		8.9.3
11. Weather aging test	1			Test		8.10
12. Radio interference voltage (RIV) test	1	Test f)				8.11

a) This test is mandatory if not performed as an acceptance test in accordance with 10.5.

b) This test is mandatory if not performed as an acceptance test in accordance with 10.6.

c) This test is performed either on a complete EGLA or a section of an EGLA, see 8.8.2.

d) This test is mandatory if not performed as an acceptance test in accordance with 10.7.

e) The vibration test is performed on one complete SVU, see 8.9.3.1

f) This test is mandatory if not performed as an acceptance test in accordance with 10.4

8.2 Insulation withstand tests on the SVU housing and on the EGLA with failed SVU

8.2.1 General

These tests demonstrate the lightning impulse withstand voltage of the SVU housing under dry conditions and the withstand voltage of the EGLA against the maximum expected switching surge and power-frequency over-voltages in the system under wet conditions if the SVU had failed and is shorted.

8.2.2 Insulation withstand test on the SVU housing

8.2.2.1 General

This test demonstrates the dielectric withstand capability of the external housing of the SVU against lightning impulse voltages.

8.2.2.2 Test procedure

The SVU housing shall be subjected to a standard lightning impulse voltage dry test according to procedure B in 7.3.1.2 of IEC 60060-1:2010.

The test shall be performed on the SVU housing with the highest specific voltage stress per unit length. The non-linear metal-oxide resistors shall be removed or replaced by parts of insulating material.

Fifteen consecutive impulses at the test voltage value shall be applied for each polarity.

Test voltage:

a) for "Series X": 1,4 times the residual voltage at the nominal discharge current according to Table 1 and 8.3.3.

b) for "Series Y": 1,13 times the residual voltage at high current impulse, but not less than 1,3 times the residual voltage at nominal discharge current according to Table 1 and 8.3.3 and 8.3.4.

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

Evaluation: The SVU shall be considered to have passed the test if the number of external disruptive discharges does not exceed two in each series of 15 impulses.

8.2.3 Insulation withstand tests on EGLA with failed SVU

8.2.3.1 General

A switching impulse wet withstand voltage test and a power-frequency wet withstand voltage test shall be performed simulating a failed SVU. The purpose of these tests is to demonstrate that no spark-over under switching surge and power-frequency over-voltages will occur if, as the worst case scenario, the SVU is shorted by a failure.

8.2.3.2 Switching impulse wet withstand voltage test

Test procedure

The test procedure shall be as follows:

Test sample: EGLA with shorted SVU. The failed SVU shall be simulated by shorting the SVU with a metal wire, while the electrode condition shall be specified after agreement between the manufacturer and the purchaser. The minimum external series gap length for the test shall be specified by the manufacturer.

Test voltage and test condition:

a) The withstand voltage value shall be claimed by the manufacturer or determined by agreement between the manufacturer and the purchaser, considering the ~~actual~~ maximum prospective switching impulse ~~withstand~~ over voltage level of the line. The altitude of installation and of the test laboratory shall be considered to determine the test voltages.

b) The 50 % flashover voltage ($U_{50,\ \mathrm{EGLA}}$) is measured by the up-and-down method in accordance with IEC 60060-1 for each polarity on the EGLA with the SVU shorted. The wave shape of the test voltage shall be 250/2500.

c) The characteristic of the rain shall be in accordance with the requirements of IEC 60060-1.

Evaluation: The withstand voltage of the EGLA is determined as

$$U_{10,\ \mathrm{EGLA}} = U_{50,\ \mathrm{EGLA}}\ (1 - 1{,}3\ \sigma),$$

calculated from the measured 50 % flashover voltage and the standard deviation σ, which is assumed to be 6 % (σ = 0,06) for switching impulse voltage. The EGLA has passed the test if the withstand value is equal to or higher than the claimed or agreed value.

NOTE For a normal distribution, as assumed here, the 10 % probability value results from the 50 % probability value minus 1,3 times the standard deviation.

8.2.3.3 Power-frequency wet withstand voltage test

The test procedure shall be as follows:

Test sample: EGLA with shorted SVU. The failed SVU shall be simulated by shorting the SVU with a metal wire. The minimum external series gap length and the conditions of the gap electrodes shall be specified by the manufacturer or agreed upon between the manufacturer and the user.

Test voltage and test condition:

a) The power-frequency wet withstand voltage test shall be performed in accordance with IEC 60060-1 on the EGLA with the SVU shorted.

b) The test voltage shall be 1,2 times the rated voltage of the EGLA.

c) The characteristic of the rain shall be in accordance with the requirements of IEC 60060-1.

Evaluation: The EGLA has passed the test if the sample withstands the test voltage for one minute.

8.3 Residual voltage tests

8.3.1 General

This test demonstrates that the residual voltages of the SVU and complete EGLA under lightning impulses are in accordance with the claimed values. All residual voltage tests shall be made on the same three sections of an SVU. The time between discharges shall be sufficient to allow the samples to return to approximately ambient temperature. The residual voltage of the EGLA is calculated from the measured residual voltage of the SVU sections times a scale factor plus a calculated inductive voltage drop across the SVU, the gap and the connection leads. The residual voltage of the SVU is calculated from the measured residual voltage of the SVU sections times a scale factor plus a calculated inductive voltage drop across the SVU.

8.3.2 Procedure for correction and calculation of inductive voltages

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

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

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

Procedure a)

1) Multiply the sample impulse voltage wave shape by the scale factor (see 6.2).
2) From the wave shape of the current impulse, determine the rate of change of current ($\mathrm{d}i/\mathrm{d}t$) over the entire wave shape and multiply it by the inductance in order to determine the inductive voltage drop:

$$u(t) = L \cdot \frac{\mathrm{d}i}{\mathrm{d}t} = L' \cdot h \cdot \frac{\mathrm{d}i}{\mathrm{d}t}$$

where

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

L' is the inductance per unit length in μH/m; L' = 1 μH/m;

h is either the terminal-to-terminal length in m of the SVU or of the complete EGLA including series gap and connection leads;

$\mathrm{d}i/\mathrm{d}t$ is the rate of change of current with time in kA/μs.

3) Add the results of 1) and 2) on a wave shape basis; the peak value of the resulting wave shape shall be taken as the actual current impulse residual voltage of the arrester.

Procedure b)

1) Multiply the peak value of the sample impulse voltage by the scale factor (see 6.2).
2) Determine the inductive voltage drop between the arrester terminals using the following formula:

$$U_{\mathrm{L}} = L \cdot \frac{\mathrm{d}i}{\mathrm{d}t} = L' \cdot h \cdot \frac{I_{\mathrm{d}}}{T_{\mathrm{f}}}$$

where

U_{L} is the peak value of the inductive voltage drop in kV;

L' is the inductance per unit length in μH/m; L' = 1;

h is either the terminal-to-terminal length in m of the SVU or of the complete EGLA including series gap and connection leads;

T_{f} is the front time of the current impulse in μs; T_{f} = 2;

I_{d} is the actual discharge current amplitude in kA.

3) Add the results of 1) and 2); the resulting value shall be taken as the actual current impulse residual voltage of the arrester.

8.3.3 Lightning current impulse residual voltage test

One lightning current impulse shall be applied to each of the three samples for each of the following three peak values of approximately 0,5, 1 and 2 times the nominal discharge current of the EGLA. Wave shape of the current shall be 8/20 for "Series X" arresters and 2/20 for "Series Y" arresters according to Table 1.

For the current impulses, ~~the tolerances on the adjustment of the equipment shall be such that the measured values of the current impulses are~~ there is no requirement for virtual time to half value on the tail but tolerances on the virtual front time of the current impulses shall be within the following limits:

a) for 2/20 current impulses: from 1,7 μs to 2,3 μs for virtual front time;

– from 18 μs to 22 μs for virtual time to half value on the tail;

b) for 8/20 current impulses: from 7 μs to 9 μs for virtual front time;

– from 18 μs to 22 μs for virtual time to half value on the tail.

The lightning impulse residual voltage for "Series Y" arresters is determined as per procedure a) or b) in 8.3.2. For "Series X" arresters, no inductive effects are necessary to consider.

The maximum values of the determined residual voltages shall be drawn in a residual voltage versus discharge current curve.

The value of

- 1,4 times the residual voltage at the nominal discharge current according to Table 1 for "Series X" designs,
- 1,3 times the residual voltage at nominal discharge current according to Table 1 for "Series Y" designs,

shall be lower than the minimum flashover voltage of the insulator assembly to be protected. See also 10.5.3.

NOTE If the routine test cannot be carried out on a complete SVU at nominal discharge current, then tests should shall be carried out at a current in the range of 0,01 to 1 times the nominal discharge current for comparison with the complete SVU.

8.3.4 High current impulse residual voltage test

This test applies to "Series Y" designs only. One high current impulse of the wave shape 2/20 and a peak value according to Table 1 shall be applied to each of the three samples.

For the current impulses, the tolerances on the adjustment of the equipment shall be such that the measured values of the current impulses are there is no requirement for virtual time to half value on the tail but tolerances on the virtual front time of the current impulses shall be within the following limits:

– from 1,7 μs to 2,3 μs for virtual front time;

– from 18 μs to 22 μs for virtual time to half value on the tail.

The high current impulse residual voltage is determined as per procedure a) or b) in 8.3.2.

The value of 1,13 times the high current impulse residual voltage shall be lower than the minimum flashover voltage of the insulator assembly to be protected. See also 10.5.3.

8.4 Standard lightning impulse sparkover test

This is a mandatory type test only if not an acceptance test for each specific insulator assembly according to 10.5 is performed. As a type test, it is performed without the insulator assembly.

The purpose of this test is to determine the 50 % spark-over voltage of the EGLA under lightning impulse voltage stress.

The test sample is one EGLA with the maximum gap distance for a given designated system, without the insulator assembly.

Wave shape shall be 1,2/50. The 50 % spark-over voltage ($U_{50,\ EGLA}$) shall be verified by the up-and-down method according to IEC 60060-1.

NOTE 1 The protective margin between the spark-over voltage of the EGLA and the flashover voltage of the insulator assembly to be protected ~~may~~ can be evaluated by $U_{50,\ \mathrm{EGLA}}$ plus X times the standard deviation, ($U_{50,\ \mathrm{EGLA}} + X{\cdot}\sigma$) not being higher than $U_{50,\ \mathrm{Insulator}}$ minus X times the standard deviation, ($U_{50,\ \mathrm{Insulator}} - X{\cdot}\sigma$) of the insulator assembly to be protected, if agreed between manufacturer and user. X is to be agreed upon between the manufacturer and the user. The standard deviation (σ) is set to be 3 % for 1,2/50 impulses.

NOTE 2 A ~~recommended~~ typical value for X is 2,5.

NOTE 3 Experience during testing has shown that the spark-over voltage of the EGLA ~~may~~ can be influenced by the close vicinity of the insulator assembly.

8.5 High current impulse withstand test

8.5.1 Selection of test samples

The test shall be performed on three sections of an SVU. The sections shall have a residual voltage at nominal discharge current at the highest end of the variation range declared by the manufacturer. In order to comply with these specifications the following shall be fulfilled:

a) The ratio between the residual voltage at nominal discharge current of the complete SVU and the residual voltage at nominal discharge current of the section is defined by n. The volume of the resistor elements used as test samples shall not be greater than the minimum volume of all resistor elements used in the complete SVU divided by n.

b) The reference voltage U_{ref} of the SVU of the test section should be equal to the minimum reference voltage of the SVU of the EGLA divided by n. If the reference voltage of the SVU of the test section is greater than the minimum reference voltage of SVU of the complete EGLA divided by n, the factor n shall be reduced correspondingly. If the reference voltage of the SVU of the test section is less than the minimum reference voltage of SVU of the complete EGLA divided by n, the test section is not allowed to be used.

8.5.2 Test procedure

Two high current impulses of same polarity, having peak values ~~(tolerance $^{\ \ 0}_{+10}$ %)~~ and wave shapes according to Table 1, shall be applied to the three sections. Time interval between the impulse applications shall allow the sample to cool to ambient temperature.

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

a) for 2/20 current impulses:
   - from 90 % to 110 % of the specified peak value;
   - from 1,7 µs to 2,3 µs for virtual front time;
   - from 18 µs to 22 µs for virtual time to half value on the tail;
   - the peak value of any opposite polarity current wave shall be less than 20 % of the peak value of the current;
   - small oscillations on the impulse are permissible provided their amplitude near the peak of the impulse is less than 5 % of the peak value. Under these conditions, for the purpose of measurement, a mean curve shall be accepted for determination of the peak value.

b) for 4/10 current impulses:
   - from 90 % to 110 % of the specified peak value;
   - from 3,5 µs to 4,5 µs for virtual front time;
   - from 9 µs to 11 µs for virtual time to half value on the tail.
   - the peak value of any opposite polarity current wave shall be less than 20 % of the peak value of the current;
   - small oscillations on the impulse are permissible provided their amplitude near the peak of the impulse is less than 5 % of the peak value. Under these conditions, for the

purpose of measurement, a mean curve shall be accepted for determination of the peak value.

8.5.3 Test evaluation

a) The reference voltage measured before and after the test shall have changed by not more than 10 %.

b) Any change in residual voltage at nominal discharge current measured before and after the test shall be within (– 2 % to + 5 %).

c) Visual examination of the test samples after the test shall reveal no evidence of puncture, flashover and cracking or other significant damage of the test sample. If the metal-oxide resistors cannot be removed from the test samples for visual examination, the following additional tests shall be performed to ensure that no damage occurred during the test. After the residual voltage test (b), two impulses at nominal discharge current shall be applied to the test sample. The first impulse shall be applied after sufficient time to allow cooling of the sample to ambient temperature. The second impulse is applied 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, and the difference of the residual voltage between the initial measurement before the test and the last of the two impulses after the test shall not exceed a range of (– 2 % to + 5 %).

8.6 Test to verify the repetitive charge transfer rating, Q_{rs} ~~with~~ lightning discharges ~~capability test~~

8.6.1 MO resistors

8.6.1.1 General

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

Repetitive charge transfer capability is specified as an impulse current stress that can be withstood by the MO resistors of an EGLA twenty times without mechanical or unacceptable electrical damage. One impulse current stress is considered to represent a charge transfer event that may occur under real system conditions.

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 8.6.1.5. By this approach it is assumed that the performance of the individual MO resistors can also be assigned to a full EGLA 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 the current impulse shape shall be approximately sinusoidal. The time duration for which the instantaneous value of the impulse current is between 5 % and 100 % of its peak value shall be within 200 μs to 230 μs. The peak of any opposite polarity current wave shall be less than 5 % of the peak value of the current. The current peak value of each impulse on each test sample shall lie between 90 % and 110 % of the selected peak value.

An EGLA shall be assigned a Q_{rs} value from the list given in 8.6.1.5.

A first test sequence shall be performed on 10 samples of MO resistors selected according to 8.6.1.2. 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.

8.6.1.2 Selection of test samples

This test shall be performed on three samples. These The test samples shall include complete SVUs, SVU sections or metal-oxide resistor elements which have not been subjected to any previous tests except as necessary for evaluation purposes of this test.

The samples to be chosen for the lightning impulse discharge capability test to verify the repetitive charge transfer rating shall have a residual voltage at nominal discharge current at the highest end of the variation range declared by the manufacturer. Furthermore, in the case of multi-column arresters SVUs, the highest value of uneven current distribution shall be considered. In order to comply with these specifications the following shall be fulfilled.

a) The ratio between the residual voltage at nominal discharge current of the complete SVU and the residual voltage at nominal discharge current of the section is defined by n. The volume of the resistor elements used as test samples shall not be greater than the minimum volume of all resistor elements used in the complete SVU divided by n.

b) The reference voltage U_{ref} of the SVU of the test section should be equal to the minimum reference voltage of the SVU of the EGLA divided by n. If the reference voltage of the SVU of the test section is greater than the minimum reference voltage of SVU of the complete EGLA divided by n, the factor n shall be reduced correspondingly. If the reference voltage of the SVU of the test section is less than the minimum reference voltage of SVU of the complete EGLA divided by n, the test section is not allowed to be used.

c) The samples 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)$_{actual}$.

8.6.1.3 Test procedure

Before commencing the tests, the lightning impulse residual voltage at nominal discharge current and the reference voltage of each test sample shall be measured for evaluation purposes.

Each lightning impulse discharge capability test shall consist of 18 discharge operations divided into six groups of three operations. Intervals between operations shall be 50 s to 60 s and between groups such that the sample cools to near ambient temperature.

Following the 18 discharge operations and after the sample has cooled to near ambient temperature, the residual voltage tests and the reference voltage tests, which were made before the test, shall be repeated for comparison with the values obtained before the test, and the values shall not have changed by more than (– 2 % to + 5 %).

Visual examination of the test samples after the test shall reveal no evidence of puncture, flashover, cracking or other significant damage of the metal-oxide resistors.

In case of a design where the resistors cannot be removed for inspection, an additional impulse shall be applied after the sample has cooled to ambient temperature. If the sample has withstood this 19th impulse without damage (checked by the oscillographic records) the sample is considered to have passed the test.

Figure 2 gives an overview of the test procedure.

Initial tests • Residual voltage test at nominal discharge current • Reference voltage test at specified reference current
Application of 1,1 times Q_{rs} • 1st sequence: 20 impulses per sample (10 samples) • if not more than one sample failure during 1st sequence: test passed • if not more than two sample failures during 1st sequence: conduct 2nd sequence with 10 samples, 20 impulses per sample • if more than two sample failures in 1st sequence or any sample failure in 2nd sequence: test failed
Test evaluation: check for • no mechanical damage at visual inspection • change of reference voltage within ±5 % • change of residual voltage at nominal discharge current within ±5 % • withstand capability to one 8/20 current impulse of at least 0,5 kA/cm² peak current density or 2 times I_n, whichever is lower

IEC

Figure 2 – Test procedure to verify the repetitive charge transfer rating, Q_{rs}

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

The samples shall fulfil the requirements in 8.6.1.2.

The following procedure shall be followed:

a) Each sample shall be subjected to a residual voltage test at nominal discharge current and a reference voltage test at specified reference current before and after the test.

b) 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.

c) The wave shape and duration of the current impulses shall be as 8.6.1.

d) The charge content of each impulse shall be at least equal to the claimed repetitive charge transfer rating (selected from the list given in 8.6.1.5) multiplied by 1,1.

NOTE 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.

8.6.1.4 Test evaluation

The full test shall be considered passed if either.

a) not more than one sample failed during the first sequence, or

b) 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 8.6.1.5 shall be selected, and the test shall be repeated for this lower charge level following the procedure given in 8.6.1.3.

NOTE 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 = 0,0056 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 = 0,0056 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:

a) there is no indication of mechanical damage (puncture, flashover or cracking);

b) any change of the reference voltage before and after the test, measured at the same temperature ± 3 K, is within ±5 %;

c) any change of the residual voltage at nominal discharge current before and after the test is within ±5 %;

d) a final application of a current impulse 8/20 µs of an amplitude resulting in a current density of at least 0,5 kA/cm^2 or in 2 times I_n, whichever is lower, is passed without mechanical damage.

NOTE Puncture of the metallization is not considered a mechanical damage if all other pass criteria are met.

~~**8.6.3 Test parameters for the lightning impulse discharge capability test**~~

~~The current peak value is selected by the manufacturer to obtain a particular charge. The current impulse shape shall be approximately sinusoidal. The time duration for which the instantaneous value of the impulse current is greater than 5 % of its peak value shall be within 200 µs to 230 µs. The peak of any opposite polarity current wave shall be less than 5 % of the peak value of the current. The current peak value of each impulse on each test sample shall lie between 100 % and 110 % of the selected peak value.~~

~~**8.6.4 Measurements during the lightning impulse discharge capability test**~~

~~Charge and peak current shall be reported for each impulse as well as the duration of time during which the instantaneous value of the impulse current is greater than 5 % of its peak value. Oscillograms of the typically applied voltage and current waveforms shall be plotted on the same time scale.~~

~~**8.6.5 Rated lightning impulse discharge capability**~~

~~Average peak current and charge shall be calculated from the 18 discharge operations.~~

~~The rated lightning impulse discharge capability of the arrester is the combination of the following:~~

~~a) the lowest average peak current for any of the 3 test samples;~~

~~b) a charge value selected from the list of 8.6.6 lower than or equal to the lowest average charge for any of the 3 test samples.~~

8.6.1.5 List of rated charge values

The following values, expressed in C, are standardized as rated charge values: 0,1; 0,2; 0,3; 0,4; 0,6; 0,8; 1; 1,2; 1,4; 1,6; 1,8; 2; 2,4; 2,8; 3,2; 3,6; 4~~; 4,4; 4,8; 5,2; 5,6; 6; 6,4; 6,8; 7,2; 7,6; 8; 8,4; 8,8; 9,2; 9,6; 10~~.

If higher values shall be specified this shall be done in steps of 0,4 C.

8.6.2 Series gap

8.6.2.1 General

This test applies to the series gap for externally gapped line arresters (EGLA) with gap spacing of 20cm or less.

The purpose of this test is to verify the repetitive charge withstand capability of the series gap under lightning impulse discharges. The test shall be performed on one series gap with a Q_{rs} value not less than the Q_{rs} value specified for the MO resistors of SVU.

8.6.2.2 Test procedure

Figure 3 gives an overview of the test procedure.

Pre- tests • Determination of the 50 % spark-over voltage of the series gap under lightning impulse voltage stress for both polarities. The shortest flashover distance for the design shall be used. The test can be performed without the insulator assembly. The 50 % spark-over voltage ($U_{50,\ EGLA\ series\ gap}$) shall be verified by the up-and-down method according to IEC 60060-1 (refer to 8.4). • For the application of lightning impulse discharges, the series gap can be integrated in series with one of the ten test samples of test used in 8.6.1 to verify the repetitive charge transfer rating, Q_{rs}. The flashover distance of the series gap shall be adjusted to at least 10 mm to get an arc.
Application of Q_{rs} • 20 impulses of lightning impulse discharges
Post-test • Repeat of pre-test to determine the 50 % spark-over voltage for both polarities

IEC

Figure 3 – Test procedure to verify the repetitive charge withstand of the series gap

8.6.2.3 Test evaluation

The 50 % spark-over voltage for each polarity in the post-test shall not have changed from the values determined in the pre-test by more than ±10 %.

8.7 Short-circuit tests

8.7.1 General

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

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

With respect to short-circuit current performance, it is important to distinguish between two designs of SVUs:

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

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

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

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

Depending on the type of SVU and test voltage, different requirements apply with regard to the number of test samples, initiation of short-circuit current and amplitude of the first short-circuit current peak. Table 4 shows a summary of these requirements which are further explained in the following subclauses.

8.7.2 Preparation of the test samples

8.7.2.1 General

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

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

~~NOTE~~ Figure 4 shows different examples of SVU units.

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

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

8.7.2.2 "Design A" SVUs

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

No differences with regard to polymer housings or porcelain housings are made in the preparation of the test samples. However, differences partly apply in the test procedure (see 8.7.4.3). In this case, "Design A" SVUs with polymeric sheds which are not made of porcelain or other hollow insulators, and which are as brittle as ceramics, shall be considered and tested as porcelain-housed SVUs.

8.7.2.3 "Design B" SVUs

8.7.2.3.1 General

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

8.7.2.3.2 Polymer-housed SVUs

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

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

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

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

– Voltage source method: the initial current should typically be in the range 5 to 10 mA/cm^2. The short-circuit current should typically be between 1 A and 30 A. The voltage source need not be adjusted after the initial setting, although small adjustments might be necessary in order to fail the resistors in the given time range.
– Current source method: Typically a current density of around 15 mA/cm^2 with a variation of ± 50 %, will result in failure of the resistors in the given time range. The short-circuit current should typically be between 10 A and 30 A. The current source need not be adjusted after the initial setting, although small adjustments might be necessary in order to fail the resistors in the given time range.

8.7.2.3.3 Porcelain-housed SVUs

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

8.7.3 Mounting of the test sample

The SVU units to be tested can be either mounted directly to a base according to the mounting arrangements as shown in Figure 5a and Figure 5b, or mounted hanging in accordance with the installation recommendations of the manufacturer. The choice of test installation is up to the manufacturer. In case of suspended mounting, the bottom end of the SVU shall be at the same level as the upper edge of the circular enclosure.

For a base-mounted SVU, the mounting arrangement is shown in Figure 5a and Figure 5b. The distance to the ground from the insulating platform and the conductors shall be as indicated in Figure 5a and Figure 5b.

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

For base-mounted SVUs, the bottom end fitting of the test sample shall be mounted on a test base that is at the same height as a surrounding circular or square enclosure. The test base shall be of insulating material or may be of conducting material if its surface dimensions are smaller than the surface dimensions of the SVU bottom end fitting. The test base and the enclosure shall be placed on top of an insulating platform, as shown in Figure 5a and Figure 5b. For non-base-mounted SVUs, the same requirements apply to the bottom of the SVU. The arcing distance between the top end cap and any other metallic object (floating or grounded), except for the base of the SVU, shall be at least 1,6 times the height of the sample SVU, but not less than 0,9 m. The enclosure shall be made of non-metallic material and be positioned symmetrically with respect to the axis of the test sample. It shall not be permitted to open or move during the test. The height of the enclosure shall be 40 cm ± 10 cm, and its diameter (or side, in case of a square enclosure) shall be equal to the greater of 1,8 m or D in the Equation below:

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

where

H is the height of tested SVU unit;

D_{SVU} is the diameter of tested SVU unit.

Porcelain-housed SVUs shall be mounted according to Figure 5a. Polymer housed SVUs shall be mounted according to Figure 5b.

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

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

NOTE The routing shown in Figure 5a is the most unfavourable to use during the initial phase of the test before venting occurs (especially in the case of a SVU fitted with a pressure relief device). Positioning the sample as shown in Figure 5a, with the venting ports facing in the direction of the test source, may cause the external arc to be swept in closer proximity to the SVU housing than otherwise. As a result, a thermal shock effect may cause excessive chipping and shattering of porcelain weather sheds, as compared to the other possible orientations of the venting ports. However, during the remaining arcing time, this routing forces the arc to move away from the SVU, and thus reduces the risk of the SVU catching fire. Both the initial phase of the test as well as the part with risk of catching fire are important, especially for SVUs where the external part of the housing is made of polymeric material.

For all polymer-housed SVUs, the ground conductor ~~should~~ shall be directed to the opposite direction as the incoming conductor, as described in Figure 5b. In this way, the arc will stay close to the SVU during the entire duration of the short-circuit current, thus creating the most unfavourable conditions with regards to the fire hazard.

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

8.7.4 High-current short-circuit tests

8.7.4.1 General

Three samples shall be tested at currents based on selection of a rated short-circuit current selected from Table 5. All three samples shall be prepared according to 8.7.2 and mounted according to 8.7.3.

Tests shall be made in a single-phase test circuit, with an open-circuit test voltage of 77 % to 107 % of the rated voltage of the test sample, as outlined in 8.7.4.2. However, it is expected that tests on high-voltage SVUs will have to be made at laboratories which might not have the sufficient short-circuit power capability to carry out these tests at 77 % or more of the test sample rated voltage. Accordingly, an alternative procedure for making the high-current, short-circuit tests at a reduced voltage is given in 8.7.4.3. The measured total duration of test current flowing through the circuit shall be ≥ 0,2 s.

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

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

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

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

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

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

For all the reduced short-circuit currents, the r.m.s. value shall be in accordance with Table 5 and the peak value of the first half-cycle of the prospective current shall be at least √2 times the r.m.s. value of this current.

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

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

~~NOTE~~ The X/R ratio of the test circuit impedance, without the SVU connected, should preferably be at least 15. In cases where the test circuit impedance X/R ratio is less than 15, the test voltage may be increased or the impedance may be reduced, in such a way that, for the rated short-circuit current, the peak value of the first half-cycle of the prospective current is equal to, or greater than, 2,5 times the required test current level. For the reduced current level tests, the tolerances in Table 5 are met.

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

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

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

The following exception for the test at rated short-circuit current is valid for "Design A" polymer-housed SVUs only (see 8.7.2.2 for the definition of polymer- and porcelain-housed SVUs): if the rated voltage of the test sample is more than 150 kV and a first peak value of ≥ 2,5 times the rated short-circuit current cannot be achieved, an additional test sample shall be tested. This additional test sample shall be tested according to either 8.7.4.2 or 8.7.4.3. It shall have a rated voltage of ≥ 150 kV and shall also not be shorter than the shortest SVU unit used for the actual SVU design. The rated short-circuit current value shall be the lowest of the r.m.s. current from the test on the longest unit and the r.m.s. current defined according to testing with either 8.7.4.2 or 8.7.4.3 from the test on the minimum 150 kV rated unit. Both tests shall be reported.

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

For all the reduced short-circuit currents the r.m.s. value shall be in accordance with Table 5 and the peak value of the first half-cycle of the actual SVU test current shall be at least √2 times the r.m.s. value of this current.

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

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

For pre-failed SVUs, therefore, it is recommended to ensure that the SVU represents a sufficiently low impedance prior to applying the short-circuit current by reapplying the pre-failing, or similar, circuit during a maximum of 2 s immediately before applying the short-circuit test current (see Figure 6). It is acceptable to increase the short-circuit current of the pre-applied circuit up to 300 A (r.m.s). If so, its maximum duration, which depends on the current magnitude, shall not exceed the following value:

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

where

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

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

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

8.7.5 Low-current short-circuit test

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

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

8.7.6 Evaluation of test results

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

a) No violent shattering.

~~NOTE~~ Structural failure of the sample is permitted as long as criteria b) and c) are met.

b) No parts of the test sample shall be allowed to be found outside the enclosure, except for

- fragments, less than 60 g each, of ceramic material such as from metal-oxide resistors or porcelain;
- pressure relief vent covers and diaphragms;

- soft parts of polymeric materials.

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

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

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

~~NOTE~~ It may be of particular importance for EGLA applications that safety considerations on ejected fragments, mechanical integrity and even a certain strength after failure are required. In that case, different test procedures and evaluations may be established between the manufacturer and the user (as an example, it may be required that after the tests the SVU ~~should~~ still be able to be lifted and removed by its top end).

Table 4 – Test requirements

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

Table 5 – Required currents for short-circuit tests

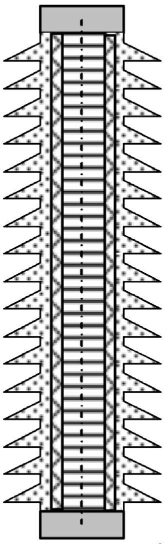
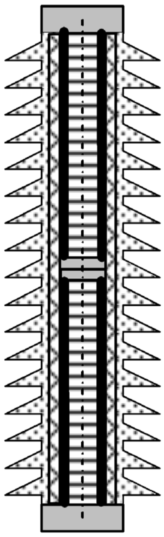
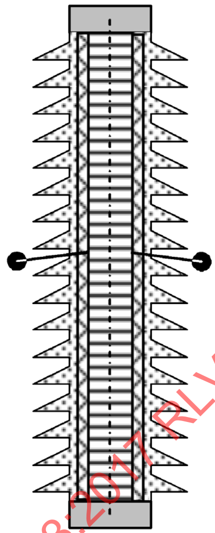
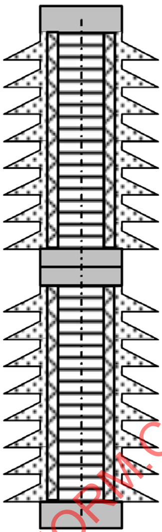
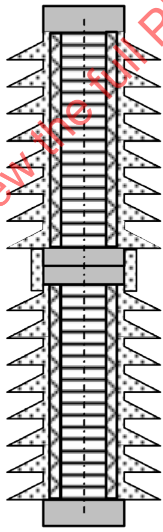
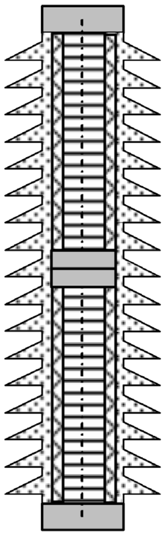
Rated short-circuit current I_s	Reduced short-circuit currents ±10 %		Low short-circuit current with a duration of 1 s [a]
A	A		A
80 000	50 000	25 000	600 ± 200
63 000	25 000	12 000	600 ± 200
50 000	25 000	12 000	600 ± 200
40 000	25 000	12 000	600 ± 200
31 500	12 000	6 000	600 ± 200
20 000	12 000	6 000	600 ± 200
16 000	6 000	3 000	600 ± 200
10 000	6 000	3 000	600 ± 200
5 000	3 000	1 500	600 ± 200

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

~~NOTE~~ If an existing type of SVU, already qualified for one of the rated currents in Table 5, is being qualified for a higher rated-current value available in this table, it should be tested only at the new rated value. Any extrapolation can only be extended by two steps of rated short-circuit current.

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

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

 Number of units = 1	 Number of units = 1	 Number of units = 1
Case a) **One mechanical and electrical unit**	**Case b)** **Two mechanical internal assemblies covered by one common housing providing final mechanical strength**	**Case c)** **One mechanical unit covered by a housing with an intermediate potential grading element**
 Number of units = 2	 Number of units = 1	 Number of units = 1
Case d) **Two mechanical units covered by individual housings each and assembled afterwards**	**Case e)** **Two mechanical units of final mechanical strength, intermediate flanges covered by soft insulating material after assembly**	**Case f)** **Two mechanical units covered by individual housings each and assembled afterwards**

Key

MO elements

Metallic parts

Mechanical structure for assembly

Final mechanically supporting part of housing

Soft outer part of housing

Figure 4 – Examples of SVU units

Dimensions in metres

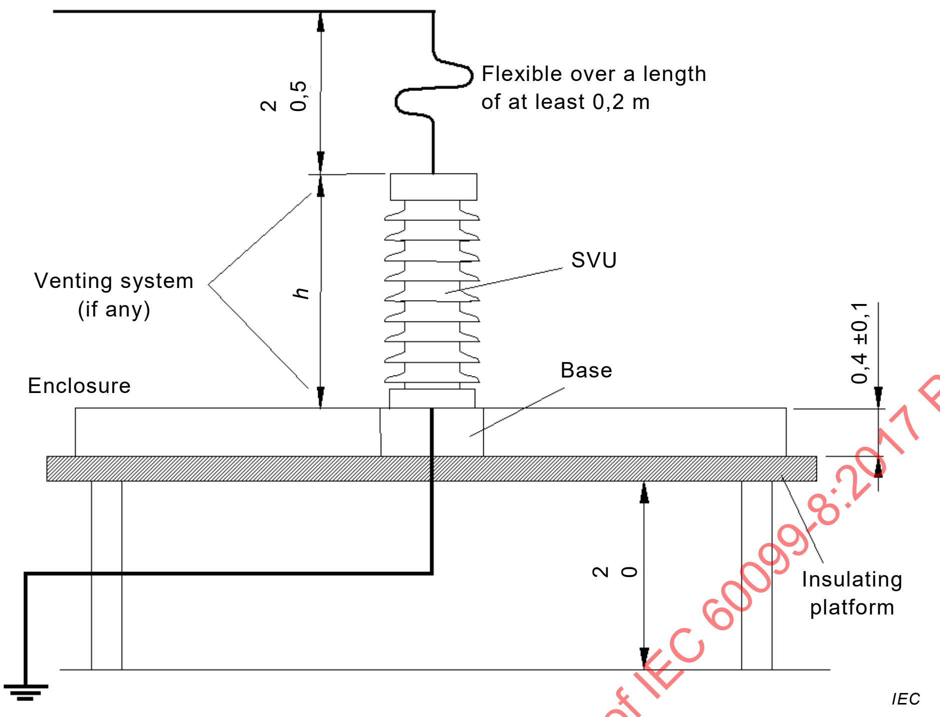


Figure 5a – Circuit layout for porcelain-housed SVUs (all leads and venting systems in the same plane)

Dimensions in metres

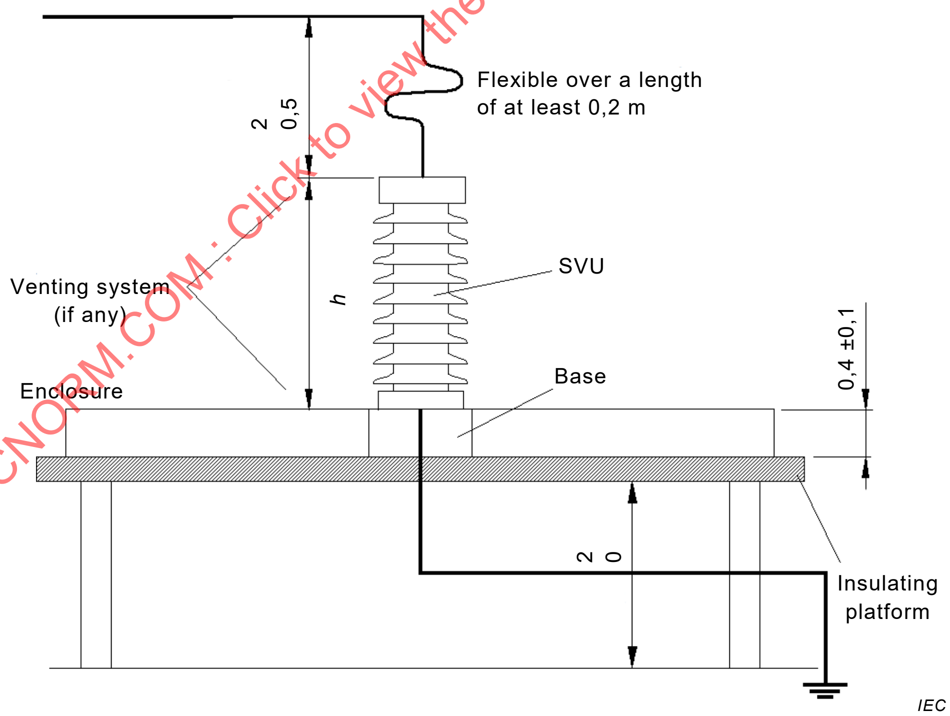
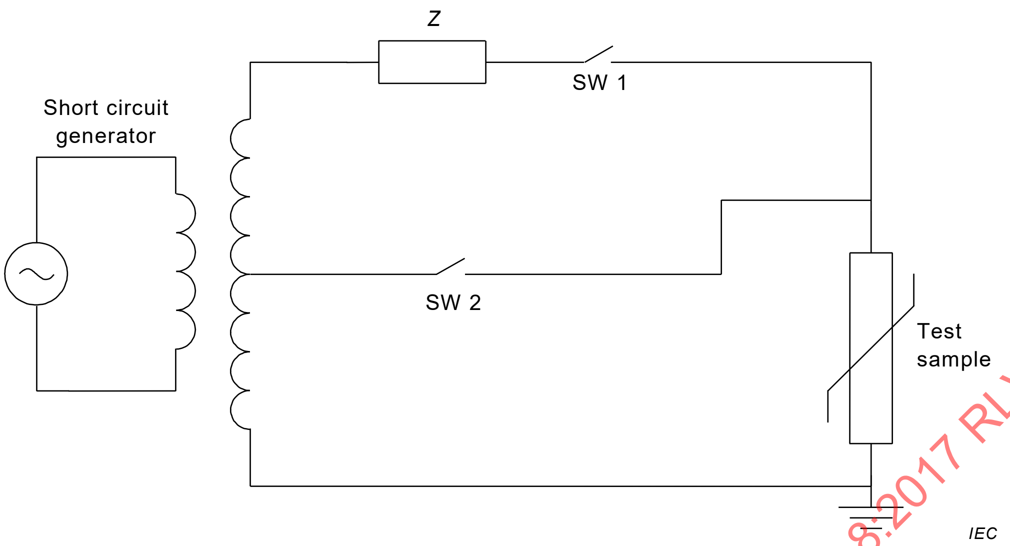


Figure 5b – Circuit layout for polymer-housed SVUs (all leads and venting systems in the same plane)

Figure 5 – Short-circuit test setup



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

Figure 6 – Example of a test circuit for re-applying pre-failing circuit immediately before applying the short-circuit test current

8.8 Follow current interrupting test

8.8.1 General

This test is to verify follow current interrupting operation of an EGLA after the series gap had sparked over under a lightning impulse voltage. The test sample is a complete EGLA or a section of an EGLA.

This test also verifies the performance of the EGLA under polluted conditions by taking into account the current that would flow over the surface of the SVU housing due to the presence of a wetted pollution layer.

This test may be performed either as a type test with an SDD level and EGLA configuration selected by the manufacturer or, alternatively, as an acceptance test with the SDD level agreed upon between the manufacturer and the purchaser, (see 10.6).

The follow current interrupting test shall be performed by either “Test method A” (see 8.8.2) or “Test method B” (see 8.8.3). If the pollution severity on site is "Very heavy” according to the definition in IEC TS 60815-1, "Test method B" shall be applied. Else, the choice of the test method is upon the manufacturer. For “Test method A” the EGLA Housings shall be designed according to the IEC 60815 series.

NOTE With "Test method A", the effect of pollution on the SVU external surface current is modelled by an additional linear resistor connected in parallel to the SVU, and the test is performed under clean and dry conditions. "Test method B" is a test under artificial pollution conditions.

8.8.2 "Test method A"

8.8.2.1 Requirements on the test circuit

The impedance of the power-frequency voltage source shall be such that during the flow of follow current, the peak value of power-frequency voltage, measured at the EGLA terminals, does not fall below the peak value of the rated voltage of the test specimen and after the interruption of follow current, the peak voltage does not exceed the peak value of the rated voltage by more than 10 %. An example of a test circuit is given in Annex A.

8.8.2.2 Test procedure

The EGLA test sample shall be prepared as follows

a) The non-linear metal-oxide resistor part shall be a complete SVU, or an SVU section, or a pile of metal-oxide resistor elements; the scale factor n (ratio of the rated voltage of the complete EGLA to the rated voltage of the EGLA test sample) shall not be higher than five. If the rated voltage of the complete EGLA is higher than 12 kV the rated voltage of the test sample shall not be lower than 12 kV.

b) 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 SVU divided by n.

c) The reference voltage U_{ref} of the SVU of the test section should be equal to the minimum reference voltage of the SVU of the EGLA divided by n. If the reference voltage of the SVU of the test section is greater than the minimum reference voltage of the SVU of the complete EGLA divided by n, the factor n shall be reduced correspondingly. If the reference voltage of the SVU of the test section is less than the minimum reference voltage of the SVU of the complete EGLA divided by n, the test section is not allowed to be used.

d) A linear resistor shall be connected in parallel with the SVU in order to provide sufficiently high follow current.

e) The external series gap shall be composed of the same electrodes as those of the EGLA. Its length shall be not greater than the minimum gap length specified by the manufacturer. It is not necessary to scale the gap.

The test shall be conducted as follows:

A power-frequency voltage equal to the rated voltage of the EGLA or EGLA section shall be applied to the test sample.

The follow current flowing through the external series gap during the test will result as the addition of the following two components:

- the leakage current on the SVU polluted surface simulated by means of the linear resistor connected in parallel to the SVU;
- the internal resistive current through the non linear metal-oxide resistor blocks when energised at the rated voltage.

The resistance of the linear resistor necessary to simulate the leakage current on the SVU polluted surface shall be calculated as $R = F/K$, F being the form factor (according to IEC 60507) of the SVU housing and K the layer conductivity.

The layer conductivity K shall be taken from Table 3 of IEC 60507:2013 at the line corresponding to the selected SDD. The accepted tolerance for the resistance shall be $^{\ 0}_{-20}$ % of the calculated value.

~~NOTE~~ In the case of an EGLA, the pollution layer on the SVU is not under voltage until spark-over occurs. In a worst-case scenario, the pollution layer will be totally wetted under rain conditions and will remain so since drying due to surface leakage currents does not occur. As there is no dry band arcing activity, the pollution layer may be assumed as a linear resistance.

NOTE With this method, the current level is higher than in operating service conditions, because the calculation does not take into account the voltage drop across the external series gap of the EGLA.

Lightning impulse~~s~~ voltages shall then be applied to the EGLA in order to initiate spark-over and provide a conductive channel across the external series gap. The impulse generator shall be adjusted to obtain systematic spark-over of the gap.

8.8.2.3 Test sequence

The lightning impulse~~s~~ voltages, having the same or opposite polarity as the actual half cycle of the alternating voltage, shall be applied (30° to 0°) before the instant of peak voltage.

A first test shall be performed with a gap length small enough to show that the power source is able to supply and maintain the specified follow current.

The parallel linear resistor shall be adjusted such that the total follow current during the tests is at least equal to the estimated value.

Thereafter, the gap length shall be adjusted to the minimum specified value. Then, five spark-over operations at each polarity of the actual half cycle of the alternating voltage shall be performed. If follow current is not established, more spark-over operations shall be performed until follow current was established five times for each polarity.

Permanent oscillograms of power-frequency voltage and follow current associated with each discharge shall be taken. These oscillograms shall show the voltage across and the current trough the test sample throughout the period from one complete cycle before application of the impulse to ten complete cycles after the final interruption of the follow current. Final interruption of the follow current shall occur within the half-cycle in which the impulse is applied. There shall be no further spark-over of the sample in any subsequent half cycle.

8.8.2.4 Test evaluation

The sample has passed the test if for the ten spark-over operations the follow current is interrupted within the first half cycle of the power-frequency voltage and if there is no further spark-over in any subsequent half cycle.

8.8.3 "Test method B"

8.8.3.1 Requirements on the test circuit

The impedance of the power-frequency voltage source shall be such that during the flow of follow current, the peak value of power-frequency voltage, measured at the EGLA terminals, does not fall below the peak value of the rated voltage of the test specimen and after the interruption of follow current, the peak voltage does not exceed the peak value of the rated voltage by more than 10 %. An example of a test circuit is given in Annex A.

8.8.3.2 Test procedure and test sequence

The EGLA test sample shall be prepared as follows:

a) A section of an EGLA or a complete EGLA shall be prepared as test sample.

b) The non-linear metal-oxide resistor part shall be a complete SVU or an SVU section; the scale factor n (ratio of the rated voltage of the complete EGLA to the rated voltage of the EGLA test sample) shall not be higher than five. If the rated voltage of the complete EGLA is higher than 12 kV the rated voltage of the test sample shall not be smaller than 12 kV.

c) The volume of the resistor elements shall not be greater than the minimum volume of all resistor elements used in the complete SVU divided by n.

d) The reference voltage U_{ref} of the SVU of the test section should be equal to the minimum reference voltage of the SVU of the EGLA divided by n. If the reference voltage of the SVU of the test section is greater than the minimum reference voltage of the SVU of the complete EGLA divided by n, the factor n shall be reduced correspondingly. If the reference voltage of the SVU of the test section is less than the minimum reference voltage of the SVU of the complete EGLA divided by n, the test section is not allowed to be used.

e) The external series gap shall be composed of the same electrodes as those of the EGLA. Its length shall be not greater than the minimum gap length specified by the manufacturer. It is not necessary to scale the gap.

The contamination slurry shall be prepared in accordance with the solid layer method in IEC 60507 or any equivalent method, in which resistivity of the slurry can be determined from the specified SDD value.

The test shall be conducted as follows:

The housing of the SVU shall be clean and dry and at ambient temperature. Washing with a detergent may be necessary in order to remove oil films, but the detergent should be thoroughly rinsed off with water.

The surface hydrophobicity of the SVU shall be completely removed in order to simulate surface leakage currents to be expected in the worst case under the specified polluted condition.

With the arrester de-energized, the contaminant shall be applied to the whole insulation surface of the SVU, including the undersides of the sheds. The pollution layer shall appear as a continuous film. The pollution coating may be applied by either spraying, dipping or flow-coating.

NOTE 1 The following procedure is suggested to remove hydrophobicity on a polymeric (especially for silicone rubber) housing surface temporarily for the testing, without any damage of the surface or any additional chemical agent in the pollutant:

a) Prepare slurry, which contains approximately 1 kg of Tonoko or Kaolin in 1 l of water.
b) Spray the slurry as uniformly as possible on the hydrophobic housing surface.
c) Dry the polluted surface under natural ambient conditions.
d) Wash off the deposited Tonoko or Kaolin roughly, by running tap water, for example. After this process some amount of Tonoko or Kaolin will remain on the surface, which suppresses recovery of the hydrophobicity temporarily.

~~NOTE~~ Prior to the testing, salt deposit density according to the above procedure should be checked on the same design of polymeric housing surface.

NOTE 2 Once the hydrophobicity is removed by the procedure given in NOTE 1, testing on the test specimen needs to be completed within one day, in order to prevent recovery of hydrophobicity.

Within (3 min to 3,5 min) after the contaminant has been applied to the test sample it shall be exposed to its rated voltage for a time duration long enough to initiate one spark-over operation of the test sample.

The lightning impulse~~s~~ voltages, having the same or opposite polarity as the actual half cycle of the alternating voltage, shall be applied (30° to 0°) before the instant of peak voltage.

A first test shall be performed with a gap length small enough to show that the power source is able to supply and maintain the specified follow current.

Thereafter, the gap length shall be adjusted to the minimum specified value. Then, five spark-over operations at each polarity of the actual half cycle of the alternating voltage shall be performed. If follow current is not established, more spark-over operations shall be performed until follow current was established five times for each polarity.

The pollution layer shall be renewed after each spark-over operation.

Permanent oscillograms of power-frequency voltage and follow current associated with each discharge shall be taken. These oscillograms shall show the voltage across and the current trough the test sample throughout the period from one complete cycle before application of the impulse to ten complete cycles after the final interruption of the follow current. Final interruption of the follow current shall occur within the half-cycle in which the impulse is applied. There shall be no further spark-over of the sample in any subsequent half cycle.

NOTE The time interval between spark-over operations need not to be specified for this test.

8.8.3.3 Test evaluation

The sample has passed the test if

a) no flashover occurred on the SVU surface;
b) for the ten spark-over operations the follow current is interrupted within the half-cycle of power-frequency voltage during which the spark-over occurs and if there is no further spark-over in any subsequent half cycle.

8.9 Mechanical load tests on the SVU

8.9.1 General

These tests demonstrate that the SVU is able to withstand the mechanical strength values (SLL and SSL) and the vibrational loads specified by the manufacturer.

8.9.2 Bending test

8.9.2.1 General

This test demonstrates that the SVU is able to withstand the mechanical strength values (SLL and SSL) specified by the manufacturer. The test shall be performed on three or six samples of SVUs or SVU units. The complete test procedure is shown by the flow chart in Clause B.5.

8.9.2.2 Test procedure for porcelain and cast resin housed SVUs

8.9.2.2.1 General

This test applies to porcelain and cast-resin housed SVUs of EGLAs for ~~U_m~~ U_s > 52 kV. It also applies to porcelain and cast-resin housed SVUs of EGLAs for ~~U_m~~ U_s ≤ 52 kV for which the manufacturer claims cantilever strength.

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

The test shall be performed on complete SVU units without internal overpressure. For single-unit SVU designs, the test shall be performed on the longest unit of the design. Where an SVU contains more than one unit or where the SVU 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 Clause B.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 Clause B.2.

8.9.2.2.2 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 SVU. If the SVU 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 SVU to the maximum bending moment.

8.9.2.2.3 Test procedure

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

Three samples shall be tested. If the test to verify the SSL (see 8.9.2.2.3.2) 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 ~~Care should be taken because~~ The housing of an SVU ~~can~~ might splinter while under load and might present a handling hazard.

8.9.2.2.3.2 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 9.1, item c)) and an internal partial discharge test (see 9.1, item b)). 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 ~~Care should be taken because~~ The housing of an SVU ~~may break and~~ might splinter while under load and might present a handling hazard.

~~NOTE Agreement must be made with the manufacturer~~ If it is necessary for any reason to apply a load that is more than 5 % above SSL an agreement must be made with the manufacturer.

8.9.2.2.4 Test evaluation

The SVU shall have passed the test if

– the mean value of breaking load, MBL, is ≥ 1,2 x SSL;
– for the SSL test
  - there is no visible mechanical damage;
  - the remaining permanent deflection is ≤ 3 mm or ≤ 10 % (whichever is greater) of maximum deflection during the test;
  - the test samples pass the leakage check in accordance with 9.1c);
  - the internal partial discharge level of the test samples does not exceed the value specified in 9.1 b);

8.9.2.3 Test procedure for polymer (except cast resin) housed SVUs

8.9.2.3.1 General

This test applies to polymer (except cast-resin) housed SVUs (with and without enclosed gas volume) of EGLAs for ~~U_m~~ U_s > 52 kV. It also applies to polymer (except cast-resin) housed SVUs of EGLAs for ~~U_m~~ U_s ≤ 52 kV for which the manufacturer claims cantilever strength.

Cast-resin housed SVUs shall be tested according to 8.9.2.2. SVUs that have no declared cantilever strength shall be submitted to the terminal torque preconditioning according to 8.9.2.3.3.2 a), the thermal preconditioning according to 8.9.2.3.3.2 c) and the water immersion test according to 8.9.2.3.3.3.

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

The test shall be performed on complete SVU units with the highest rated voltage of the unit. For single-unit SVU designs, the test shall be performed on the longest unit with the highest rated voltage of that unit of the design. Where an SVU contains more than one unit or where the SVU 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 Clause B.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 (two steps for SVUs of EGLAs for ~~U_m~~ U_s ≤ 52 kV) 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 Clause B.2 and on the 3rd sample a mechanical preconditioning test as per 8.9.2.3.3.2;
– on all three samples a water immersion test as per 8.9.2.3.3.3.

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

~~NOTE~~ If +5 % is exceeded this should be agreed upon with the manufacturer.

NOTE The cyclic test is not required for SVUs of EGLAs for ~~U_m~~ U_s ≤ 52 kV.

8.9.2.3.2 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 0,7 times U_{ref} and at an ambient temperature of 20 °C ± 15 K;
  - internal partial discharge test according to 9.1 b);
  - residual voltage test at (0,01 to 1) times the nominal discharge current; the current wave shape shall be in the range of T_1/T_2 = (4 to 10)/(10 to 25) µs;
– leakage checks in accordance with 9.1 c) for SVUs with enclosed gas volume and separate sealing system.

If the partial discharge test according to 9.1 b) and the leakage check according to 9.1 c) 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 SVU. If the SVU 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 SVU to the maximum bending moment.

8.9.2.3.3 Test procedure

8.9.2.3.3.1 General

The test shall be performed on three samples. For SVUs of EGLAs for ~~U_m~~ U_s > 52 kV, the test is performed in three steps. For SVUs of EGLAs for ~~U_m~~ U_s ≤ 52 kV, the test is performed in two steps.

a) SVUs of EGLAs for ~~U_m~~ U_s > 52 kV

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 – 0,5 Hz.

~~NOTE~~ Due to the control of the testing machine it may take some cycles to obtain the SLL. The maximum number of these cycles ~~should~~ shall be agreed upon with the manufacturer. These cycles ~~should~~ 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 8.9.2.3.3.2.

Step 3:

Subject all three samples to the water immersion test according to 8.9.2.3.3.3.

b) SVUs of EGLAs for ~~U_m~~ U_s ≤ 52 kV

Step 1.1:

Subject two samples 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 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 1.2:

Subject a third sample to mechanical/thermal preconditioning according to 8.9.2.3.3.2.

Step 2:

Subject all three samples to the water immersion test according to 8.9.2.3.3.3.

8.9.2.3.3.2 Mechanical/thermal preconditioning

This preconditioning constitutes part of the test procedure of 8.9.2.3.3 and shall be performed on one of the test samples as defined in 8.9.2.3.3.

a) Terminal torque preconditioning

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

b) Thermo-mechanical preconditioning

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

The sample is submitted to the specified long-term load (SLL) in four directions and in thermal variations as described in Figure 7 and Figure 8.

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

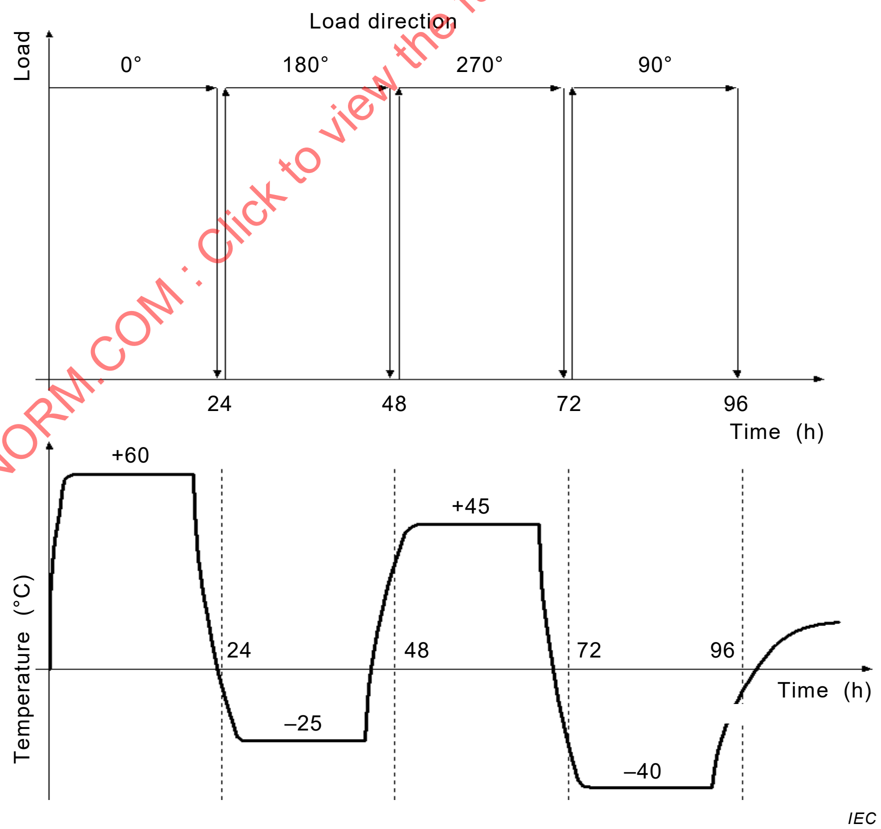


Figure 7 – Thermo-mechanical test

The thermal variations consist of two 48 h cycles of heating and cooling as described in Figure 7. The temperature of the hot and cold periods shall be maintained for at least 16 h. The test shall be conducted in air.

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 8.

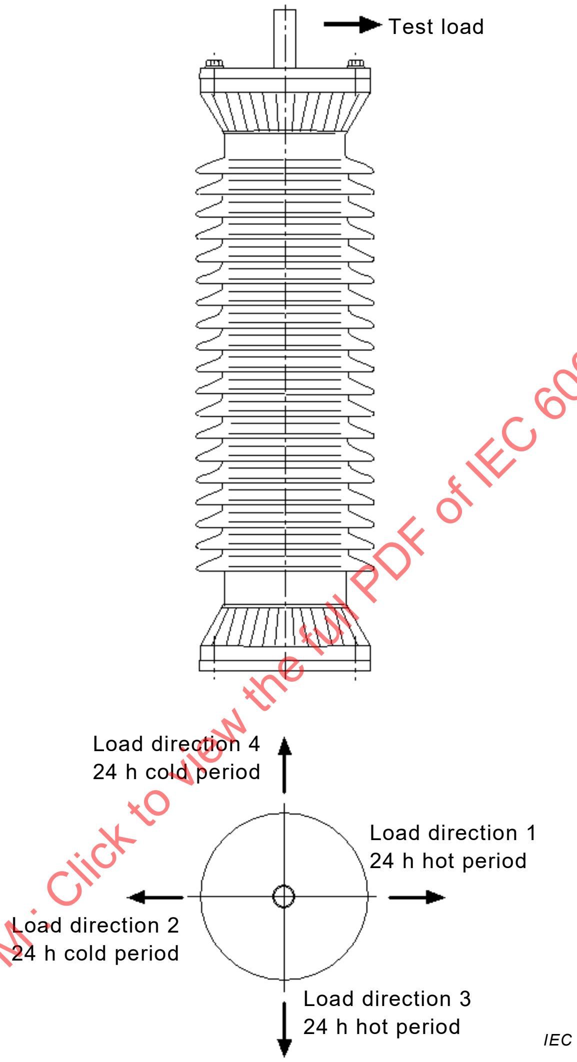


Figure 8 – Example of the test arrangement for the thermo-mechanical test and direction of the cantilever load

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.

c) Thermal preconditioning

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

The sample is submitted to the thermal variations as described in Figure 7 without any load applied.

The thermal variations consist of two 48 h cycles of heating and cooling as described in Figure 7. The temperature of the hot and cold periods shall be maintained for at least 16 h. The test shall be conducted in air.

8.9.2.3.3.3 Water immersion test

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

~~NOTE~~ The temperature of the 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 SVU 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 SVU shall be removed from the water and cooled to ambient temperature for not longer than three thermal time constants of the sample. 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 9. Evaluation tests shall be made within the time specified in 8.9.2.3.3.4. After removing the sample from the water it may be washed with tap water.

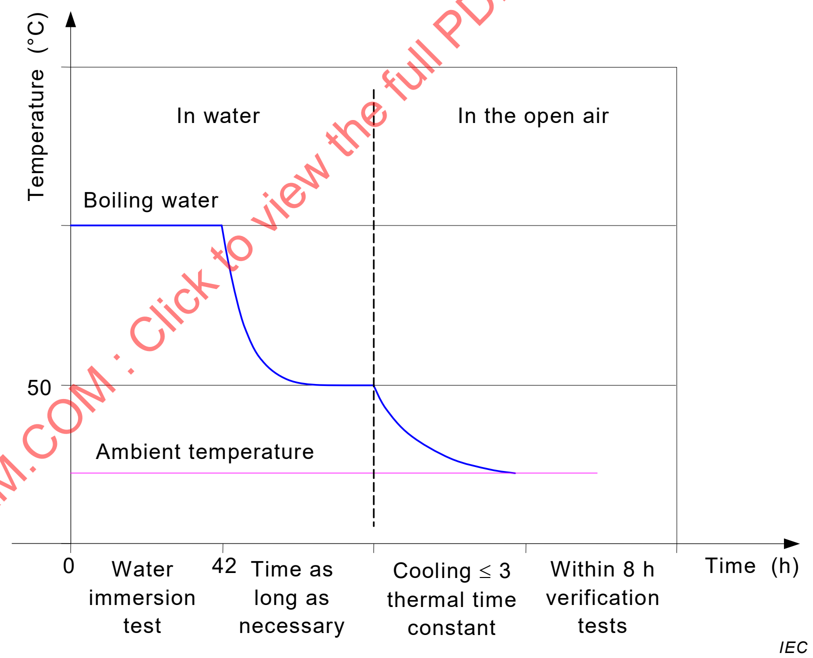


Figure 9 – Test sequence of the water immersion test

8.9.2.3.3.4 Determination fo thermal time constant

The SVU containing the most MO resistors per unit length of a multi-unit arrester shall be 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 shall be 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.

For the purpose of this standard the thermal time constant is the time where the temperature has decreased by 63 % of the temperature difference between start and ambient temperature.

8.9.2.3.4 Test evaluation

Tests according to 8.9.2.3.2 shall be repeated on each test sample.

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

a) SVUs of EGLAs for ~~U_m~~ U_s > 52 kV

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 9:

- the increase in watt losses, measured at 0,7 times U_{ref} 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 (0,7 times U_{ref}) or 20 %;
- the internal partial discharge measured at 0,7 times U_{ref} does not exceed 10 pC;

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

- for SVUs with enclosed gas volume and separate sealing system, the samples pass the leakage test in accordance with 9.1 c);
- 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 nominal 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 s to 60 s apart.

NOTE In case of extra long SVUs 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 SVU insulation to make contact with the internal stack at a metal spacer and in this way be able to test shorter SVU sections.

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

b) SVUs of EGLAs for ~~U_m~~ U_s ≤ 52 kV

After step 1:

– there is no visible damage;

– for step 1.1, 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 any remaining permanent deflection after the test shall be reported.

After step 2:

within 8 h after cooling as defined in Figure 9:

– the increase in watt losses, measured at 0,7 times U_{ref} 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 (0,7 times U_{ref}) or 20 %;

– the internal partial discharge measured at 0,7 times U_{ref} does not exceed 10 pC; at any time after the above watt losses and partial discharge measurements:

– for SVUs with enclosed gas volume and separate sealing system, the samples pass the leakage test in accordance with 9.1 c);

– the residual voltage measured 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 nominal 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 50s to 60 s apart.

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

NOTE In case of extra long SVUs where the blocks can be dismantled, the residual voltage 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 SVU insulation to make contact with the internal stack at a metal spacer and in this way be able to test shorter SVU sections.

8.9.3 Vibration test

8.9.3.1 General

This test demonstrates that the SVU is able to withstand the vibration stress specified by the manufacturer. The test shall be performed on one complete SVU.

This is a mandatory test if not performed as an acceptance test according to 10.7.

~~NOTE~~ The vibration test should also be performed on the spark gap. The mechanical stress should be comparable to the stress which is required for the SVU, and the test sample installation condition should be agreed between the manufacturer and the purchaser.

8.9.3.2 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:
  - internal partial discharge test according to 9.1 b);
  - residual voltage test at (0,01 to 1) times the nominal discharge current; the current wave shape shall be in the range of T_1/T_2 = (4 to 10)/(10 to 25) µs;
- leakage checks in accordance with 9.1 c) for SVUs with enclosed gas volume and separate sealing system.

If the partial discharge test according to 9.1 b) and the leakage check according to 9.1c) have been performed as routine tests they need not be repeated at this time.

8.9.3.3 Test procedure and test condition

- Installation condition: Intended most critical way of mounting
- Load: Actual electrode or loaded by maximum specified weight
- Acceleration at SVU's free end: 1·g
- Number of oscillations: $1 \cdot 10^6$ (one million)
- Frequency: Resonance frequency of the SVU
- Direction of oscillations: Intended most critical direction relative to the sample axis

~~NOTE~~ Other acceleration values than 1 × g may be specified on agreement between the manufacturer and the purchaser.

8.9.3.4 Test evaluation

~~The test evaluation shall be carried out as follows:~~

~~a) The reference voltage measured before and after the test shall have changed by not more than 5 %.~~

~~b) A partial discharge test according to 9.1 b) shall be passed successfully.~~

~~c) Any change in residual voltage at (0,01 to 1) times nominal discharge current and a current wave shape in the range of T_1/T_2 = (4 to 10)/(10 to 25) µs measured before and after the test shall be within – 2 % to + 5 %.~~

~~d) Visual examination of the test sample after the test shall reveal no evidence of puncture, flashover and cracking or other significant damage of the test sample. If the metal-oxide resistors cannot be removed from test sample for visual examination, the following additional tests shall be performed to ensure that no damage occurred during the test. After the residual voltage test c), two impulses at nominal discharge current shall be applied to the test sample. The first impulse shall be applied after sufficient time to allow cooling of the sample to ambient temperature. The second impulse shall be applied 50 to 60 s after the first one. During the two impulses, the oscillograms of both voltage and current shall not reveal any breakdown, and the difference of the residual voltage between the initial measurement before the test and the last of the two impulses after the test shall not exceed a range of – 2 % to + 5 %.~~

Tests according to 8.9.3.2 shall be repeated on each test sample.

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

a) the internal partial discharge measured at 0,7 times U_{ref} does not exceed 10 pC;

b) for SVUs with enclosed gas volume and separate sealing system, the samples pass the leakage test in accordance with 9.1 c);

c) 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;

d) the difference in voltage between two successive impulses at nominal 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 s to 60 s apart.

NOTE In case of extra-long SVUs 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 SVU insulation to make contact with the internal stack at a metal spacer and in this way be able to test shorter SVU sections.

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

8.10 Weather aging tests

8.10.1 General

The environmental tests demonstrate by accelerated test procedures that the sealing mechanism and the exposed metal combinations of the SVU are not impaired by environmental conditions. The test shall be performed on one complete SVU of any length. For SVUs with an enclosed gas volume and a separate sealing system, the internal parts may be omitted. SVUs 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 SVU.

8.10.2 Sample preparation

Prior to the tests, the test sample shall be subjected to a leakage check by any sensitive method adopted by the manufacturer.

8.10.3 Test procedure

8.10.3.1 General

The tests specified in Subclauses 8.10.3.2 and 8.10.3.3 shall be performed on one sample in the sequence given.

8.10.3.2 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.

8.10.3.3 Salt mist test

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

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

8.10.4 Test evaluation

The SVU shall have passed the tests if the sample passes again the leakage check of 8.10.2.

8.10.5 Additional test procedure for polymer (composite and cast resin) housed SVUs

8.10.5.1 General

For SVUs with polymer (composite and cast resin) housings, resistance to UV radiation shall be demonstrated by the UV test according to 8.10.5.2 and 8.10.5.3 (in line with 9.3.2 of IEC 62217:2012). ~~If a weather aging test report on the 5 000-h-test (Test Series B) according to 60099-4, 10.8.14 is available for the design, this may substitute the UV test if agreed between the manufacturer and the purchaser.~~

8.10.5.2 Procedure

Select three specimens of shed and housing materials for this test (with markings included, if applicable). The insulator housing material shall be subjected to a 1 000 h UV light test using one of the following test methods. Markings on the housing, if any, shall be directly exposed to UV light:

- Xenon-arc methods: ISO 4892-1 and ISO 4892-2, using method A without dark periods, standard spray cycle, black-standard/black panel temperatures of 65 °C, an irradiance of around 550 W/m^2
- Fluorescent UV method: ISO 4892-1 and ISO 4892-3, using type I fluorescent UV lamp, exposure method 1 or 2.

~~NOTE A revision of the UV test is currently under consideration by Cigré WG D1.14.~~

8.10.5.3 Acceptance criteria

After the test, markings on shed or housing material shall be legible; surface degradations such as cracks and raised areas are not permitted. In case of doubt concerning such degradation, two surface roughness measurements shall be made on each of the three specimens. The roughness, R_z as defined in ISO 4287, shall be measured along a sampling length of at least 2,5 mm. R_z shall not exceed 0,1 mm.

NOTE ISO 3274 gives details of surface roughness measurement instruments.

8.11 Radio interference voltage (RIV) test

This test applies to EGLA intended for use on systems with Us ≥ 72,5 kV.

The EGLA with an insulator configuration determined by the manufacturer to be appropriate shall be tested in accordance with the RIV test procedure of IEC 60099-4. The test voltage shall be the rated voltage (U_r) of the EGLA.

The EGLA with the insulator assembly shall be assembled in such a way that it simulates actual system installations. The test shall be performed on the longest EGLA, with the highest rated voltage used for a particular EGLA type. The test voltage shall be applied between the terminals of the EGLA.

The test shall be performed under dry conditions. The maximum radio interference level of the EGLA with the insulator assembly energized at the test voltage shall not exceed 2 500 μV.

9 Routine tests

9.1 General

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

a) Measurement of reference voltage (U_{ref}) of each SVU unit (see 3.7 and 6.8). The measured values shall be within a range specified by the manufacturer.

b) Internal partial discharge test. This test shall be performed on each SVU unit. The test sample may be shielded against external partial discharges. The power-frequency voltage shall be increased to at least 0,7 times U_{ref}. At this voltage, the partial discharge level shall be measured according to IEC 60270. The measured value for the partial discharge shall not exceed 10 pC.

c) For SVU units with sealed housing and an included gas volume, a leakage check shall be made on each SVU unit by any sensitive method adopted by the manufacturer.

d) Residual voltage test of the SVU. The test may be performed either on a complete SVU, SVU units or on a sample comprising one or several metal-oxide resistor elements. The manufacturer shall specify a suitable lightning impulse current in the range between 0,01 and 1 times the nominal current at which the residual voltage is measured. If not directly measured, the residual voltage of the complete SVU is taken as the sum of the residual voltages of the resistor elements or the individual SVU units. The residual voltage for the complete SVU shall not be higher than the value specified by the manufacturer. The residual voltage shall be specified without inductive voltage drop due to the size of the SVU.

   ~~NOTE~~ The residual voltage test may alternatively be performed with an impulse current corresponding to the maximum expected follow current value through the non-linear metal-oxide resistors. This point on the U-I-characteristic must then have been measured in the type test (8.3.3).

10 Acceptance tests

10.1 General

When the purchaser specifies acceptance tests in the purchase agreement, tests shall be selected among the following tests. The number and the way of preparation of test samples are given in Table 6, where "A" stands for the nearest lower whole number of the cubic root of the number of EGLA to be supplied.

Table 6 – Acceptance tests

Test item	Number of test samples	EGLA with (w) or without (wo) insulator	Section of EGLA with (w) or without (wo) insulator	Unit of SVU	Clause number
1. Reference voltage	"A"			Test	10.2
2. Internal partial discharge test	"A"			Test	10.3
3. RIV test [a]	1	Test (w)			10.4
4. Test for coordination between insulator withstand and EGLA protective level [b]	1	Test (w)			10.5
5. Follow current interrupting test [c]	1	Test (wo) [d]	Test (wo) [d]		10.6
6. Vibration test [e]	1			Test (wo) [f]	10.7

a) This test is mandatory if not performed as a type test in accordance with 8.11.

b) This test is mandatory if not performed as a type test in accordance with 8.4.

c) This test is mandatory if not performed as a type test in accordance with 8.8.

d) This test is performed either on a complete EGLA or a section of an EGLA, see 8.8.2.

e) This test is mandatory if not performed as a type test in accordance with 8.9.3.

f) This test is performed on a complete SVU including mounting hardware and the electrode of the external series gap attached.

10.2 Reference voltage measurement of SVU

The reference voltage of the SVU shall be measured in accordance with 3.7 and 6.8. The measured values shall be within a range specified by the manufacturer.

10.3 Internal partial discharge test of SVU

The power-frequency voltage shall be increased to at least 0,7 times U_{ref}. At this voltage, the partial discharge level shall be measured according to IEC 60270. The measured value for the partial discharge shall not exceed 10 pC. The test sample may be shielded against external partial discharges.

10.4 Radio interference voltage (RIV) test

This test applies to EGLA intended for use on systems with Us ≥ 72,5 kV.

The EGLA with the insulator assembly to be protected shall be tested in accordance with ~~8.12~~ the RIV test procedure of IEC 60099-4. The test voltage shall be the maximum continuous phase to ground system voltage ($U_s/\sqrt{3}$) that will be applied in service.

The EGLA with the insulator assembly shall be assembled in such a way that it simulates actual system installations. The test shall be performed on the longest EGLA, with the highest rated voltage used for a particular EGLA type. The test voltage shall be applied between the terminals of the EGLA.

The test shall be performed under dry conditions. The maximum radio interference level of the EGLA with the insulator assembly energized at the test voltage shall not exceed 2 500 µV.

10.5 Test for coordination between insulator withstand and EGLA protective level

10.5.1 General

This test for coordination between insulator withstand and EGLA protective level is mandatory as an acceptance test if not a type test according to 8.4 is performed. The test verifies the correct front-of-wave and standard lightning impulse spark-over voltages for the EGLA with the typical insulator assembly having the shortest insulation distance to be protected for the actual system.

Test sample is a complete EGLA with the insulator assembly connected in parallel.

10.5.2 Front-of-wave Steep front impulse spark-over test

10.5.2.1 General

Front-of-wave lightning Steep front impulse voltages of a virtual steepness of wave front enough to cause spark-over at wave front or around the peak according to Table 7 shall be applied to the test sample, five times for each polarity under dry conditions.

Table 7 – Virtual steepness of wave front of steep front-of-wave lightning impulses

Rated voltage of EGLA kV	Virtual steepness of wave front kV/µs
$3 < U_r \leq 10$	8,3 U_r
$10 < U_r \leq 120$	7,0 U_r
$120 < U_r \leq 200$	6,0 U_r
$200 < U_r \leq 300$	1 300
$300 < U_r \leq 420$	1 500
$U_r > 420$	2 000

10.5.2.2 Test evaluation

The EGLA has passed the test if all spark-overs at wave front or around the peak occurred in the external series gap and no flashovers occurred at the insulator assembly.

10.5.3 Standard lightning impulse sparkover test

10.5.3.1 General

The purpose of this test is to determine the margin of protection the EGLA offers the insulator.

10.5.3.2 Test procedure

The test voltage shall be a standard lightning impulse voltage 1,2/50. The purpose of this test is to verify the 50 % spark-over voltage value $U_{50,\ \mathrm{EGLA}}$ and to confirm sufficient protective margin between the spark-over voltage of the EGLA and the flashover voltage of the insulator to be protected.

The following test sequences a) and b) shall be performed in succession:

a) The 50 % spark-over voltage of the EGLA shall be verified for each polarity by the up-and-down method according to IEC 60060-1.

b) The series gap spacing of the EGLA shall be increased such that no spark-over occurs in the following test sequence: 15 lightning impulses voltages of each polarity with a peak value equal to $(1+X \times \sigma)$ times the 50 % spark-over voltage shall be applied to the test sample. The parameter X, specifying the protective margin between EGLA and insulator, shall be agreed upon between manufacturer and user. The minimum acceptable value is $X = 1,3$.

NOTE If agreed between the manufacturer and the user, the 50 % flashover voltage of the insulator assembly may be verified by the up-and-down test.

NOTE The protective margin should be evaluated by $U_{50,\ EGLA}$ plus X times the standard deviation, ($U_{50,\ EGLA}$ + $X\sigma$) not being higher than $U_{50,\ Insulator}$ minus X times the standard deviation, ($U_{50,\ Insulator}$ – X x σ) of the insulator assembly to be protected. The value of X and the allowed number of flashovers of the insulator assembly are to be agreed upon between manufacturer and user. The standard deviation (σ) is set to be 3 % for 1,2/50 impulses.

NOTE A recommended typical value for X is 2,5.

10.5.3.3 Test evaluation

The sample has passed the test if no flash-over occurs on the insulator assembly during test sequences a) and b) if no other criteria have been agreed upon between manufacturer and user (see NOTE 2 of 10.5.3.2).

10.6 Follow current interrupting test

10.6.1 General

This test is to verify follow current interrupting operation of the EGLA after the series gap has sparked over under a lightning impulse voltage. The test sample is a complete EGLA or a section of EGLA.

The test also verifies the performance of the EGLA under polluted conditions by taking into account the current that would flow over the surface of the SVU housing due to the presence of a wetted pollution layer.

This test shall be performed either as an acceptance test with the SDD level agreed upon between manufacturer and purchaser or, alternatively, as a type test with a SDD level and EGLA configuration selected by the manufacturer, see 8.8.

The test shall be performed by either “Test method A” (see 8.8.2) or “Test method B” (see 8.8.3). If the pollution severity on site is "Very heavy” according to the definition in IEC TS 60815-1, "test method B" shall be applied. Else, the choice of the test method is upon the manufacturer. For “Test method A” the EGLA housings shall be designed according to the IEC 60815 series.

NOTE With "test method A", the effect of pollution on the SVU external surface leakage current is modelled by an additional linear resistor connected in parallel to the SVU, and the test is performed under clean and dry conditions. "Test method B" is a test under artificial pollution conditions.

10.6.2 Test procedure

See 8.8.2.2 and 8.8.3.2.

10.6.3 Test sequence

See 8.8.2.3 and 8.8.3.2.

10.6.4 Test evaluation

See 8.8.2.4 and 8.8.3.3.

10.7 Vibration test on the SVU with attached electrode

10.7.1 General

This test demonstrates that the complete SVU including the attached electrode of the external series gap and mounting hardware is able to withstand the vibration stress expected in service.

This is a mandatory test if not performed as a type test according to 8.9.3.

10.7.2 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:
  - internal partial discharge test according to 9.1 b);
  - residual voltage test at (0,01 to 1) times the nominal discharge current; the current wave shape shall be in the range of T_1/T_2 = (4 to 10)/(10 to 25) µs;

– leakage checks in accordance with 9.1 c) for SVUs with enclosed gas volume and separate sealing system.

If the partial discharge test according to 9.1 b) and the leakage check according to 9.1 c) have been performed as routine tests they need not be repeated at this time.

10.7.3 Test procedure and test condition

• Installation condition:	Mounting as in the intended in-service installation including mounting hardware and the electrode at the SVU
• Acceleration at SVU's free end:	1 × g
• Number of oscillations:	1 × 10^6 (one million)
• Frequency:	Resonance frequency of the installation
• Direction of oscillations:	Most critical load direction of the intended in-service installation

NOTE Other acceleration values than 1xg may be specified on agreement between the manufacturer and the purchaser.

10.7.4 Test evaluation

~~a) The reference voltage measured before and after the test shall have changed by not more than 5 %.~~

~~b) A partial discharge test according to 9.1 b) shall be passed successfully.~~

~~c) Any change in residual voltage at (0,01 to 1) times nominal discharge current and a current wave shape in the range of T1/T2 = (4 to 10)/(10 to 25) µs measured before and after the test shall be within (– 2 % to + 5 %).~~

~~d) Visual examination of the test sample after the test shall reveal no evidence of puncture, flashover and cracking or other significant damage of the test sample. If the metal-oxide resistors cannot be removed from test sample for visual examination, the following additional tests shall be performed to ensure that no damage occurred during the test. After the residual voltage test c), two impulses at nominal discharge current shall be applied to the test sample. The first impulse shall be applied after sufficient time to allow cooling of the sample to ambient temperature. The second impulse shall be applied 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, and the difference of the residual voltage between the initial measurement before the test and the last of the two impulses after the test shall not exceed a range of (– 2 % to + 5 %).~~

Tests according to 10.7.2 shall be repeated on each test sample.

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

a) the internal partial discharge measured at 0,7 times U_{ref} does not exceed 10 pC;

b) for SVUs with enclosed gas volume and separate sealing system, the samples pass the leakage test in accordance with 9.1 c);

c) 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;

d) the difference in voltage between two successive impulses at nominal 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 s to 60 s apart.

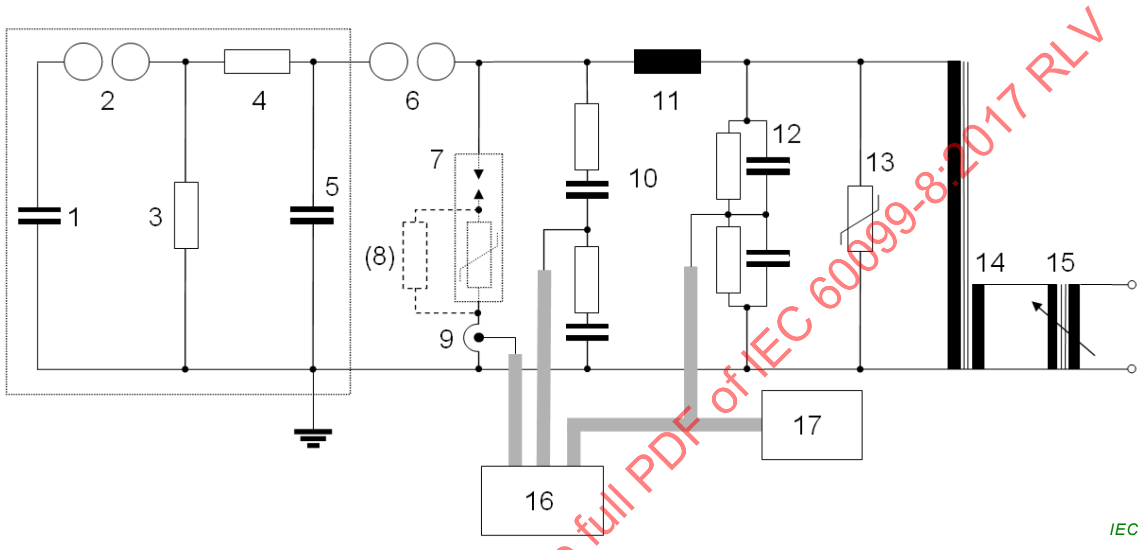
NOTE In case of extra-long SVUs where the blocks can be dismantled this part of the evaluation test can be performed on individual blocks or stacks of blocks. If the blocks cannot be dismantled a possible procedure would be to drill a hole in the SVU insulation to make contact with the internal stack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

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

Annex A
(informative)

Example of a test circuit for the follow current interrupting test

Figure A.1 gives an example of a test circuit for the follow current interrupting test on an EGLA of (15 to 50) kV rated voltage. The linear resistor (8) is only present for "Test method A".



Key

1	Charging capacitance of impulse generator
2	Triggering spark gap of impulse generator
3	Tail resistance for wave shape 1,2/50 of impulse generator
4	Front resistance for wave shape 1,2/50 of impulse generator
5	Load capacitance of impulse generator
6	Blocking sphere gap (sphere diameter 500 mm; gap length 1 300 mm)
7	Device under test: EGLA (SVU plus series gap)
	U_r = 15 kV to 50 kV, gap length = 200 mm to 1 700 mm
8	Parallel linear resistor to simulate SVU surface leakage current (only for "Test method A")
9	Current transformer
10	Damped capacitive divider
11	Inductance, L = 52 mH
12	Mixed RC divider
13	Metal-oxide surge arrester for protection of high-voltage test transformer, U_r = 156 kV
14	High-voltage test transformer
15	Regulating transformer
16	Three-channel oscilloscope
17	Peak/√2 digital voltmeter

Figure A.1 – Example of a test circuit for the follow current interrupting test

Annex B
(normative)

Mechanical considerations

B.1 Test of bending moment

In the case of a multi-unit SVU, each unit shall be tested with the bending moment according to Figure B.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.

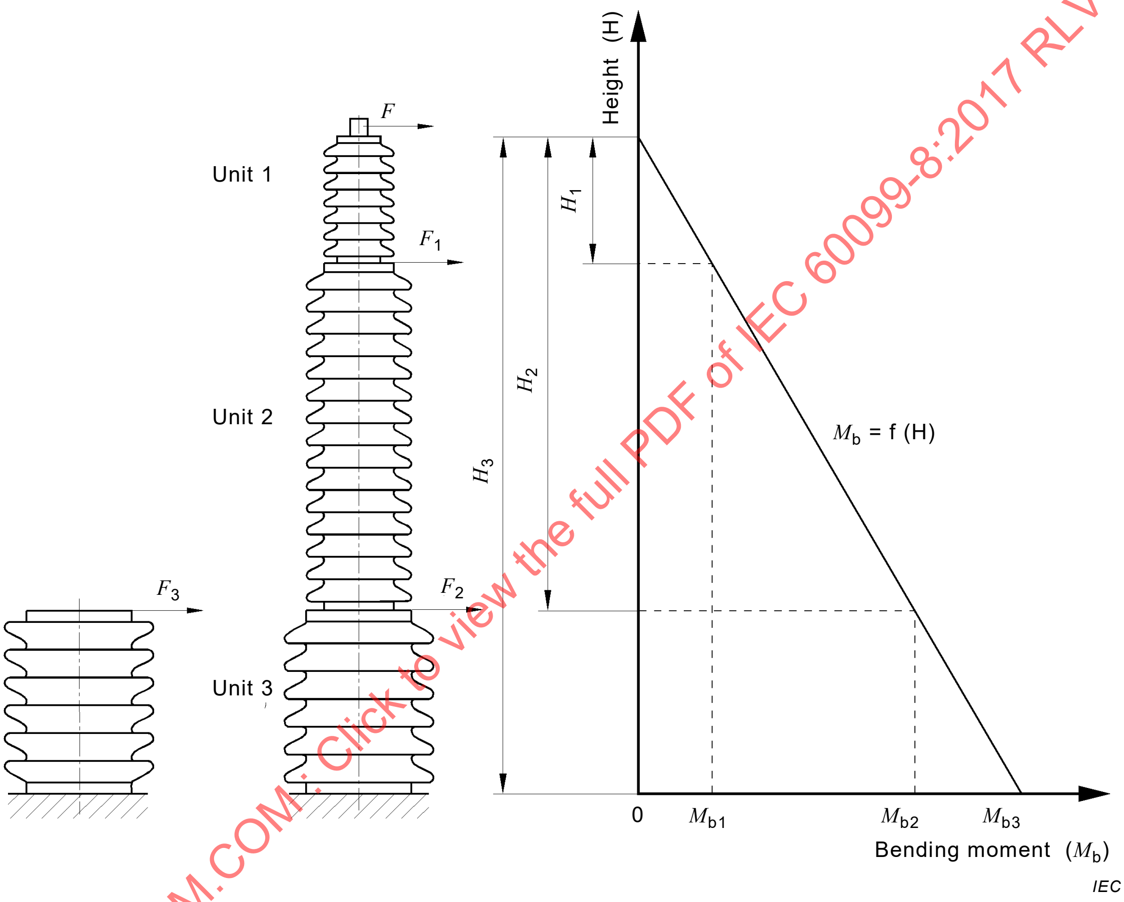


Figure B.1 – Bending moment – Multi-unit SVU

Testing the complete SVU, 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:

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

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

B.2 Definition of mechanical loads

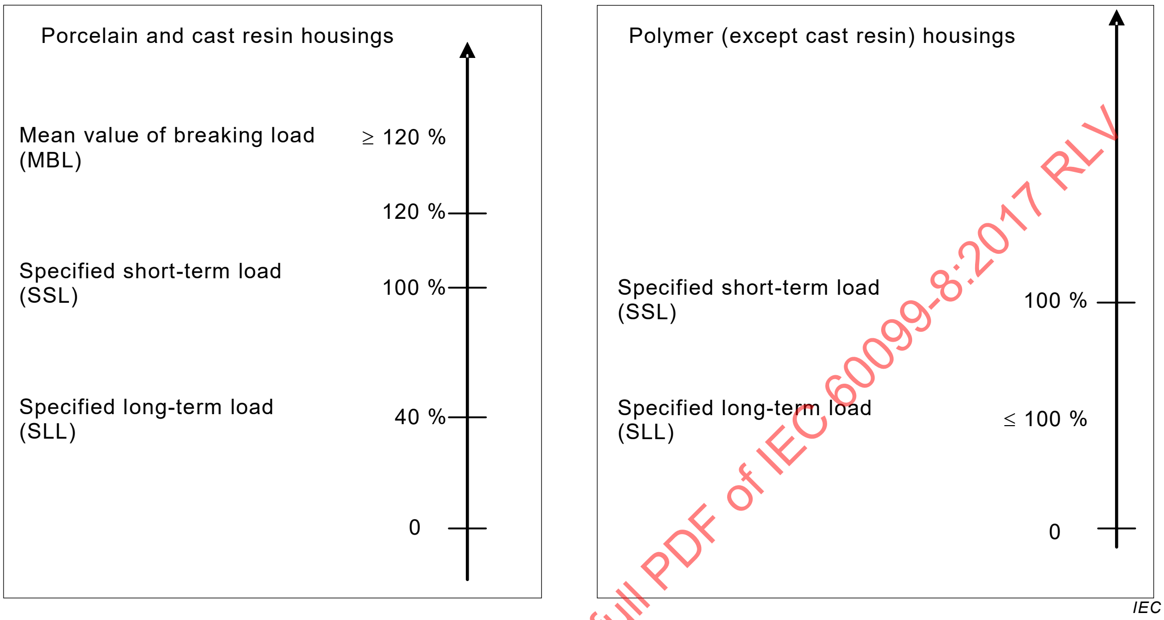


Figure B.2 – Definition of mechanical loads

Figure B.2 shows the definition of mechanical loads.

B.3 Definition of seal leak rate

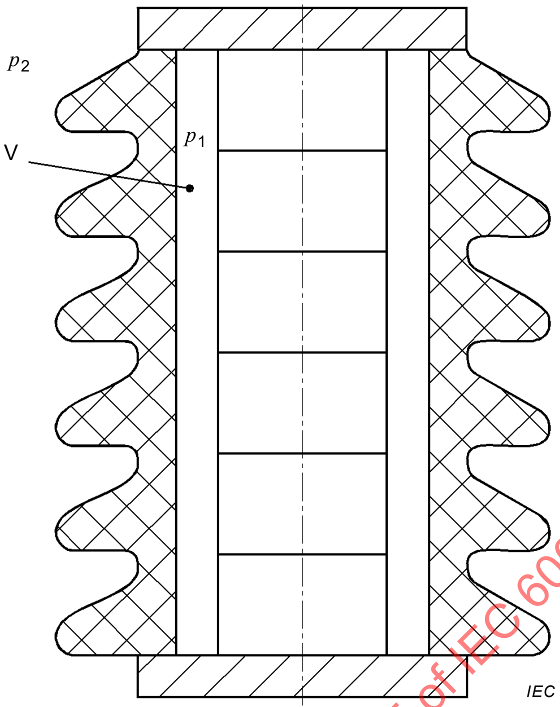


Figure B.3 – SVU unit

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, as shown in Figure B.3.

Seal leak rate $= \frac{\Delta p_1 \times V}{\Delta t}$ at $|p_1 - p_2| \geq 70$ kPa and at a temperature of +20 °C ± 15 K,

where

$\Delta p_1 = p_1(t_2) - p_1(t_1)$;

$p_1(t)$ is the internal gas pressure of the arrester housing as a function of time (Pa);

p_2 is the gas pressure exterior to the arrester (Pa);

t_1 is the start time of the considered time interval (s);

t_2 is the end time of the considered time interval (s);

$\Delta t = t_2 - t_1$;

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

B.4 Calculation of wind-bending-moment

Figure B.4 indicates dimensions of an SVU used for the calculation of wind-bending moment.

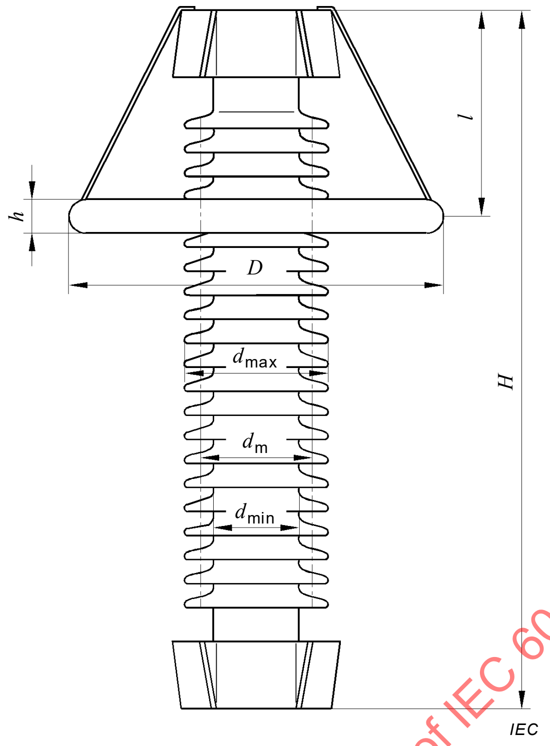


Figure B.4 – SVU dimensions

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

where

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

$d_m = (d_{max} + d_{min})/2$

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

H is the height of the arrester (m);

d_m is the mean value of the insulator diameter (m);

h is the thickness of the grading/corona ring (m);

D is the diameter of the grading/corona ring (m);

l is the grading/corona 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).

B.5 Flow chart – Procedures of tests of bending moment for porcelain/cast resin and polymer-housed SVUs

Figure B.5 shows procedures of tests of bending moment for porcelain/cast resin and polymer-housed SVUs.

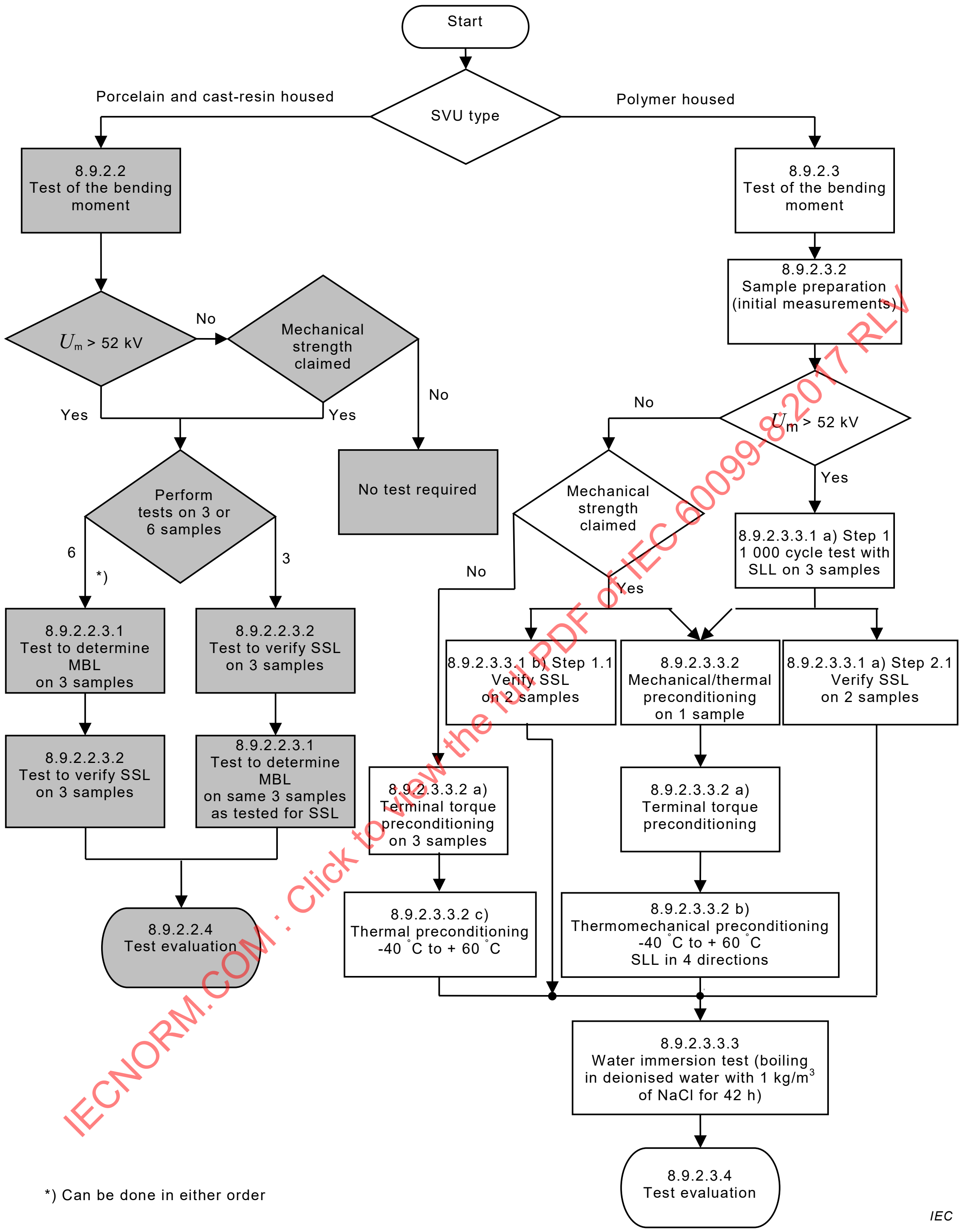


Figure B.5 – Procedures of tests of bending moment for porcelain/cast resin and polymer-housed SVUs

Annex C
(normative)

Special service conditions

C.1 General

A list of possible special service conditions is given in Annex A of IEC 60099-4:2014, referred to as abnormal service conditions in that Annex. A short guidance on the topics is given as follows:

C.2 Temperature in excess of +40 °C or below –40 °C

Low temperature may give problems with the sealing for arresters with enclosed gas volume. Polymer-housed arresters may be sensitive to very low temperatures close to and below –50 °C. Polymer material may become brittle at such low temperatures. The manufacturer must be consulted before use at lower temperatures than given by the IEC and verification tests requested.

C.3 Application at altitudes higher than 1 000 m

The external insulation strength decreases with altitudes. In particular this requires that the arcing distance of the housing and the series gap distance must be considered regarding the decreased insulation strength of the air. Guidance is found in IEC 60071-2.

C.4 Fumes or vapours that may cause deterioration of insulating surface or mounting hardware

For particular fumes or vapours, consult the manufacturer.

C.5 Excessive contamination by smoke, dirt, salt spray or other conducting materials

Severe air pollution such as salt spray smoke and dirt may affect the spark-over voltage of the gap.

C.6 Excessive exposure to moisture, humidity, dripping water, or steam

The manufacturer shall be consulted. However, most polymer arresters should be able to withstand if their performance has been verified in moisture and weather ageing tests as per IEC 60099-4.

C.7 Live washing of arrester

The manufacturer should be consulted if live washing is requested.

C.8 Unusual transportation or storage

The manufacturer shall be consulted and in particular cases tests shall be performed to verify an acceptable performance of the arrester.

C.9 Non-vertical erection and suspended erection

Non-vertical erections introduce a bending moment therefore this erection shall be checked with and accepted by the manufacturer. Suspended erection may also result in a bending moment if the connection is not made moment-free.

C.10 Wind speed > 34 m/s

The additional mechanical stress on the arrester shall be considered. The manufacturer shall be consulted.

C.11 Earthquake

The stress on the arrester approximately can be estimated from standard seismic data and arrester data on resonance frequency and damping and compared with mechanical withstand standards for the arrester. The installation methods are important as pedestals may magnify the stresses while e.g. flexible hanging will lower the stresses.

For more accurate information different seismic tests could be applied. (See IEC 62271-300, IEEE 693 or national standards such as from Japan, China or Chile).

C.12 Torsional loading of the arrester

The manufacturer shall be consulted.

Bibliography

IEEE C62.11, *Standard for metal-oxide surge arrester for alternating current power circuits (>1 kV)*

ISO 3274, *Geometrical Product Specifications (GPS) – Surface texture: Profile method – Nominal characteristics of contact (stylus) instruments*

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IEC 60099-8

Edition 2.0 2017-11

INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

Surge arresters –
Part 8: Metal-oxide surge arresters with external series gap (EGLA) for overhead transmission and distribution lines of a.c. systems above 1 kV

Parafoudres –
Partie 8: Parafoudres à oxyde métallique avec éclateur extérieur en série (EGLA) pour lignes aériennes de transmission et de distribution de réseaux à courant alternatif de plus de 1 kV

IEC 60099-8:2017-11(en-fr)

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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SURGE ARRESTERS –

Part 8: Metal-oxide surge arresters with external series gap (EGLA) for overhead transmission and distribution lines of a.c. systems above 1 kV

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 60099-8 has been prepared by IEC technical committee 37: Surge arresters.

This bilingual version (2018-10) corresponds to the monolingual English version, published in 2017-11.

This second edition cancels and replaces the first edition published in 2011. This edition constitutes a technical revision.

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

a) The Lightning discharge capability test has been completely re-written and re-named to Test to verify the repetitive charge transfer rating, Qrs with lightning discharges to reflect changes introduced in IEC 60099-4 Ed. 3 (2014) regarding new methods for rating the energy and charge handling capability of metal-oxide arresters. In addition to testing to evaluate the performance of the MO resistors, procedures for evaluating the performance of the EGLA series gaps have been introduced.

b) Omissions from Ed. 1 of this standard have been included, notably an RIV test and a means for determining the thermal time constant of the SUV portion of the EGLA.

c) Definitions for new terms have been added

d) A number of NOTES in Ed. 1 have been converted to normative requirements

A number of editorial changes have been made throughout the document to improve grammar and general flow of information.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
37/436/FDIS	37/438/RVD

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

The French version of this standard has not been voted upon.

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

A list of all parts of IEC 60098 series, under the general title *Surge arresters*, can be found on the IEC website.

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

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

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

This part of IEC 60099 applies to the externally gapped line arrester (EGLA)

This type of surge arrester is connected directly in parallel with an insulator assembly. It comprises a series varistor unit (SVU), made up from non-linear metal-oxide resistors encapsulated in a polymer or porcelain housing, and an external series gap (see Figure 1).

The purpose of an EGLA is to protect the parallel-connected insulator assembly from lightning-caused over-voltages. The external series gap, therefore, should spark over only due to fast-front over-voltages. The gap should withstand all power-frequency and slow-front over-voltages occurring on the system.

In the event of SVU failure, the external series gap should be able to isolate the SVU from the system.

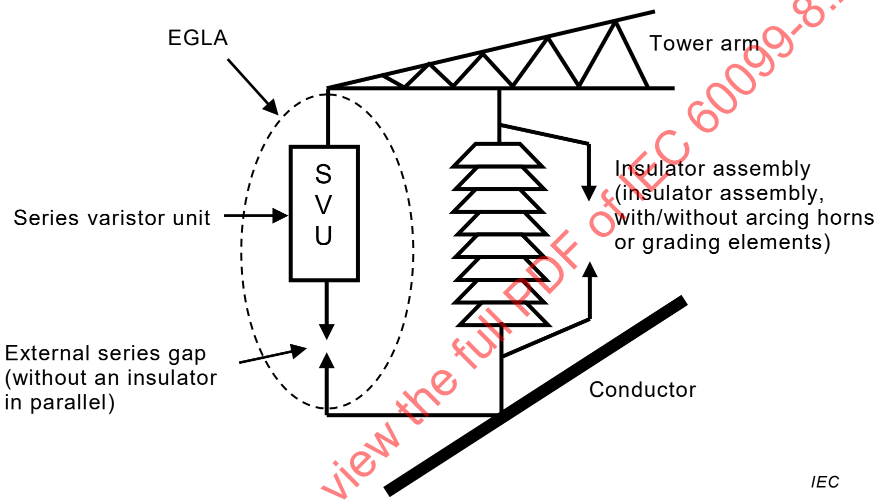


Figure 1 – Configuration of an EGLA with insulator and arcing horn

SURGE ARRESTERS –

Part 8: Metal-oxide surge arresters with external series gap (EGLA) for overhead transmission and distribution lines of a.c. systems above 1 kV

1 Scope

This part of IEC 60099 covers metal-oxide surge arresters with external series gap (externally gapped line arresters (EGLA)) that are applied on overhead transmission and distribution lines, only to protect insulator assemblies from lightning-caused flashovers.

This document defines surge arresters to protect the insulator assembly from lightning-caused over-voltages only. Therefore, and since metal-oxide resistors are not permanently connected to the line, the following items are not considered for this document:

- switching impulse spark-over voltage;
- residual voltage at steep current and switching current impulse;
- thermal stability;
- long-duration current impulse withstand duty;
- power-frequency voltage versus time characteristics of an arrester;
- disconnector test;
- aging duties by power-frequency voltage.

Considering the particular design concept and the special application on overhead transmission and distribution lines, some unique requirements and tests are introduced, such as the verification test for coordination between insulator withstand and EGLA protective level, the follow current interrupting test, mechanical load tests, etc.

Designs with the EGLA's external series gap installed in parallel to an insulator are not covered by this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60060-1:2010, *High-voltage test techniques – Part 1: General definitions and test requirements*

IEC 60060-2:2010, *High-voltage test techniques – Part 2: Measuring systems*

IEC 60068-2-11:1981, *Basic environmental testing procedures – Part 2-11: Tests – Test Ka: Salt mist*

IEC 60068-2-14:2009, *Environmental testing – Part 2-14: Tests – Test N: Change of temperature*

IEC 60099-4:2014, *Surge arresters – Part 4: Metal-oxide surge arresters without gaps for a.c. systems*

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

IEC 60507:2013, *Artificial pollution tests on high-voltage ceramic and glass insulators to be used on a.c. systems*

IEC TS 60815-1:2008, *Selection and dimensioning of high-voltage insulators intended for use in polluted conditions – Part 1: Definitions, information and general principles*

IEC 62217:2012, *Polymeric HV insulators for indoor and outdoor use – General definitions, test methods and acceptance criteria*

ISO 4287, *Geometrical Product Specifications (GPS) – Surface texture: Profile method – Terms, definitions and surface texture parameters*

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 sources*

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

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
externally gapped line arrester
EGLA
arrester designed for installation on overhead lines to protect an insulator assembly from lightning-caused fast-front over-voltages only

Note 1 to entry: This is accomplished by raising the spark-over level of the external series gap to a level that isolates the arrester from power-frequency over-voltages and from the worst case slow-front over-voltages due to switching and fault events expected on the line to which it is applied.

3.2
series varistor unit
SVU
non-linear metal-oxide resistor part, contained in a housing, which must be connected with an external series gap to construct the complete arrester

Note 1 to entry: The series varistor unit may include several units.

3.3
section of an EGLA
complete, suitably assembled part of a complete EGLA necessary to represent the behaviour of a complete EGLA with respect to a particular test

3.4
section of an SVU
complete, suitably assembled part of an SVU unit necessary to represent the behaviour of an SVU with respect to a particular test

3.5
unit of an SVU
completely housed part of an SVU which may be connected in series and/or in parallel with other units of an SVU to construct, in combination with the external series gap, an EGLA of higher voltage and/or current rating

3.6
rated voltage of an EGLA
U_r
maximum permissible r.m.s. value of power-frequency voltage that can be applied continuously between the EGLA terminals, and at which it is designed to operate correctly

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

Note 2 to entry: The rated voltage of an EGLA is comparable to Uc of all other types of MO-arresters.

3.7
reference voltage of an SVU
U_{ref}
peak value of power-frequency voltage divided by √2, which should be applied to the SVU to obtain the reference current

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

3.8
reference current of an SVU
I_{ref}
peak value (the higher peak value of the two polarities if the current is asymmetrical) of the resistive component of a power-frequency current used to determine the reference voltage of the SVU

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 SVU units negligible. It is to be specified by the manufacturer.

Note 2 to entry: Depending on the nominal discharge current of the EGLA, the reference current will be typically in the range of 0,05 mA to 1,0 mA per square centimetre of metal-oxide resistor area for a single column SVU.

3.9
rated short-circuit current of an SVU
I_s
r.m.s. value of the highest short-circuit current under which the SUV will not fail in a manner that causes violent shattering of the housing and under which self-extinguishing of open flames (if any) will occur within a defined period of time

3.10
residual voltage of an EGLA
peak value of voltage that appears across the terminal-to-terminal length of the EGLA including series gap and connection leads during the passage of discharge current

3.11
residual voltage of an SVU
peak value of voltage that appears between the terminals of the SVU during the passage of discharge current

3.12
surface leakage current of an SVU
current that flows on the surface of the SVU

3.13
follow current
I_{follow}
the current immediately following an impulse through an EGLA with the power-frequency voltage as the source

3.14
specified long-term load of an SVU
SLL
mechanical force perpendicular to the longitudinal axis of an SVU, allowed to be continuously applied during service without causing any mechanical damage to the SVU

3.15
specified short-term load of an SVU
SSL
greatest mechanical force perpendicular to the longitudinal axis of an SVU, 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 SVU

3.16
mean breaking load of an SVU
MBL
average breaking load for porcelain or cast resin-housed SVUs determined from tests

3.17
high current impulse
peak value of discharge current having a 4/10 or 2/20 impulse shape, which is used to test the withstand capability of the SVU on extreme lightning occasions

3.18
salt deposit density
SDD
amount of salt in the deposit on a given surface of the SVU housing, divided by the area of this surface; generally expressed in mg/cm^2

3.19
verification test for coordination between insulator withstand and EGLA protective level
test used to verify that the EGLA will exhibit correct sparkover operation and clamp the overvoltage caused by lightning considerably lower than the flashover voltage of the parallel-connected insulator assembly

3.20
vibration withstand test
test to verify that the SVU and its connectors can withstand the specified mechanical vibration levels

3.21
lightning impulse discharge
approximately sine half-wave current impulse having a time duration within 200 μs to 230 μs during which the instantaneous value of the impulse current is between 5 % and 100 % of its peak value

3.22
repetitive charge transfer rating
Q_{rs}
maximum specified charge transfer capability of an EGLA, in the form of a single event or group of surges that may be transferred through an EGLA without causing mechanical failure or unacceptable electrical degradation to the MO resistors

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.

4 Identification and classification

4.1 EGLA identification

An EGLA shall be identified by the following minimum information, which shall appear on a nameplate permanently attached to the arrester:

- rated voltage U_r in kV;
- rated frequency in Hz, only if it is less than 48 Hz or larger than 62 Hz;
- classification series information (examples: "X1", "Y2");
- rated short-circuit current I_s in kA;
- manufacturer's name or trade mark;
- year of manufacture;
- serial number (at least for arresters for $U_s > 52$ kV);
- lightning discharge capability (only charge value) in C; example: "0.4 C".

Information on required gap spacing including tolerances shall be given in an appropriate way, for example in the manual.

4.2 EGLA classification

EGLAs are classified by their nominal discharge currents and their high current impulse withstand capabilities as per Table 1, and they shall meet at least the test requirements and performance characteristics specified in Table 3. These arresters have no operating duties for slow-front surges and power-frequency over-voltages.

Table 1 – EGLA classification – "Series X" and "Series Y"

Series X					Series Y				
Class name	X1	X2	X3	X4	Class name	Y1	Y2	Y3	Y4
Nominal discharge current (kA), 8/20	5	5	10	20	Nominal discharge current (kA), 2/20	5	10	15	20
High current impulse (kA), 4/10	40	65	100	100	High current impulse (kA), 2/20	10	25	40	65

"Series X" corresponds to the classification used in IEC 60099-4. A nominal discharge current of 8/20 wave shape and a high current impulse of 4/10 wave shape are used in IEC and in IEEE standards. "Series Y" corresponds to the classification applied e.g. in Japan on shielded line applications. Specification of wave shape 2/20 both for the nominal discharge current and for the high current impulse is based on this special application.

According to service conditions, other high current impulse values than those specified in this table may be applied.

5 Standard ratings and service conditions

5.1 Standard rated voltages

Standard values of rated voltages (r.m.s. values) are specified in Table 2 in equal voltage steps within specified voltage ranges.

Table 2 – Steps of rated voltages (r.m.s. values)

Range of rated voltages (kV)	**Steps of rated voltage** (kV)
3 to 30	1
> 30 to 54	3
> 54 to 96	6
> 96 to 288	12
> 288 to 396	18
> 396	24
NOTE Other values of rated voltage may be acceptable, provided they are multiples of 6.	

5.2 Standard rated frequencies

The standard rated frequencies are 48 Hz to 62 Hz.

5.3 Standard nominal discharge currents

The standard nominal discharge currents for 8/20 or 2/20 shapes are: 5 kA, 10 kA, 15 kA and 20 kA.

5.4 Service conditions

5.4.1 Normal service conditions

EGLAs which conform to this document shall be suitable for normal operation under the following normal service conditions:

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

b) altitude not exceeding 1000 m;

c) frequency of the a.c. power supply not less than 48 Hz and not more than 62 Hz;

d) power-frequency voltage applied continuously between the terminals of the EGLA not exceeding its rated voltage;

e) mechanical conditions: not specified (see NOTE);

f) wind speed: not specified (see NOTE);

g) pollution conditions: pollution by dust, smoke, corrosive gases, vapours or salt may occur; pollution does not exceed “heavy” as defined in IEC TS 60815-1.

NOTE It is recognized that mechanical and environmental issues are important for service, but due to the large variety of possible installation configurations it is not possible to provide standard values for items e) and f).

5.4.2 Special 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 document in case of special service conditions is subject to agreement between the manufacturer and the purchaser. A list of possible special service conditions is given in Annex C.

6 Requirements

6.1 Insulation withstand of the SVU and the complete EGLA

6.1.1 Insulation withstand of the housing of the SVU

The housing of the SVU shall withstand a lightning impulse voltage of

a) for "Series X": 1,4 times the residual voltage at the nominal discharge current

b) for "Series Y": 1,13 times the residual voltage at high current impulse, but not less than 1,3 times the residual voltage at nominal discharge current

NOTE The factor of 1,4 in case a) covers variations in atmospheric conditions up to 1 000m altitude and discharge currents up to three times the nominal discharge current.

6.1.2 Insulation withstand of EGLA with shorted (failed) SVU

The EGLA shall have the following insulation withstand performance:

a) the EGLA shall withstand the specified switching impulse withstand voltage level of the system even if the SVU has been shorted due to overloading (failure);

b) the EGLA shall be able to withstand the maximum temporary over-voltages phase to ground for their maximum durations even if the SVU has been shorted due to overloading (failure).

6.2 Residual voltages

The purpose of the measurement of residual voltages is to obtain the maximum residual voltages for a given design for all specified currents and 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 EGLA design for any current and wave shape is calculated from the residual voltage of SVU sections tested during type tests multiplied by a specific scale factor plus a calculated inductive voltage drop across the SVU, the gap and connection leads. The 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.

The value of the residual voltage of the EGLA at nominal discharge current and at high current impulse, respectively, multiplied by a factor as given in 6.1.1, shall be lower than the minimum flashover voltage of the insulator assembly to be protected.

6.3 High current duty

The capability of the SVU for discharging operations shall be demonstrated by injecting two high current impulses.

6.4 Lightning discharge capability

The capability of the metal-oxide resistors including the series gap of the EGLA to withstand lightning discharges having current waveforms with durations of several tens of microseconds for arresters applied on shielded lines and several hundreds of microseconds for arresters on unshielded lines shall be demonstrated. The related test also covers effects of multiple lightning strikes.

6.5 Short-circuit performance of the SVU

The manufacturer shall claim a short-circuit rating of the SVU. The short-circuit currents according to this rating shall not cause violent shattering of the SVU, and any open flames shall self-extinguish in a given time.

The gap is not subject of the short-circuit tests on the SVU, and its short-circuit performance is recommended to be verified separately. The gap should be able to maintain its mechanical integrity after having been subjected to the rated short-circuit current of the EGLA, and its spark-over voltage should not be decreased.

6.6 Mechanical performance

For the EGLA to be mounted on transmission towers or poles, mechanical performance to withstand tensile, bending and/or vibration loads due to wind pressure, conductor vibration abnormal load during installation work and moisture ingress shall be demonstrated.

The applicable values of tensile and bending loads shall be agreed between the manufacturer and the purchaser.

The SVU shall be able to withstand the vibration load to be expected in service.

The complete EGLA including gap assembly and mounting structure should be able to withstand at least the same mechanical stress.

6.7 Weather aging of SVU

The SVU must be able to withstand the environmental stress expected in service. Environmental tests demonstrate by accelerated test procedures that the sealing mechanism and the exposed metal combinations of the SVU are not impaired by environmental conditions. For SVUs with polymer (composite and cast resin) housings, resistance to UV radiation has to be demonstrated in addition.

6.8 Reference voltage of the SVU

The reference voltage (U_{ref}) of the SVU shall be measured at the reference current on sections and units when required. The measurement shall be performed at an ambient temperature of 20 °C ± 15 K, and the actual temperature shall be recorded.

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

6.9 Internal partial discharges

The level of internal partial discharges in the SVU in the tests according to 9.1 and 10.3 shall not exceed 10 pC.

6.10 Coordination between insulator withstand and EGLA protective level

The correct coordination between flashover characteristics of the insulator assembly, the spark-over voltage of the EGLA with front-of-wave and standard lightning impulses and the residual voltage of the EGLA at nominal discharge current and, for “Series Y” arresters, at high current impulse shall be demonstrated.

Any spark-over operation for lightning impulse voltage shall occur in the external series gap of the EGLA, without causing any flashover of the insulator assembly to be protected.

The value of

- for "Series X": 1,4 times the residual voltage at the nominal discharge current according to Table 1 and 8.3.3;
- for "Series Y": 1,13 times the residual voltage at high current impulse, but not less than 1,3 times the residual voltage at nominal discharge current according to Table 1 and 8.3.3 and 8.3.4.

must be lower than $U_{50,\ Insulator}$ minus X times the standard deviation, ($U_{50,\ Insulator} - X \times \sigma$), of the insulator assembly to be protected, where σ = 0,03 and X is to be agreed upon between manufacturer and user, a recommended value being X = 2,5.

6.11 Follow current interrupting

Follow current interrupting operation of the EGLA under wet and polluted conditions shall be demonstrated by a test procedure which takes these operating conditions into account. Performing a follow current interrupting test is mandatory, either as a type test according to 8.8 or as an acceptance test according to 10.6.

6.12 Electromagnetic compatibility

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

In normal working operating conditions, the EGLA shall not emit significant disturbances. A radio interference voltage test (RIV) shall be applied as an acceptance test to the complete EGLA (see 10.4). The maximum radio interference level of the EGLA energized at the maximum continuous phase to ground system voltage ($U_s/\sqrt{3}$) shall not exceed 2 500 µV.

6.13 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.

7 General testing procedure

7.1 Measuring equipment and uncertainty

The measuring equipment shall meet the requirements of IEC 60060-2 and IEC 60099-4. The values obtained shall be accepted as uncertainty 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.

7.2 Test samples

Unless otherwise specified, for each test item, the complete test sequence shall be carried out on the same test sample. The number of test samples is given in Table 3. The test samples shall be new, clean, completely assembled and arranged to simulate the condition in service.

When tests are made on sections or units, the following shall be fulfilled:

a) The ratio between rated voltage of the complete EGLA to the rated voltage of the section or unit is defined as n.

b) 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 EGLA divided by n.

c) The reference voltage U_{ref} of the SVU of the test section should be equal to the minimum reference voltage of the SVU of the EGLA divided by n. If the reference voltage of the SVU of the test section is greater than the minimum reference voltage of the SVU of the complete EGLA divided by n, the factor n shall be reduced correspondingly. If the reference voltage of the SVU of the test section is less than the minimum reference voltage of the SVU of the complete EGLA divided by n, the test section is not allowed to be used.

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

8 Type tests

8.1 General

Table 3 identifies the type tests that shall be performed on the complete EGLA or on components of the EGLA.

Table 3 – Type tests (all tests to be performed with or without insulator assembly; by manufacturer's decision)

Test item	Number of test samples	EGLA	Section of EGLA	Unit of SVU	Section of SVU	Clause number
Insulation withstand tests						
1.1 Housing withstand test of SVU	1			Test		8.2.2
1.2 EGLA withstand test with failed SVU	1	Test				8.2.3
2. Residual voltage tests	3				Test	8.3
3. Standard lightning impulse sparkover test [a]	1	Test				8.4
4. High current impulse withstand test	3				Test	8.5
5. Test to verify the repetitive charge transfer rating, Q_{rs} with lightning discharges: MO resistors	10 (20)				Test	8.6.1
6. Test to verify the repetitive charge transfer rating, Q_{rs} with lightning discharges Series gap	1				Test	8.6.2
7. Short-circuit tests	4 or 5			Test		8.7
8. Follow current interrupting test [b]	1	Test [c]	Test [c]			8.8
9. Bending test	3 or 6			Test		8.9.2
10. Vibration test [d]	1			Test [e]		8.9.3
11. Weather aging test	1			Test		8.10
12. Radio interference voltage (RIV) test	1	Test [f]				8.11

[a] This test is mandatory if not performed as an acceptance test in accordance with 10.5.

[b] This test is mandatory if not performed as an acceptance test in accordance with 10.6.

[c] This test is performed either on a complete EGLA or a section of an EGLA, see 8.8.2.

[d] This test is mandatory if not performed as an acceptance test in accordance with 10.7.

[e] The vibration test is performed on one complete SVU, see 8.9.3.1

[f] This test is mandatory if not performed as an acceptance test in accordance with 10.4

8.2 Insulation withstand tests on the SVU housing and on the EGLA with failed SVU

8.2.1 General

These tests demonstrate the lightning impulse withstand voltage of the SVU housing under dry conditions and the withstand voltage of the EGLA against the maximum expected switching surge and power-frequency over-voltages in the system under wet conditions if the SVU had failed and is shorted.

8.2.2 Insulation withstand test on the SVU housing

8.2.2.1 General

This test demonstrates the dielectric withstand capability of the external housing of the SVU against lightning impulse voltages.

8.2.2.2 Test procedure

The SVU housing shall be subjected to a standard lightning impulse voltage dry test according to procedure B in 7.3.1.2 of IEC 60060-1:2010.

The test shall be performed on the SVU housing with the highest specific voltage stress per unit length. The non-linear metal-oxide resistors shall be removed or replaced by parts of insulating material.

Fifteen consecutive impulses at the test voltage value shall be applied for each polarity.

Test voltage:

a) for "Series X": 1,4 times the residual voltage at the nominal discharge current according to Table 1 and 8.3.3.

b) for "Series Y": 1,13 times the residual voltage at high current impulse, but not less than 1,3 times the residual voltage at nominal discharge current according to Table 1 and 8.3.3 and 8.3.4.

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

Evaluation: The SVU shall be considered to have passed the test if the number of external disruptive discharges does not exceed two in each series of 15 impulses.

8.2.3 Insulation withstand tests on EGLA with failed SVU

8.2.3.1 General

A switching impulse wet withstand voltage test and a power-frequency wet withstand voltage test shall be performed simulating a failed SVU. The purpose of these tests is to demonstrate that no spark-over under switching surge and power-frequency over-voltages will occur if, as the worst case scenario, the SVU is shorted by a failure.

8.2.3.2 Switching impulse wet withstand voltage test

Test procedure

The test procedure shall be as follows:

Test sample: EGLA with shorted SVU. The failed SVU shall be simulated by shorting the SVU with a metal wire, while the electrode condition shall be specified after agreement between the manufacturer and the purchaser. The minimum external series gap length for the test shall be specified by the manufacturer.

Test voltage and test condition:

a) The withstand voltage value shall be claimed by the manufacturer or determined by agreement between the manufacturer and the purchaser, considering the maximum prospective switching impulse over voltage level of the line. The altitude of installation and of the test laboratory shall be considered to determine the test voltages.

b) The 50 % flashover voltage ($U_{50,\ EGLA}$) is measured by the up-and-down method in accordance with IEC 60060-1 for each polarity on the EGLA with the SVU shorted. The wave shape of the test voltage shall be 250/2500.

c) The characteristic of the rain shall be in accordance with the requirements of IEC 60060-1.

Evaluation: The withstand voltage of the EGLA is determined as

$$U_{10,\ EGLA} = U_{50,\ EGLA}\ (1\ \text{-}1{,}3\ \sigma),$$

calculated from the measured 50 % flashover voltage and the standard deviation σ, which is assumed to be 6 % (σ = 0,06) for switching impulse voltage. The EGLA has passed the test if the withstand value is equal to or higher than the claimed or agreed value.

NOTE For a normal distribution, as assumed here, the 10 % probability value results from the 50 % probability value minus 1,3 times the standard deviation.

8.2.3.3 Power-frequency wet withstand voltage test

The test procedure shall be as follows:

Test sample: EGLA with shorted SVU. The failed SVU shall be simulated by shorting the SVU with a metal wire. The minimum external series gap length and the conditions of the gap electrodes shall be specified by the manufacturer or agreed upon between the manufacturer and the user.

Test voltage and test condition:

a) The power-frequency wet withstand voltage test shall be performed in accordance with IEC 60060-1 on the EGLA with the SVU shorted.

b) The test voltage shall be 1,2 times the rated voltage of the EGLA.

c) The characteristic of the rain shall be in accordance with the requirements of IEC 60060-1.

Evaluation: The EGLA has passed the test if the sample withstands the test voltage for one minute.

8.3 Residual voltage tests

8.3.1 General

This test demonstrates that the residual voltages of the SVU and complete EGLA under lightning impulses are in accordance with the claimed values. All residual voltage tests shall be made on the same three sections of an SVU. The time between discharges shall be sufficient to allow the samples to return to approximately ambient temperature. The residual voltage of the EGLA is calculated from the measured residual voltage of the SVU sections times a scale factor plus a calculated inductive voltage drop across the SVU, the gap and the connection leads. The residual voltage of the SVU is calculated from the measured residual voltage of the SVU sections times a scale factor plus a calculated inductive voltage drop across the SVU.

8.3.2 Procedure for correction and calculation of inductive voltages

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

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

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

Procedure a)

1) Multiply the sample impulse voltage wave shape by the scale factor (see 6.2).
2) From the wave shape of the current impulse, determine the rate of change of current ($\mathrm{d}i/\mathrm{d}t$) over the entire wave shape and multiply it by the inductance in order to determine the inductive voltage drop:

$$u(t) = L \cdot \frac{\mathrm{d}i}{\mathrm{d}t} = L' \cdot h \cdot \frac{\mathrm{d}i}{\mathrm{d}t}$$

where

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

L' is the inductance per unit length in μH/m; L' = 1 μH/m;

h is either the terminal-to-terminal length in m of the SVU or of the complete EGLA including series gap and connection leads;

$\mathrm{d}i/\mathrm{d}t$ is the rate of change of current with time in kA/μs.

3) Add the results of 1) and 2) on a wave shape basis; the peak value of the resulting wave shape shall be taken as the actual current impulse residual voltage of the arrester.

Procedure b)

1) Multiply the peak value of the sample impulse voltage by the scale factor (see 6.2).
2) Determine the inductive voltage drop between the arrester terminals using the following formula:

$$U_\mathrm{L} = L \cdot \frac{\mathrm{d}i}{\mathrm{d}t} = L' \cdot h \cdot \frac{I_\mathrm{d}}{T_\mathrm{f}}$$

where

U_L is the peak value of the inductive voltage drop in kV;

L' is the inductance per unit length in μH/m; L' = 1;

h is either the terminal-to-terminal length in m of the SVU or of the complete EGLA including series gap and connection leads;

T_f is the front time of the current impulse in μs; T_f = 2;

I_d is the actual discharge current amplitude in kA.

3) Add the results of 1) and 2); the resulting value shall be taken as the actual current impulse residual voltage of the arrester.

8.3.3 Lightning current impulse residual voltage test

One lightning current impulse shall be applied to each of the three samples for each of the following three peak values of approximately 0,5, 1 and 2 times the nominal discharge current of the EGLA. Wave shape of the current shall be 8/20 for "Series X" arresters and 2/20 for "Series Y" arresters according to Table 1.

For the current impulses, there is no requirement for virtual time to half value on the tail but tolerances on the virtual front time of the current impulses shall be within the following limits:

a) for 2/20 current impulses: from 1,7 µs to 2,3 µs for virtual front time;

b) for 8/20 current impulses: from 7 µs to 9 µs for virtual front time;

The lightning impulse residual voltage for "Series Y" arresters is determined as per procedure a) or b) in 8.3.2. For "Series X" arresters, no inductive effects are necessary to consider.

The maximum values of the determined residual voltages shall be drawn in a residual voltage versus discharge current curve.

The value of

- 1,4 times the residual voltage at the nominal discharge current according to Table 1 for "Series X" designs,
- 1,3 times the residual voltage at nominal discharge current according to Table 1 for "Series Y" designs,

shall be lower than the minimum flashover voltage of the insulator assembly to be protected. See also 10.5.3.

If the routine test cannot be carried out on a complete SVU at nominal discharge current, then tests shall be carried out at a current in the range of 0,01 to 1 times the nominal discharge current for comparison with the complete SVU.

8.3.4 High current impulse residual voltage test

This test applies to "Series Y" designs only. One high current impulse of the wave shape 2/20 and a peak value according to Table 1 shall be applied to each of the three samples.

For the current impulses, there is no requirement for virtual time to half value on the tail but tolerances on the virtual front time of the current impulses shall be within the following limits:

from 1,7 µs to 2,3 µs for virtual front time;

The high current impulse residual voltage is determined as per procedure a) or b) in 8.3.2.

The value of 1,13 times the high current impulse residual voltage shall be lower than the minimum flashover voltage of the insulator assembly to be protected. See also 10.5.3.

8.4 Standard lightning impulse sparkover test

This is a mandatory type test only if not an acceptance test for each specific insulator assembly according to 10.5 is performed. As a type test, it is performed without the insulator assembly.

The purpose of this test is to determine the 50 % spark-over voltage of the EGLA under lightning impulse voltage stress.

The test sample is one EGLA with the maximum gap distance for a given designated system, without the insulator assembly.

Wave shape shall be 1,2/50. The 50 % spark-over voltage ($U_{50,\ EGLA}$) shall be verified by the up-and-down method according to IEC 60060-1.

NOTE 1 The protective margin between the spark-over voltage of the EGLA and the flashover voltage of the insulator assembly to be protected can be evaluated by $U_{50,\ EGLA}$ plus X times the standard deviation, ($U_{50,\ EGLA} + X{\cdot}\sigma$) not being higher than $U_{50,\ Insulator}$ minus X times the standard deviation, ($U_{50,\ Insulator} - X{\cdot}\sigma$) of the insulator assembly to be protected, if agreed between manufacturer and user. X is to be agreed upon between the manufacturer and the user. The standard deviation (σ) is set to be 3 % for 1,2/50 impulses.

NOTE 2 A typical value for X is 2,5.

NOTE 3 Experience during testing has shown that the spark-over voltage of the EGLA can be influenced by the close vicinity of the insulator assembly.

8.5 High current impulse withstand test

8.5.1 Selection of test samples

The test shall be performed on three sections of an SVU. The sections shall have a residual voltage at nominal discharge current at the highest end of the variation range declared by the manufacturer. In order to comply with these specifications the following shall be fulfilled:

a) The ratio between the residual voltage at nominal discharge current of the complete SVU and the residual voltage at nominal discharge current of the section is defined by n. The volume of the resistor elements used as test samples shall not be greater than the minimum volume of all resistor elements used in the complete SVU divided by n.

b) The reference voltage U_{ref} of the SVU of the test section should be equal to the minimum reference voltage of the SVU of the EGLA divided by n. If the reference voltage of the SVU of the test section is greater than the minimum reference voltage of SVU of the complete EGLA divided by n, the factor n shall be reduced correspondingly. If the reference voltage of the SVU of the test section is less than the minimum reference voltage of SVU of the complete EGLA divided by n, the test section is not allowed to be used.

8.5.2 Test procedure

Two high current impulses of same polarity, having peak values and wave shapes according to Table 1, shall be applied to the three sections. Time interval between the impulse applications shall allow the sample to cool to ambient temperature.

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

a) for 2/20 current impulses:
   – from 90 % to 110 % of the specified peak value;
   – from 1,7 μs to 2,3 μs for virtual front time;
   – from 18 μs to 22 μs for virtual time to half value on the tail;
   – the peak value of any opposite polarity current wave shall be less than 20 % of the peak value of the current;
   – small oscillations on the impulse are permissible provided their amplitude near the peak of the impulse is less than 5 % of the peak value. Under these conditions, for the purpose of measurement, a mean curve shall be accepted for determination of the peak value.

b) for 4/10 current impulses:
   – from 90 % to 110 % of the specified peak value;
   – from 3,5 μs to 4,5 μs for virtual front time;
   – from 9 μs to 11 μs for virtual time to half value on the tail.
   – the peak value of any opposite polarity current wave shall be less than 20 % of the peak value of the current;

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

8.5.3 Test evaluation

a) The reference voltage measured before and after the test shall have changed by not more than 10 %.

b) Any change in residual voltage at nominal discharge current measured before and after the test shall be within (– 2 % to + 5 %).

c) Visual examination of the test samples after the test shall reveal no evidence of puncture, flashover and cracking or other significant damage of the test sample. If the metal-oxide resistors cannot be removed from the test samples for visual examination, the following additional tests shall be performed to ensure that no damage occurred during the test. After the residual voltage test (b), two impulses at nominal discharge current shall be applied to the test sample. The first impulse shall be applied after sufficient time to allow cooling of the sample to ambient temperature. The second impulse is applied 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, and the difference of the residual voltage between the initial measurement before the test and the last of the two impulses after the test shall not exceed a range of (– 2 % to + 5 %).

8.6 Test to verify the repetitive charge transfer rating, Q_{rs} with lightning discharges

8.6.1 MO resistors

8.6.1.1 General

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

Repetitive charge transfer capability is specified as an impulse current stress that can be withstood by the MO resistors of an EGLA twenty times without mechanical or unacceptable electrical damage. One impulse current stress is considered to represent a charge transfer event that may occur under real system conditions.

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 8.6.1.5. By this approach it is assumed that the performance of the individual MO resistors can also be assigned to a full EGLA 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 the current impulse shape shall be approximately sinusoidal. The time duration for which the instantaneous value of the impulse current is between 5 % and 100 % of its peak value shall be within 200 µs to 230 µs. The peak of any opposite polarity current wave shall be less than 5 % of the peak value of the current. The current peak value of each impulse on each test sample shall lie between 90 % and 110 % of the selected peak value.

An EGLA shall be assigned a Q_{rs} value from the list given in 8.6.1.5.

A first test sequence shall be performed on 10 samples of MO resistors selected according to 8.6.1.2. 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.

8.6.1.2 Selection of test samples

The test samples shall include complete SVUs, SVU sections or metal-oxide resistor elements which have not been subjected to any previous tests except as necessary for evaluation purposes of this test.

The samples to be chosen for the test to verify the repetitive charge transfer rating shall have a residual voltage at nominal discharge current at the highest end of the variation range declared by the manufacturer. Furthermore, in the case of multi-column SVUs, the highest value of uneven current distribution shall be considered. In order to comply with these specifications the following shall be fulfilled.

a) The ratio between the residual voltage at nominal discharge current of the complete SVU and the residual voltage at nominal discharge current of the section is defined by n. The volume of the resistor elements used as test samples shall not be greater than the minimum volume of all resistor elements used in the complete SVU divided by n.

b) The reference voltage U_{ref} of the SVU of the test section should be equal to the minimum reference voltage of the SVU of the EGLA divided by n. If the reference voltage of the SVU of the test section is greater than the minimum reference voltage of SVU of the complete EGLA divided by n, the factor n shall be reduced correspondingly. If the reference voltage of the SVU of the test section is less than the minimum reference voltage of SVU of the complete EGLA divided by n, the test section is not allowed to be used.

c) The samples 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)$_{actual}$.

8.6.1.3 Test procedure

Figure 2 gives an overview of the test procedure.

Initial tests • Residual voltage test at nominal discharge current • Reference voltage test at specified reference current
Application of 1,1 times Q_{rs} • 1st sequence: 20 impulses per sample (10 samples) • if not more than one sample failure during 1st sequence: test passed • if not more than two sample failures during 1st sequence: conduct 2nd sequence with 10 samples, 20 impulses per sample • if more than two sample failures in 1st sequence or any sample failure in 2nd sequence: test failed
Test evaluation: check for • no mechanical damage at visual inspection • change of reference voltage within ±5 % • change of residual voltage at nominal discharge current within ±5 % • withstand capability to one 8/20 current impulse of at least 0,5 kA/cm² peak current density or 2 times I_n, whichever is lower

IEC

Figure 2 – Test procedure to verify the repetitive charge transfer rating, Q_{rs}

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

The samples shall fulfil the requirements in 8.6.1.2.

The following procedure shall be followed:

a) Each sample shall be subjected to a residual voltage test at nominal discharge current and a reference voltage test at specified reference current before and after the test.

b) 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.

c) The wave shape and duration of the current impulses shall be as 8.6.1.

d) The charge content of each impulse shall be at least equal to the claimed repetitive charge transfer rating (selected from the list given in 8.6.1.5) multiplied by 1,1.

NOTE 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.

8.6.1.4 Test evaluation

The full test shall be considered passed if either.

a) not more than one sample failed during the first sequence, or

b) 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 8.6.1.5 shall be selected, and the test shall be repeated for this lower charge level following the procedure given in 8.6.1.3.

NOTE 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 = 0,0056 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 = 0,0056 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:

a) there is no indication of mechanical damage (puncture, flashover or cracking);

b) any change of the reference voltage before and after the test, measured at the same temperature ± 3 K, is within ± 5 %;

c) any change of the residual voltage at nominal discharge current before and after the test is within ± 5 %;

d) a final application of a current impulse 8/20 µs of an amplitude resulting in a current density of at least 0,5 kA/cm^2 or in 2 times I_n, whichever is lower, is passed without mechanical damage.

NOTE Puncture of the metallization is not considered a mechanical damage if all other pass criteria are met.

8.6.1.5 List of rated charge values

The following values, expressed in C, are standardized as rated charge values: 0,1; 0,2; 0,3; 0,4; 0,6; 0,8; 1; 1,2; 1,4; 1,6; 1,8; 2; 2,4; 2,8; 3,2; 3,6; 4.

If higher values shall be specified this shall be done in steps of 0,4 C.

8.6.2 Series gap

8.6.2.1 General

This test applies to the series gap for externally gapped line arresters (EGLA) with gap spacing of 20cm or less.

The purpose of this test is to verify the repetitive charge withstand capability of the series gap under lightning impulse discharges. The test shall be performed on one series gap with a Q_{rs} value not less than the Q_{rs} value specified for the MO resistors of SVU.

8.6.2.2 Test procedure

Figure 3 gives an overview of the test procedure.

Pre- tests • Determination of the 50 % spark-over voltage of the series gap under lightning impulse voltage stress for both polarities. The shortest flashover distance for the design shall be used. The test can be performed without the insulator assembly. The 50 % spark-over voltage ($U_{50,\ \mathrm{EGLA\ series\ gap}}$) shall be verified by the up-and-down method according to IEC 60060-1 (refer to 8.4). • For the application of lightning impulse discharges, the series gap can be integrated in series with one of the ten test samples of test used in 8.6.1 to verify the repetitive charge transfer rating, Q_{rs}. The flashover distance of the series gap shall be adjusted to at least 10 mm to get an arc.
Application of Q_{rs} • 20 impulses of lightning impulse discharges
Post-test • Repeat of pre-test to determine the 50 % spark-over voltage for both polarities

IEC

Figure 3 – Test procedure to verify the repetitive charge withstand of the series gap

8.6.2.3 Test evaluation

The 50 % spark-over voltage for each polarity in the post-test shall not have changed from the values determined in the pre-test by more than ±10 %.

8.7 Short-circuit tests

8.7.1 General

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

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

With respect to short-circuit current performance, it is important to distinguish between two designs of SVUs:

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

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

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

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

Depending on the type of SVU and test voltage, different requirements apply with regard to the number of test samples, initiation of short-circuit current and amplitude of the first short-circuit current peak. Table 4 shows a summary of these requirements which are further explained in the following subclauses.

8.7.2 Preparation of the test samples

8.7.2.1 General

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

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

Figure 4 shows different examples of SVU units.

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

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

8.7.2.2 "Design A" SVUs

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

No differences with regard to polymer housings or porcelain housings are made in the preparation of the test samples. However, differences partly apply in the test procedure (see 8.7.4.3). In this case, "Design A" SVUs with polymeric sheds which are not made of porcelain or other hollow insulators, and which are as brittle as ceramics, shall be considered and tested as porcelain-housed SVUs.

8.7.2.3 "Design B" SVUs

8.7.2.3.1 General

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

8.7.2.3.2 Polymer-housed SVUs

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

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

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

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

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

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

8.7.2.3.3 Porcelain-housed SVUs

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

8.7.3 Mounting of the test sample

The SVU units to be tested can be either mounted directly to a base according to the mounting arrangements as shown in Figure 5a and Figure 5b, or mounted hanging in accordance with the installation recommendations of the manufacturer. The choice of test installation is up to the manufacturer. In case of suspended mounting, the bottom end of the SVU shall be at the same level as the upper edge of the circular enclosure.

For a base-mounted SVU, the mounting arrangement is shown in Figure 5a and Figure 5b. The distance to the ground from the insulating platform and the conductors shall be as indicated in Figure 5a and Figure 5b.

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

For base-mounted SVUs, the bottom end fitting of the test sample shall be mounted on a test base that is at the same height as a surrounding circular or square enclosure. The test base shall be of insulating material or may be of conducting material if its surface dimensions are smaller than the surface dimensions of the SVU bottom end fitting. The test base and the enclosure shall be placed on top of an insulating platform, as shown in Figure 5a and Figure 5b. For non-base-mounted SVUs, the same requirements apply to the bottom of the SVU. The arcing distance between the top end cap and any other metallic object (floating or grounded), except for the base of the SVU, shall be at least 1,6 times the height of the sample SVU, but not less than 0,9 m. The enclosure shall be made of non-metallic material and be positioned symmetrically with respect to the axis of the test sample. It shall not be permitted to open or move during the test. The height of the enclosure shall be 40 cm ± 10 cm, and its diameter (or side, in case of a square enclosure) shall be equal to the greater of 1,8 m or D in the Equation below:

$$D = 1{,}2 \times (2 \times H + D_{\text{SVU}})$$

where

H is the height of tested SVU unit;

D_{SVU} is the diameter of tested SVU unit.

Porcelain-housed SVUs shall be mounted according to Figure 5a. Polymer housed SVUs shall be mounted according to Figure 5b.

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

The mounting of the SVU during the short-circuit test and, more specifically, the routing of the conductors shall represent the most unfavourable condition in service.

NOTE The routing shown in Figure 5a is the most unfavourable to use during the initial phase of the test before venting occurs (especially in the case of a SVU fitted with a pressure relief device). Positioning the sample as shown in Figure 5a, with the venting ports facing in the direction of the test source, may cause the external arc to be swept in closer proximity to the SVU housing than otherwise. As a result, a thermal shock effect may cause excessive chipping and shattering of porcelain weather sheds, as compared to the other possible orientations of the venting ports. However, during the remaining arcing time, this routing forces the arc to move away from the SVU, and thus reduces the risk of the SVU catching fire. Both the initial phase of the test as well as the part with risk of catching fire are important, especially for SVUs where the external part of the housing is made of polymeric material.

For all polymer-housed SVUs, the ground conductor shall be directed to the opposite direction as the incoming conductor, as described in Figure 5b. In this way, the arc will stay close to the SVU during the entire duration of the short-circuit current, thus creating the most unfavourable conditions with regards to the fire hazard.

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

8.7.4 High-current short-circuit tests

8.7.4.1 General

Three samples shall be tested at currents based on selection of a rated short-circuit current selected from Table 5. All three samples shall be prepared according to 8.7.2 and mounted according to 8.7.3.

Tests shall be made in a single-phase test circuit, with an open-circuit test voltage of 77 % to 107 % of the rated voltage of the test sample, as outlined in 8.7.4.2. However, it is expected that tests on high-voltage SVUs will have to be made at laboratories which might not have the sufficient short-circuit power capability to carry out these tests at 77 % or more of the test sample rated voltage. Accordingly, an alternative procedure for making the high-current, short-circuit tests at a reduced voltage is given in 8.7.4.3. The measured total duration of test current flowing through the circuit shall be ≥ 0,2 s.

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

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

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

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

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

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

For all the reduced short-circuit currents, the r.m.s. value shall be in accordance with Table 5 and the peak value of the first half-cycle of the prospective current shall be at least √2 times the r.m.s. value of this current.

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

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

The X/R ratio of the test circuit impedance, without the SVU connected, should preferably be at least 15. In cases where the test circuit impedance X/R ratio is less than 15, the test voltage may be increased or the impedance may be reduced, in such a way that, for the rated short-circuit current, the peak value of the first half-cycle of the prospective current is equal to, or greater than, 2,5 times the required test current level. For the reduced current level tests, the tolerances in Table 5 are met.

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

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

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

The following exception for the test at rated short-circuit current is valid for "Design A" polymer-housed SVUs only (see 8.7.2.2 for the definition of polymer- and porcelain-housed SVUs): if the rated voltage of the test sample is more than 150 kV and a first peak value of ≥ 2,5 times the rated short-circuit current cannot be achieved, an additional test sample shall be tested. This additional test sample shall be tested according to either 8.7.4.2 or 8.7.4.3. It shall have a rated voltage of ≥ 150 kV and shall also not be shorter than the shortest SVU unit used for the actual SVU design. The rated short-circuit current value shall be the lowest of the r.m.s. current from the test on the longest unit and the r.m.s. current defined according to testing with either 8.7.4.2 or 8.7.4.3 from the test on the minimum 150 kV rated unit. Both tests shall be reported.

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

For all the reduced short-circuit currents the r.m.s. value shall be in accordance with Table 5 and the peak value of the first half-cycle of the actual SVU test current shall be at least √2 times the r.m.s. value of this current.

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

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

For pre-failed SVUs, therefore, it is recommended to ensure that the SVU represents a sufficiently low impedance prior to applying the short-circuit current by reapplying the pre-failing, or similar, circuit during a maximum of 2 s immediately before applying the short-circuit test current (see Figure 6). It is acceptable to increase the short-circuit current of the pre-applied circuit up to 300 A (r.m.s). If so, its maximum duration, which depends on the current magnitude, shall not exceed the following value:

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

where

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

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

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

8.7.5 Low-current short-circuit test

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

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

8.7.6 Evaluation of test results

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

a) No violent shattering. Structural failure of the sample is permitted as long as criteria b) and c) are met.

b) No parts of the test sample shall be allowed to be found outside the enclosure, except for

- fragments, less than 60 g each, of ceramic material such as from metal-oxide resistors or porcelain;
- pressure relief vent covers and diaphragms;
- soft parts of polymeric materials.

c) The SVU shall be able to self-extinguish open flames within 2 min after the end of the test. Any ejected part (in or out of the enclosure) shall also self-extinguish open flames within 2 min. A shorter duration of self-extinguishing open flames for ejected parts may be agreed upon between the purchaser and the manufacturer.

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

It may be of particular importance for EGLA applications that safety considerations on ejected fragments, mechanical integrity and even a certain strength after failure are required. In that case, different test procedures and evaluations may be established between the manufacturer and the user (as an example, it may be required that after the tests the SVU still be able to be lifted and removed by its top end).

Table 4 – Test requirements

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

Table 5 – Required currents for short-circuit tests

Rated short-circuit current I_s	Reduced short-circuit currents ± 10 %		Low short-circuit current with a duration of 1 s [a]
A	A		A
80 000	50 000	25 000	600 ± 200
63 000	25 000	12 000	600 ± 200
50 000	25 000	12 000	600 ± 200
40 000	25 000	12 000	600 ± 200
31 500	12 000	6 000	600 ± 200
20 000	12 000	6 000	600 ± 200
16 000	6 000	3 000	600 ± 200
10 000	6 000	3 000	600 ± 200
5 000	3 000	1 500	600 ± 200

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

If an existing type of SVU, already qualified for one of the rated currents in Table 5, is being qualified for a higher rated-current value available in this table, it should be tested only at the new rated value. Any extrapolation can only be extended by two steps of rated short-circuit current.

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

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

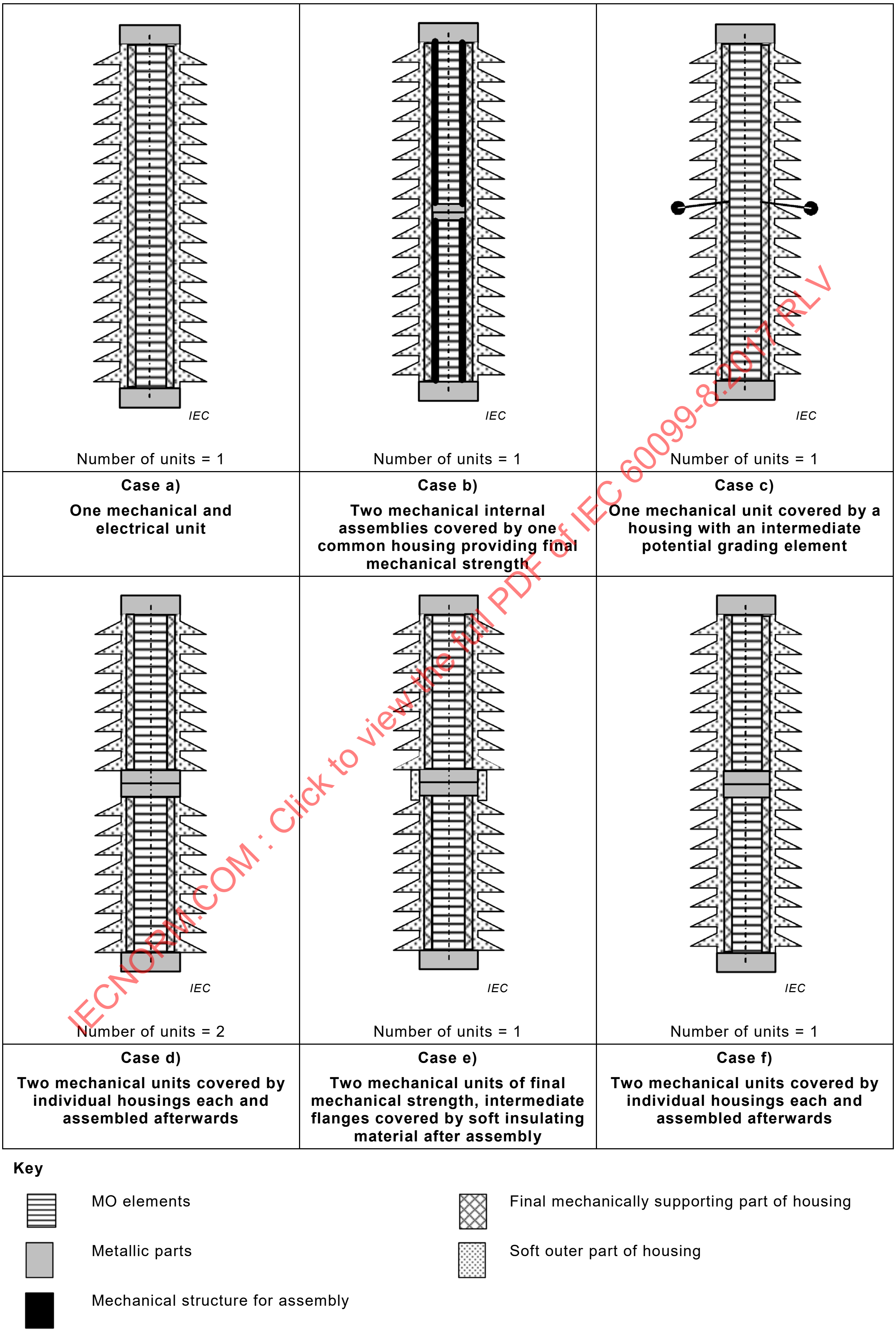


Figure 4 – Examples of SVU units

Dimensions in metres

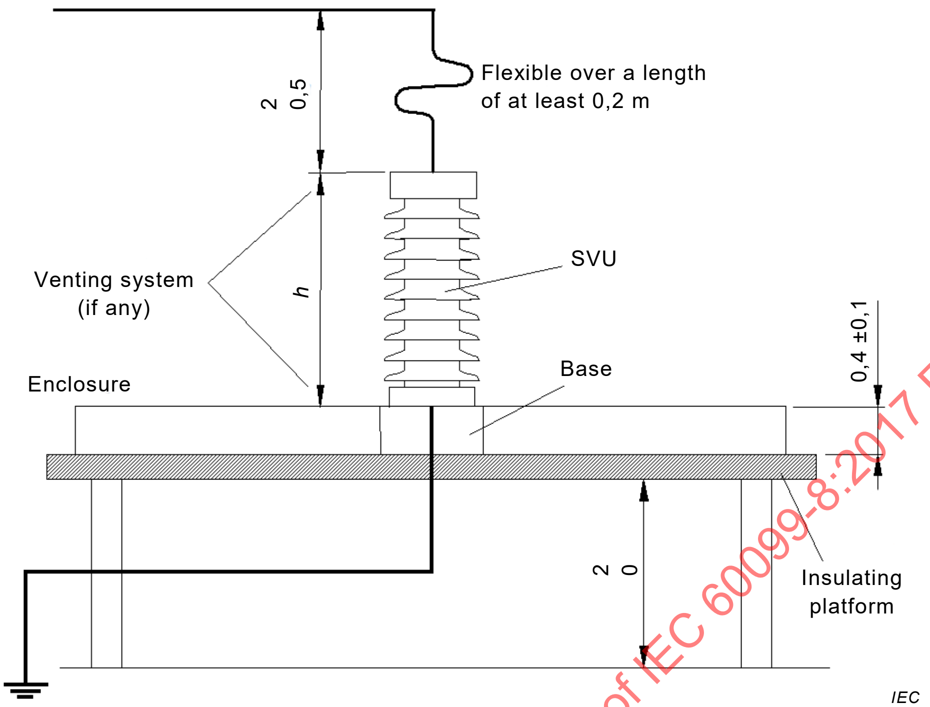


Figure 5a – Circuit layout for porcelain-housed SVUs
(all leads and venting systems in the same plane)

Dimensions in metres

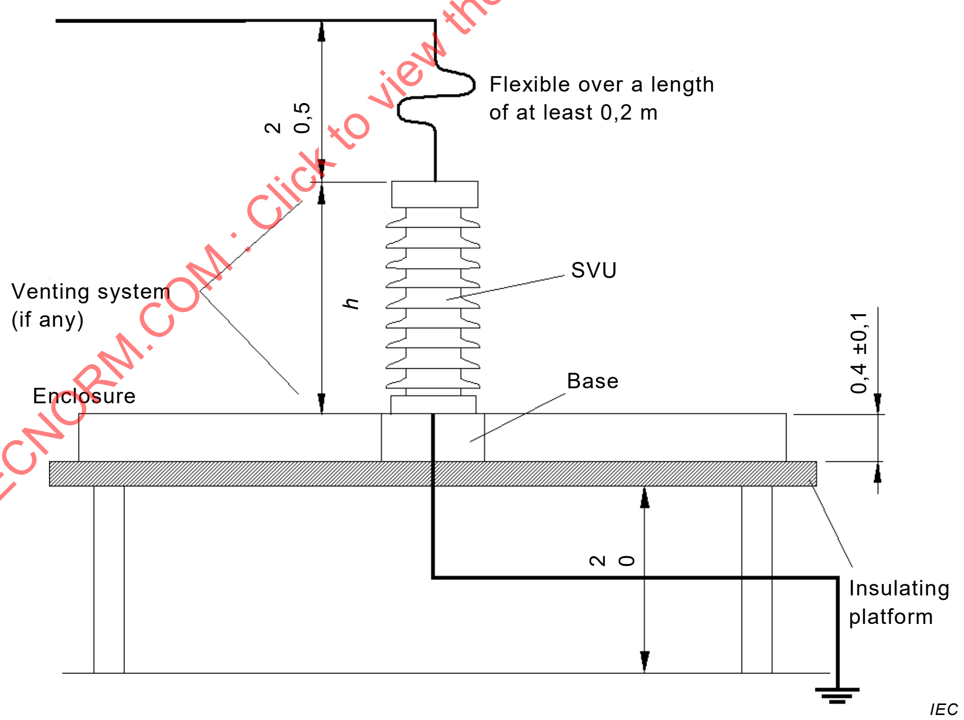
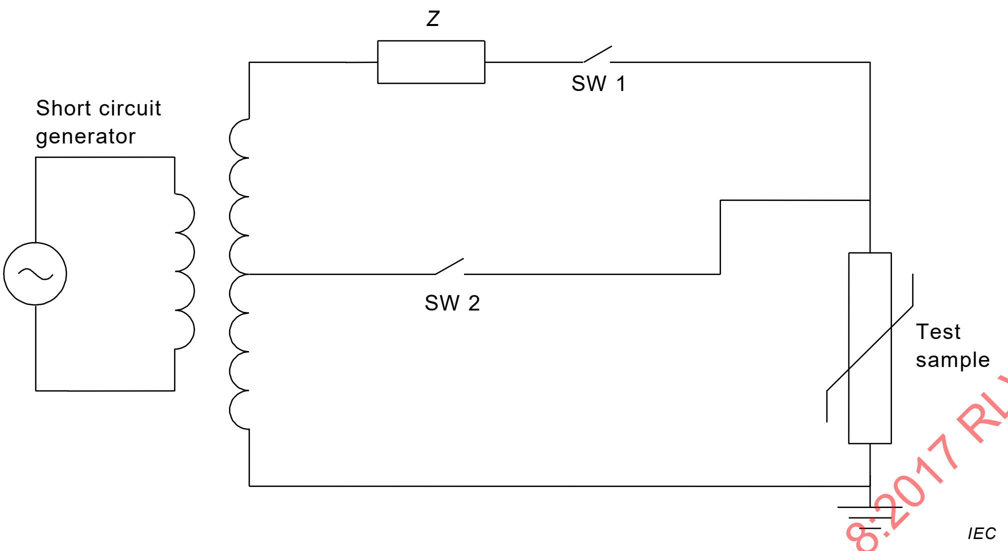


Figure 5b – Circuit layout for polymer-housed SVUs
(all leads and venting systems in the same plane)

Figure 5 – Short-circuit test setup



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

Figure 6 – Example of a test circuit for re-applying pre-failing circuit immediately before applying the short-circuit test current

8.8 Follow current interrupting test

8.8.1 General

This test is to verify follow current interrupting operation of an EGLA after the series gap had sparked over under a lightning impulse voltage. The test sample is a complete EGLA or a section of an EGLA.

This test also verifies the performance of the EGLA under polluted conditions by taking into account the current that would flow over the surface of the SVU housing due to the presence of a wetted pollution layer.

This test may be performed either as a type test with an SDD level and EGLA configuration selected by the manufacturer or, alternatively, as an acceptance test with the SDD level agreed upon between the manufacturer and the purchaser, (see 10.6).

The follow current interrupting test shall be performed by either “Test method A” (see 8.8.2) or “Test method B” (see 8.8.3). If the pollution severity on site is "Very heavy” according to the definition in IEC TS 60815-1, "Test method B" shall be applied. Else, the choice of the test method is upon the manufacturer. For “Test method A” the EGLA Housings shall be designed according to the IEC 60815 series.

NOTE With "Test method A", the effect of pollution on the SVU external surface current is modelled by an additional linear resistor connected in parallel to the SVU, and the test is performed under clean and dry conditions. "Test method B" is a test under artificial pollution conditions.

8.8.2 "Test method A"

8.8.2.1 Requirements on the test circuit

The impedance of the power-frequency voltage source shall be such that during the flow of follow current, the peak value of power-frequency voltage, measured at the EGLA terminals, does not fall below the peak value of the rated voltage of the test specimen and after the interruption of follow current, the peak voltage does not exceed the peak value of the rated voltage by more than 10 %. An example of a test circuit is given in Annex A.

8.8.2.2 Test procedure

The EGLA test sample shall be prepared as follows

a) The non-linear metal-oxide resistor part shall be a complete SVU, or an SVU section, or a pile of metal-oxide resistor elements; the scale factor n (ratio of the rated voltage of the complete EGLA to the rated voltage of the EGLA test sample) shall not be higher than five. If the rated voltage of the complete EGLA is higher than 12 kV the rated voltage of the test sample shall not be lower than 12 kV.

b) 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 SVU divided by n.

c) The reference voltage U_{ref} of the SVU of the test section should be equal to the minimum reference voltage of the SVU of the EGLA divided by n. If the reference voltage of the SVU of the test section is greater than the minimum reference voltage of the SVU of the complete EGLA divided by n, the factor n shall be reduced correspondingly. If the reference voltage of the SVU of the test section is less than the minimum reference voltage of the SVU of the complete EGLA divided by n, the test section is not allowed to be used.

d) A linear resistor shall be connected in parallel with the SVU in order to provide sufficiently high follow current.

e) The external series gap shall be composed of the same electrodes as those of the EGLA. Its length shall be not greater than the minimum gap length specified by the manufacturer. It is not necessary to scale the gap.

The test shall be conducted as follows:

A power-frequency voltage equal to the rated voltage of the EGLA or EGLA section shall be applied to the test sample.

The follow current flowing through the external series gap during the test will result as the addition of the following two components:

- the leakage current on the SVU polluted surface simulated by means of the linear resistor connected in parallel to the SVU;
- the internal resistive current through the non linear metal-oxide resistor blocks when energised at the rated voltage.

The resistance of the linear resistor necessary to simulate the leakage current on the SVU polluted surface shall be calculated as $R = F/K$, F being the form factor (according to IEC 60507) of the SVU housing and K the layer conductivity.

The layer conductivity K shall be taken from Table 3 of IEC 60507:2013 at the line corresponding to the selected SDD. The accepted tolerance for the resistance shall be $^{0}_{-20}$ % of the calculated value.

In the case of an EGLA, the pollution layer on the SVU is not under voltage until spark-over occurs. In a worst-case scenario, the pollution layer will be totally wetted under rain conditions and will remain so since drying due to surface leakage currents does not occur. As there is no dry band arcing activity, the pollution layer may be assumed as a linear resistance.

NOTE With this method, the current level is higher than in operating service conditions, because the calculation does not take into account the voltage drop across the external series gap of the EGLA.

Lightning impulse voltages shall then be applied to the EGLA in order to initiate spark-over and provide a conductive channel across the external series gap. The impulse generator shall be adjusted to obtain systematic spark-over of the gap.

8.8.2.3 Test sequence

The lightning impulse voltages, having the same or opposite polarity as the actual half cycle of the alternating voltage, shall be applied (30° to 0°) before the instant of peak voltage.

A first test shall be performed with a gap length small enough to show that the power source is able to supply and maintain the specified follow current.

The parallel linear resistor shall be adjusted such that the total follow current during the tests is at least equal to the estimated value.

Thereafter, the gap length shall be adjusted to the minimum specified value. Then, five spark-over operations at each polarity of the actual half cycle of the alternating voltage shall be performed. If follow current is not established, more spark-over operations shall be performed until follow current was established five times for each polarity.

Permanent oscillograms of power-frequency voltage and follow current associated with each discharge shall be taken. These oscillograms shall show the voltage across and the current trough the test sample throughout the period from one complete cycle before application of the impulse to ten complete cycles after the final interruption of the follow current. Final interruption of the follow current shall occur within the half-cycle in which the impulse is applied. There shall be no further spark-over of the sample in any subsequent half cycle.

8.8.2.4 Test evaluation

The sample has passed the test if for the ten spark-over operations the follow current is interrupted within the first half cycle of the power-frequency voltage and if there is no further spark-over in any subsequent half cycle.

8.8.3 "Test method B"

8.8.3.1 Requirements on the test circuit

The impedance of the power-frequency voltage source shall be such that during the flow of follow current, the peak value of power-frequency voltage, measured at the EGLA terminals, does not fall below the peak value of the rated voltage of the test specimen and after the interruption of follow current, the peak voltage does not exceed the peak value of the rated voltage by more than 10 %. An example of a test circuit is given in Annex A.

8.8.3.2 Test procedure and test sequence

The EGLA test sample shall be prepared as follows:

a) A section of an EGLA or a complete EGLA shall be prepared as test sample.

b) The non-linear metal-oxide resistor part shall be a complete SVU or an SVU section; the scale factor n (ratio of the rated voltage of the complete EGLA to the rated voltage of the EGLA test sample) shall not be higher than five. If the rated voltage of the complete EGLA is higher than 12 kV the rated voltage of the test sample shall not be smaller than 12 kV.

c) The volume of the resistor elements shall not be greater than the minimum volume of all resistor elements used in the complete SVU divided by n.

d) The reference voltage U_{ref} of the SVU of the test section should be equal to the minimum reference voltage of the SVU of the EGLA divided by n. If the reference voltage of the SVU of the test section is greater than the minimum reference voltage of the SVU of the complete EGLA divided by n, the factor n shall be reduced correspondingly. If the reference voltage of the SVU of the test section is less than the minimum reference voltage of the SVU of the complete EGLA divided by n, the test section is not allowed to be used.

e) The external series gap shall be composed of the same electrodes as those of the EGLA. Its length shall be not greater than the minimum gap length specified by the manufacturer. It is not necessary to scale the gap.

The contamination slurry shall be prepared in accordance with the solid layer method in IEC 60507 or any equivalent method, in which resistivity of the slurry can be determined from the specified SDD value.

The test shall be conducted as follows:

The housing of the SVU shall be clean and dry and at ambient temperature. Washing with a detergent may be necessary in order to remove oil films, but the detergent should be thoroughly rinsed off with water.

The surface hydrophobicity of the SVU shall be completely removed in order to simulate surface leakage currents to be expected in the worst case under the specified polluted condition.

With the arrester de-energized, the contaminant shall be applied to the whole insulation surface of the SVU, including the undersides of the sheds. The pollution layer shall appear as a continuous film. The pollution coating may be applied by either spraying, dipping or flow-coating.

NOTE 1 The following procedure is suggested to remove hydrophobicity on a polymeric (especially for silicone rubber) housing surface temporarily for the testing, without any damage of the surface or any additional chemical agent in the pollutant:

a) Prepare slurry, which contains approximately 1 kg of Tonoko or Kaolin in 1 l of water.
b) Spray the slurry as uniformly as possible on the hydrophobic housing surface.
c) Dry the polluted surface under natural ambient conditions.
d) Wash off the deposited Tonoko or Kaolin roughly, by running tap water, for example. After this process some amount of Tonoko or Kaolin will remain on the surface, which suppresses recovery of the hydrophobicity temporarily.

Prior to the testing, salt deposit density according to the above procedure should be checked on the same design of polymeric housing surface.

NOTE 2 Once the hydrophobicity is removed by the procedure given in NOTE 1, testing on the test specimen needs to be completed within one day, in order to prevent recovery of hydrophobicity.

Within (3 min to 3,5 min) after the contaminant has been applied to the test sample it shall be exposed to its rated voltage for a time duration long enough to initiate one spark-over operation of the test sample.

The lightning impulse voltages, having the same or opposite polarity as the actual half cycle of the alternating voltage, shall be applied (30° to 0°) before the instant of peak voltage.

A first test shall be performed with a gap length small enough to show that the power source is able to supply and maintain the specified follow current.

Thereafter, the gap length shall be adjusted to the minimum specified value. Then, five spark-over operations at each polarity of the actual half cycle of the alternating voltage shall be performed. If follow current is not established, more spark-over operations shall be performed until follow current was established five times for each polarity.

The pollution layer shall be renewed after each spark-over operation.

Permanent oscillograms of power-frequency voltage and follow current associated with each discharge shall be taken. These oscillograms shall show the voltage across and the current trough the test sample throughout the period from one complete cycle before application of the impulse to ten complete cycles after the final interruption of the follow current. Final interruption of the follow current shall occur within the half-cycle in which the impulse is applied. There shall be no further spark-over of the sample in any subsequent half cycle.

NOTE The time interval between spark-over operations need not to be specified for this test.

8.8.3.3 Test evaluation

The sample has passed the test if

a) no flashover occurred on the SVU surface;
b) for the ten spark-over operations the follow current is interrupted within the half-cycle of power-frequency voltage during which the spark-over occurs and if there is no further spark-over in any subsequent half cycle.

8.9 Mechanical load tests on the SVU

8.9.1 General

These tests demonstrate that the SVU is able to withstand the mechanical strength values (SLL and SSL) and the vibrational loads specified by the manufacturer.

8.9.2 Bending test

8.9.2.1 General

This test demonstrates that the SVU is able to withstand the mechanical strength values (SLL and SSL) specified by the manufacturer. The test shall be performed on three or six samples of SVUs or SVU units. The complete test procedure is shown by the flow chart in Clause B.5.

8.9.2.2 Test procedure for porcelain and cast resin housed SVUs

8.9.2.2.1 General

This test applies to porcelain and cast-resin housed SVUs of EGLAs for $U_s > 52$ kV. It also applies to porcelain and cast-resin housed SVUs of EGLAs for $U_s \leq 52$ kV for which the manufacturer claims cantilever strength.

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

The test shall be performed on complete SVU units without internal overpressure. For single-unit SVU designs, the test shall be performed on the longest unit of the design. Where an SVU contains more than one unit or where the SVU 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 Clause B.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 Clause B.2.

8.9.2.2.2 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 SVU. If the SVU 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 SVU to the maximum bending moment.

8.9.2.2.3 Test procedure

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

Three samples shall be tested. If the test to verify the SSL (see 8.9.2.2.3.2) 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 SVU might splinter while under load and might present a handling hazard.

8.9.2.2.3.2 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 9.1, item c)) and an internal partial discharge test (see 9.1, item b)). 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 SVU might splinter while under load and might present a handling hazard.

If it is necessary for any reason to apply a load that is more than 5 % above SSL an agreement must be made with the manufacturer.

8.9.2.2.4 Test evaluation

The SVU shall have passed the test if

– the mean value of breaking load, MBL, is ≥ 1,2 x SSL;
– for the SSL test
  - there is no visible mechanical damage;
  - the remaining permanent deflection is ≤ 3 mm or ≤ 10 % (whichever is greater) of maximum deflection during the test;
  - the test samples pass the leakage check in accordance with 9.1c);
  - the internal partial discharge level of the test samples does not exceed the value specified in 9.1 b);

8.9.2.3 Test procedure for polymer (except cast resin) housed SVUs

8.9.2.3.1 General

This test applies to polymer (except cast-resin) housed SVUs (with and without enclosed gas volume) of EGLAs for U_s > 52 kV. It also applies to polymer (except cast-resin) housed SVUs of EGLAs for U_s ≤ 52 kV for which the manufacturer claims cantilever strength.

Cast-resin housed SVUs shall be tested according to 8.9.2.2. SVUs that have no declared cantilever strength shall be submitted to the terminal torque preconditioning according to 8.9.2.3.3.2 a), the thermal preconditioning according to 8.9.2.3.3.2 c) and the water immersion test according to 8.9.2.3.3.3.

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

The test shall be performed on complete SVU units with the highest rated voltage of the unit. For single-unit SVU designs, the test shall be performed on the longest unit with the highest rated voltage of that unit of the design. Where an SVU contains more than one unit or where the SVU 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 Clause B.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 (two steps for SVUs of EGLAs for $U_s \leq 52$ kV) 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 Clause B.2 and on the 3rd sample a mechanical preconditioning test as per 8.9.2.3.3.2;
– on all three samples a water immersion test as per 8.9.2.3.3.3.

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

If +5 % is exceeded this should be agreed upon with the manufacturer.

NOTE The cyclic test is not required for SVUs of EGLAs for $U_s \leq 52$ kV.

8.9.2.3.2 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 0,7 times U_{ref} and at an ambient temperature of 20 °C ± 15 K;
  - internal partial discharge test according to 9.1 b);
  - residual voltage test at (0,01 to 1) times the nominal discharge current; the current wave shape shall be in the range of T_1/T_2 = (4 to 10)/(10 to 25) µs;
– leakage checks in accordance with 9.1 c) for SVUs with enclosed gas volume and separate sealing system.

If the partial discharge test according to 9.1 b) and the leakage check according to 9.1 c) 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 SVU. If the SVU 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 SVU to the maximum bending moment.

8.9.2.3.3 Test procedure

8.9.2.3.3.1 General

The test shall be performed on three samples. For SVUs of EGLAs for U_s > 52 kV, the test is performed in three steps. For SVUs of EGLAs for U_s ≤ 52 kV, the test is performed in two steps.

a) SVUs of EGLAs for U_s > 52 kV

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 – 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 agreed upon with 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 8.9.2.3.3.2.

Step 3:

Subject all three samples to the water immersion test according to 8.9.2.3.3.3.

b) SVUs of EGLAs for U_s ≤ 52 kV

Step 1.1:

Subject two samples 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 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 1.2:

Subject a third sample to mechanical/thermal preconditioning according to 8.9.2.3.3.2.

Step 2:

Subject all three samples to the water immersion test according to 8.9.2.3.3.3.

8.9.2.3.3.2 Mechanical/thermal preconditioning

This preconditioning constitutes part of the test procedure of 8.9.2.3.3 and shall be performed on one of the test samples as defined in 8.9.2.3.3.

a) Terminal torque preconditioning

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

b) Thermo-mechanical preconditioning

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

The sample is submitted to the specified long-term load (SLL) in four directions and in thermal variations as described in Figure 7 and Figure 8.

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.

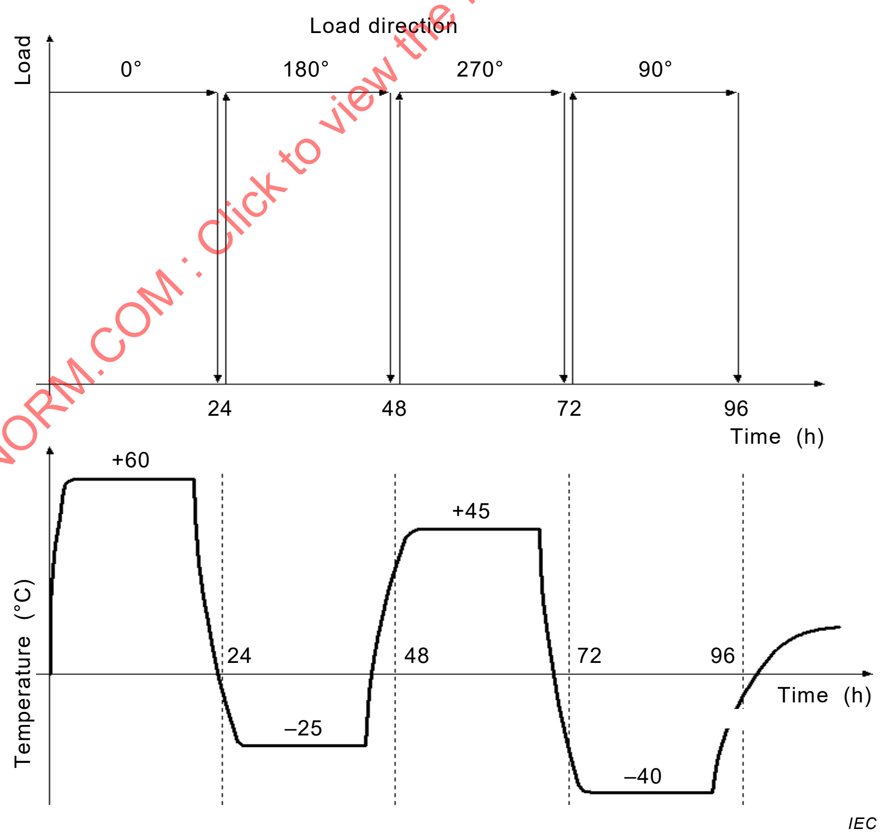


Figure 7 – Thermo-mechanical test

The thermal variations consist of two 48 h cycles of heating and cooling as described in Figure 7. The temperature of the hot and cold periods shall be maintained for at least 16 h. The test shall be conducted in air.

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 8.

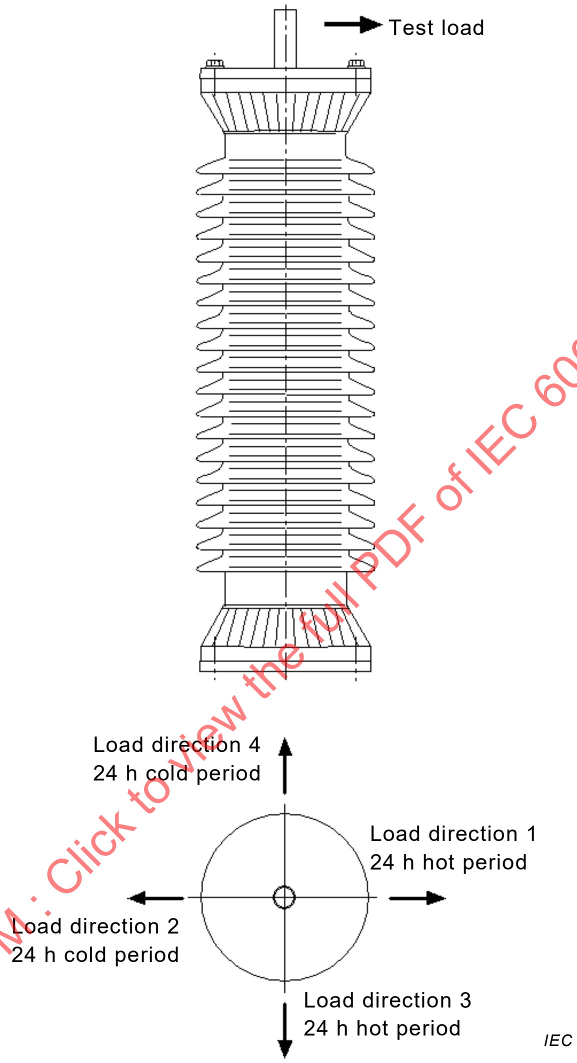


Figure 8 – Example of the test arrangement for the thermo-mechanical test and direction of the cantilever load

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.

c) Thermal preconditioning

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

The sample is submitted to the thermal variations as described in Figure 7 without any load applied.

The thermal variations consist of two 48 h cycles of heating and cooling as described in Figure 7. The temperature of the hot and cold periods shall be maintained for at least 16 h. The test shall be conducted in air.

8.9.2.3.3.3 Water immersion test

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

The temperature of the 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 SVU 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 SVU shall be removed from the water and cooled to ambient temperature for not longer than three thermal time constants of the sample. 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 9. Evaluation tests shall be made within the time specified in 8.9.2.3.3.4. After removing the sample from the water it may be washed with tap water.

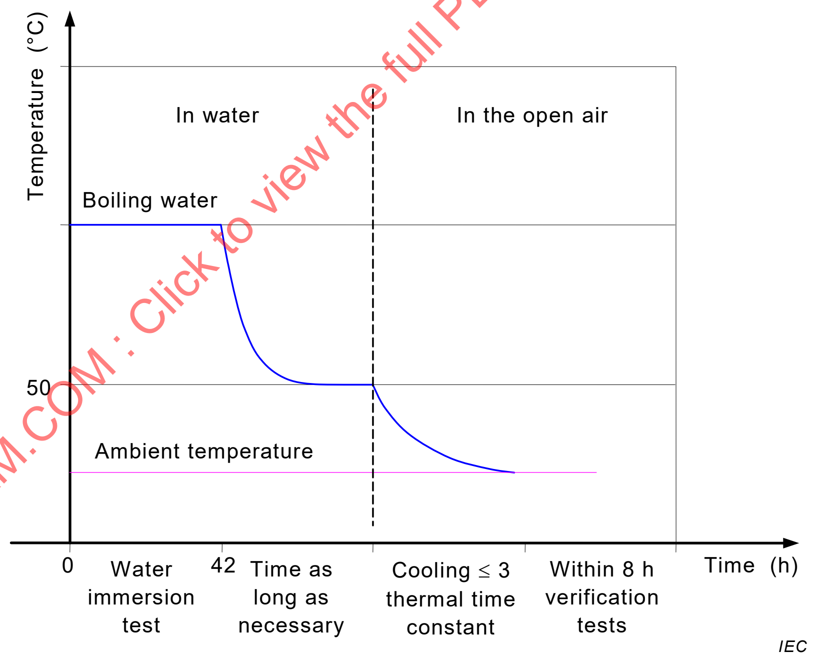


Figure 9 – Test sequence of the water immersion test

8.9.2.3.3.4 Determination fo thermal time constant

The SVU containing the most MO resistors per unit length of a multi-unit arrester shall be 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 shall be 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.

For the purpose of this standard the thermal time constant is the time where the temperature has decreased by 63 % of the temperature difference between start and ambient temperature.

8.9.2.3.4 Test evaluation

Tests according to 8.9.2.3.2 shall be repeated on each test sample.

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

a) SVUs of EGLAs for U_s > 52 kV

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 9:

- the increase in watt losses, measured at 0,7 times U_{ref} 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 (0,7 times U_{ref}) or 20 %;

– the internal partial discharge measured at 0,7 times U_{ref} does not exceed 10 pC; at any time after the above watt losses and partial discharge measurements:

– for SVUs with enclosed gas volume and separate sealing system, the samples pass the leakage test in accordance with 9.1 c);

– 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 nominal 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 s to 60 s apart.

NOTE In case of extra long SVUs 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 SVU insulation to make contact with the internal stack at a metal spacer and in this way be able to test shorter SVU sections.

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

b) SVUs of EGLAs for $U_s \leq$ 52 kV

After step 1:

– there is no visible damage;

– for step 1.1, 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 any remaining permanent deflection after the test shall be reported.

After step 2:

within 8 h after cooling as defined in Figure 9:

– the increase in watt losses, measured at 0,7 times U_{ref} 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 (0,7 times U_{ref}) or 20 %;

– the internal partial discharge measured at 0,7 times U_{ref} does not exceed 10 pC; at any time after the above watt losses and partial discharge measurements:

– for SVUs with enclosed gas volume and separate sealing system, the samples pass the leakage test in accordance with 9.1 c);

– the residual voltage measured 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 nominal 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 50s to 60 s apart.

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

NOTE In case of extra long SVUs where the blocks can be dismantled, the residual voltage 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 SVU insulation to make contact with the internal stack at a metal spacer and in this way be able to test shorter SVU sections.

8.9.3 Vibration test

8.9.3.1 General

This test demonstrates that the SVU is able to withstand the vibration stress specified by the manufacturer. The test shall be performed on one complete SVU.

This is a mandatory test if not performed as an acceptance test according to 10.7.

The vibration test should also be performed on the spark gap. The mechanical stress should be comparable to the stress which is required for the SVU, and the test sample installation condition should be agreed between the manufacturer and the purchaser.

8.9.3.2 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:
  - internal partial discharge test according to 9.1 b);
  - residual voltage test at (0,01 to 1) times the nominal discharge current; the current wave shape shall be in the range of T_1/T_2 = (4 to 10)/(10 to 25) µs;
- leakage checks in accordance with 9.1 c) for SVUs with enclosed gas volume and separate sealing system.

If the partial discharge test according to 9.1 b) and the leakage check according to 9.1c) have been performed as routine tests they need not be repeated at this time.

8.9.3.3 Test procedure and test condition

- Installation condition: Intended most critical way of mounting
- Load: Actual electrode or loaded by maximum specified weight
- Acceleration at SVU's free end: 1·g
- Number of oscillations: $1 \cdot 10^6$ (one million)
- Frequency: Resonance frequency of the SVU
- Direction of oscillations: Intended most critical direction relative to the sample axis

Other acceleration values than 1 × g may be specified on agreement between the manufacturer and the purchaser.

8.9.3.4 Test evaluation

Tests according to 8.9.3.2 shall be repeated on each test sample.

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

a) the internal partial discharge measured at 0,7 times U_{ref} does not exceed 10 pC;

b) for SVUs with enclosed gas volume and separate sealing system, the samples pass the leakage test in accordance with 9.1 c);

c) 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;

d) the difference in voltage between two successive impulses at nominal 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 s to 60 s apart.

NOTE In case of extra-long SVUs 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 SVU insulation to make contact with the internal stack at a metal spacer and in this way be able to test shorter SVU sections.

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

8.10 Weather aging tests

8.10.1 General

The environmental tests demonstrate by accelerated test procedures that the sealing mechanism and the exposed metal combinations of the SVU are not impaired by environmental conditions. The test shall be performed on one complete SVU of any length. For SVUs with an enclosed gas volume and a separate sealing system, the internal parts may be omitted. SVUs 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 SVU.

8.10.2 Sample preparation

Prior to the tests, the test sample shall be subjected to a leakage check by any sensitive method adopted by the manufacturer.

8.10.3 Test procedure

8.10.3.1 General

The tests specified in Subclauses 8.10.3.2 and 8.10.3.3 shall be performed on one sample in the sequence given.

8.10.3.2 Temperature cycling test

The test shall be performed according to IEC 60068-2-14. The hot period shall be at a temperature of at least +40 °C, but not higher than +70 °C. The cold period shall be at least 85 K below the value actually applied in the hot period; however, the lowest temperature in the cold period shall not be lower than –50 °C:

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

8.10.3.3 Salt mist test

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

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

8.10.4 Test evaluation

The SVU shall have passed the tests if the sample passes again the leakage check of 8.10.2.

8.10.5 Additional test procedure for polymer (composite and cast resin) housed SVUs

8.10.5.1 General

For SVUs with polymer (composite and cast resin) housings, resistance to UV radiation shall be demonstrated by the UV test according to 8.10.5.2 and 8.10.5.3 (in line with 9.3.2 of IEC 62217:2012).

8.10.5.2 Procedure

Select three specimens of shed and housing materials for this test (with markings included, if applicable). The insulator housing material shall be subjected to a 1 000 h UV light test using one of the following test methods. Markings on the housing, if any, shall be directly exposed to UV light:

- Xenon-arc methods: ISO 4892-1 and ISO 4892-2, using method A without dark periods, standard spray cycle, black-standard/black panel temperatures of 65 °C, an irradiance of around 550 W/m^2
- Fluorescent UV method: ISO 4892-1 and ISO 4892-3, using type I fluorescent UV lamp, exposure method 1 or 2.

8.10.5.3 Acceptance criteria

After the test, markings on shed or housing material shall be legible; surface degradations such as cracks and raised areas are not permitted. In case of doubt concerning such degradation, two surface roughness measurements shall be made on each of the three specimens. The roughness, R_z as defined in ISO 4287, shall be measured along a sampling length of at least 2,5 mm. R_z shall not exceed 0,1 mm.

NOTE ISO 3274 gives details of surface roughness measurement instruments.

8.11 Radio interference voltage (RIV) test

This test applies to EGLA intended for use on systems with Us ≥ 72,5 kV.

The EGLA with an insulator configuration determined by the manufacturer to be appropriate shall be tested in accordance with the RIV test procedure of IEC 60099-4. The test voltage shall be the rated voltage (U_r) of the EGLA.

The EGLA with the insulator assembly shall be assembled in such a way that it simulates actual system installations. The test shall be performed on the longest EGLA, with the highest rated voltage used for a particular EGLA type. The test voltage shall be applied between the terminals of the EGLA.

The test shall be performed under dry conditions. The maximum radio interference level of the EGLA with the insulator assembly energized at the test voltage shall not exceed 2 500 μV.

9 Routine tests

9.1 General

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

a) Measurement of reference voltage (U_{ref}) of each SVU unit (see 3.7 and 6.8). The measured values shall be within a range specified by the manufacturer.

b) Internal partial discharge test. This test shall be performed on each SVU unit. The test sample may be shielded against external partial discharges. The power-frequency voltage shall be increased to at least 0,7 times U_{ref}. At this voltage, the partial discharge level shall be measured according to IEC 60270. The measured value for the partial discharge shall not exceed 10 pC.

c) For SVU units with sealed housing and an included gas volume, a leakage check shall be made on each SVU unit by any sensitive method adopted by the manufacturer.

d) Residual voltage test of the SVU. The test may be performed either on a complete SVU, SVU units or on a sample comprising one or several metal-oxide resistor elements. The manufacturer shall specify a suitable lightning impulse current in the range between 0,01 and 1 times the nominal current at which the residual voltage is measured. If not directly measured, the residual voltage of the complete SVU is taken as the sum of the residual voltages of the resistor elements or the individual SVU units. The residual voltage for the complete SVU shall not be higher than the value specified by the manufacturer. The residual voltage shall be specified without inductive voltage drop due to the size of the SVU.

   The residual voltage test may alternatively be performed with an impulse current corresponding to the maximum expected follow current value through the non-linear metal-oxide resistors. This point on the U-I-characteristic must then have been measured in the type test (8.3.3).

10 Acceptance tests

10.1 General

When the purchaser specifies acceptance tests in the purchase agreement, tests shall be selected among the following tests. The number and the way of preparation of test samples are given in Table 6, where "A" stands for the nearest lower whole number of the cubic root of the number of EGLA to be supplied.

Table 6 – Acceptance tests

Test item	Number of test samples	EGLA with (w) or without (wo) insulator	Section of EGLA with (w) or without (wo) insulator	Unit of SVU	Clause number
1. Reference voltage	"A"			Test	10.2
2. Internal partial discharge test	"A"			Test	10.3
3. RIV test [a)]	1	Test (w)			10.4
4. Test for coordination between insulator withstand and EGLA protective level [b)]	1	Test (w)			10.5
5. Follow current interrupting test [c)]	1	Test (wo) [d)]	Test (wo) [d)]		10.6
6. Vibration test [e)]	1			Test (wo) [f)]	10.7

a) This test is mandatory if not performed as a type test in accordance with 8.11.

b) This test is mandatory if not performed as a type test in accordance with 8.4.

c) This test is mandatory if not performed as a type test in accordance with 8.8.

d) This test is performed either on a complete EGLA or a section of an EGLA, see 8.8.2.

e) This test is mandatory if not performed as a type test in accordance with 8.9.3.

f) This test is performed on a complete SVU including mounting hardware and the electrode of the external series gap attached.

10.2 Reference voltage measurement of SVU

The reference voltage of the SVU shall be measured in accordance with 3.7 and 6.8. The measured values shall be within a range specified by the manufacturer.

10.3 Internal partial discharge test of SVU

The power-frequency voltage shall be increased to at least 0,7 times U_{ref}. At this voltage, the partial discharge level shall be measured according to IEC 60270. The measured value for the partial discharge shall not exceed 10 pC. The test sample may be shielded against external partial discharges.

10.4 Radio interference voltage (RIV) test

This test applies to EGLA intended for use on systems with Us ≥ 72,5 kV.

The EGLA with the insulator assembly to be protected shall be tested in accordance with the RIV test procedure of IEC 60099-4. The test voltage shall be the maximum continuous phase to ground system voltage ($U_s/\sqrt{3}$) that will be applied in service.

The EGLA with the insulator assembly shall be assembled in such a way that it simulates actual system installations. The test shall be performed on the longest EGLA, with the highest rated voltage used for a particular EGLA type. The test voltage shall be applied between the terminals of the EGLA.

The test shall be performed under dry conditions. The maximum radio interference level of the EGLA with the insulator assembly energized at the test voltage shall not exceed 2 500 µV.

10.5 Test for coordination between insulator withstand and EGLA protective level

10.5.1 General

This test for coordination between insulator withstand and EGLA protective level is mandatory as an acceptance test if not a type test according to 8.4 is performed. The test verifies the correct front-of-wave and standard lightning impulse spark-over voltages for the EGLA with the typical insulator assembly having the shortest insulation distance to be protected for the actual system.

Test sample is a complete EGLA with the insulator assembly connected in parallel.

10.5.2 Steep front impulse test

10.5.2.1 General

Steep front impulse voltages of a virtual steepness of wave front enough to cause spark-over at wave front or around the peak according to Table 7 shall be applied to the test sample, five times for each polarity under dry conditions.

Table 7 – Virtual steepness of wave front of steep front impulses

Rated voltage of EGLA kV	Virtual steepness of wave front kV/µs
$3 < U_r \leq 10$	8,3 U_r
$10 < U_r \leq 120$	7,0 U_r
$120 < U_r \leq 200$	6,0 U_r
$200 < U_r \leq 300$	1 300
$300 < U_r \leq 420$	1 500
$U_r > 420$	2 000

10.5.2.2 Test evaluation

The EGLA has passed the test if all spark-overs at wave front or around the peak occurred in the external series gap and no flashovers occurred at the insulator assembly.

10.5.3 Standard lightning impulse sparkover test

10.5.3.1 General

The purpose of this test is to determine the margin of protection the EGLA offers the insulator.

10.5.3.2 Test procedure

The test voltage shall be a standard lightning impulse voltage 1,2/50. The purpose of this test is to verify the 50 % spark-over voltage value $U_{50,\ \mathrm{EGLA}}$ and to confirm sufficient protective margin between the spark-over voltage of the EGLA and the flashover voltage of the insulator to be protected.

The following test sequences a) and b) shall be performed in succession:

a) The 50 % spark-over voltage of the EGLA shall be verified for each polarity by the up-and-down method according to IEC 60060-1.

b) The series gap spacing of the EGLA shall be increased such that no spark-over occurs in the following test sequence: 15 lightning impulse voltages of each polarity with a peak value equal to $(1+X \times \sigma)$ times the 50 % spark-over voltage shall be applied to the test sample. The parameter X, specifying the protective margin between EGLA and insulator, shall be agreed upon between manufacturer and user. The minimum acceptable value is $X = 1{,}3$.

If agreed between the manufacturer and the user, the 50 % flashover voltage of the insulator assembly may be verified by the up-and-down test.

The protective margin should be evaluated by $U_{50,\ \mathrm{EGLA}}$ plus X times the standard deviation, $(U_{50,\ \mathrm{EGLA}} + X\sigma)$ not being higher than $U_{50,\ \mathrm{Insulator}}$ minus X times the standard deviation, $(U_{50,\ \mathrm{Insulator}} - X \times \sigma)$ of the insulator assembly to be protected. The value of X and the allowed number of flashovers of the insulator assembly are to be agreed upon between manufacturer and user. The standard deviation (σ) is set to be 3 % for 1,2/50 impulses.

NOTE A typical value for X is 2,5.

10.5.3.3 Test evaluation

The sample has passed the test if no flash-over occurs on the insulator assembly during test sequences a) and b) if no other criteria have been agreed upon between manufacturer and user (see NOTE 2 of 10.5.3.2).

10.6 Follow current interrupting test

10.6.1 General

This test is to verify follow current interrupting operation of the EGLA after the series gap has sparked over under a lightning impulse voltage. The test sample is a complete EGLA or a section of EGLA.

The test also verifies the performance of the EGLA under polluted conditions by taking into account the current that would flow over the surface of the SVU housing due to the presence of a wetted pollution layer.

This test shall be performed either as an acceptance test with the SDD level agreed upon between manufacturer and purchaser or, alternatively, as a type test with a SDD level and EGLA configuration selected by the manufacturer, see 8.8.

The test shall be performed by either “Test method A” (see 8.8.2) or “Test method B” (see 8.8.3). If the pollution severity on site is "Very heavy” according to the definition in IEC TS 60815-1, "test method B" shall be applied. Else, the choice of the test method is upon the manufacturer. For “Test method A” the EGLA housings shall be designed according to the IEC 60815 series.

NOTE With "test method A", the effect of pollution on the SVU external surface leakage current is modelled by an additional linear resistor connected in parallel to the SVU, and the test is performed under clean and dry conditions. "Test method B" is a test under artificial pollution conditions.

10.6.2 Test procedure

See 8.8.2.2 and 8.8.3.2.

10.6.3 Test sequence

See 8.8.2.3 and 8.8.3.2.

10.6.4 Test evaluation

See 8.8.2.4 and 8.8.3.3.

10.7 Vibration test on the SVU with attached electrode

10.7.1 General

This test demonstrates that the complete SVU including the attached electrode of the external series gap and mounting hardware is able to withstand the vibration stress expected in service.

This is a mandatory test if not performed as a type test according to 8.9.3.

10.7.2 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:
  - internal partial discharge test according to 9.1 b);
  - residual voltage test at (0,01 to 1) times the nominal discharge current; the current wave shape shall be in the range of T_1/T_2 = (4 to 10)/(10 to 25) μs;

– leakage checks in accordance with 9.1 c) for SVUs with enclosed gas volume and separate sealing system.

If the partial discharge test according to 9.1 b) and the leakage check according to 9.1 c) have been performed as routine tests they need not be repeated at this time.

10.7.3 Test procedure and test condition

• Installation condition:	Mounting as in the intended in-service installation including mounting hardware and the electrode at the SVU
• Acceleration at SVU's free end:	1 × g
• Number of oscillations:	1 × 10^6 (one million)

- Frequency: Resonance frequency of the installation
- Direction of oscillations: Most critical load direction of the intended in-service installation

Other acceleration values than 1xg may be specified on agreement between the manufacturer and the purchaser.

10.7.4 Test evaluation

Tests according to 10.7.2 shall be repeated on each test sample.

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

a) the internal partial discharge measured at 0,7 times U_{ref} does not exceed 10 pC;

b) for SVUs with enclosed gas volume and separate sealing system, the samples pass the leakage test in accordance with 9.1 c);

c) 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;

d) the difference in voltage between two successive impulses at nominal 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 s to 60 s apart.

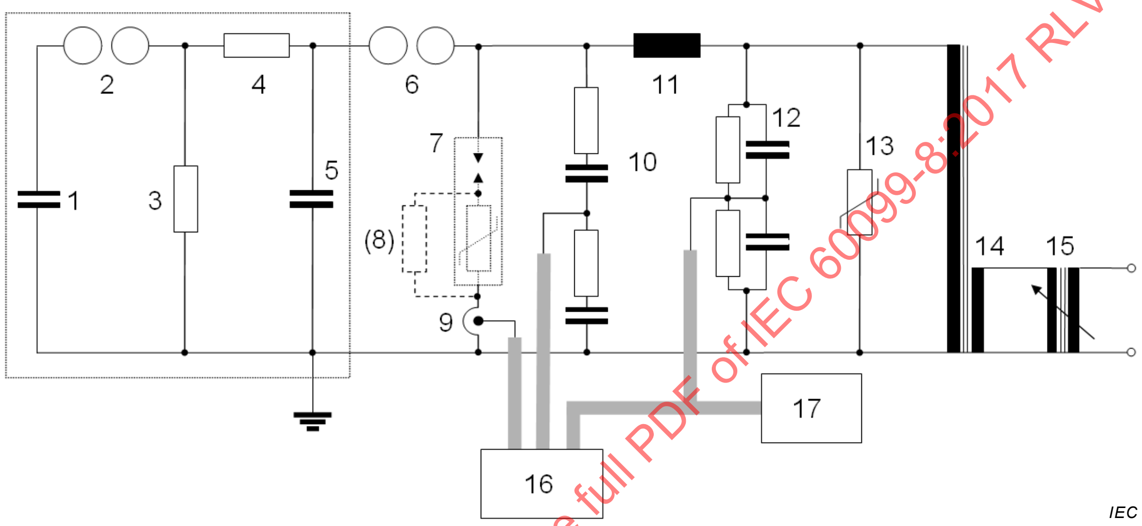
NOTE In case of extra-long SVUs where the blocks can be dismantled this part of the evaluation test can be performed on individual blocks or stacks of blocks. If the blocks cannot be dismantled a possible procedure would be to drill a hole in the SVU insulation to make contact with the internal stack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

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

Annex A
(informative)

Example of a test circuit for the follow current interrupting test

Figure A.1 gives an example of a test circuit for the follow current interrupting test on an EGLA of (15 to 50) kV rated voltage. The linear resistor (8) is only present for "Test method A".



Key

1	Charging capacitance of impulse generator
2	Triggering spark gap of impulse generator
3	Tail resistance for wave shape 1,2/50 of impulse generator
4	Front resistance for wave shape 1,2/50 of impulse generator
5	Load capacitance of impulse generator
6	Blocking sphere gap (sphere diameter 500 mm; gap length 1 300 mm)
7	Device under test: EGLA (SVU plus series gap)
	U_r = 15 kV to 50 kV, gap length = 200 mm to 1 700 mm
8	Parallel linear resistor to simulate SVU surface leakage current (only for "Test method A")
9	Current transformer
10	Damped capacitive divider
11	Inductance, L = 52 mH
12	Mixed RC divider
13	Metal-oxide surge arrester for protection of high-voltage test transformer, U_r = 156 kV
14	High-voltage test transformer
15	Regulating transformer
16	Three-channel oscilloscope
17	Peak/√2 digital voltmeter

Figure A.1 – Example of a test circuit for the follow current interrupting test

Annex B
(normative)

Mechanical considerations

B.1 Test of bending moment

In the case of a multi-unit SVU, each unit shall be tested with the bending moment according to Figure B.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.

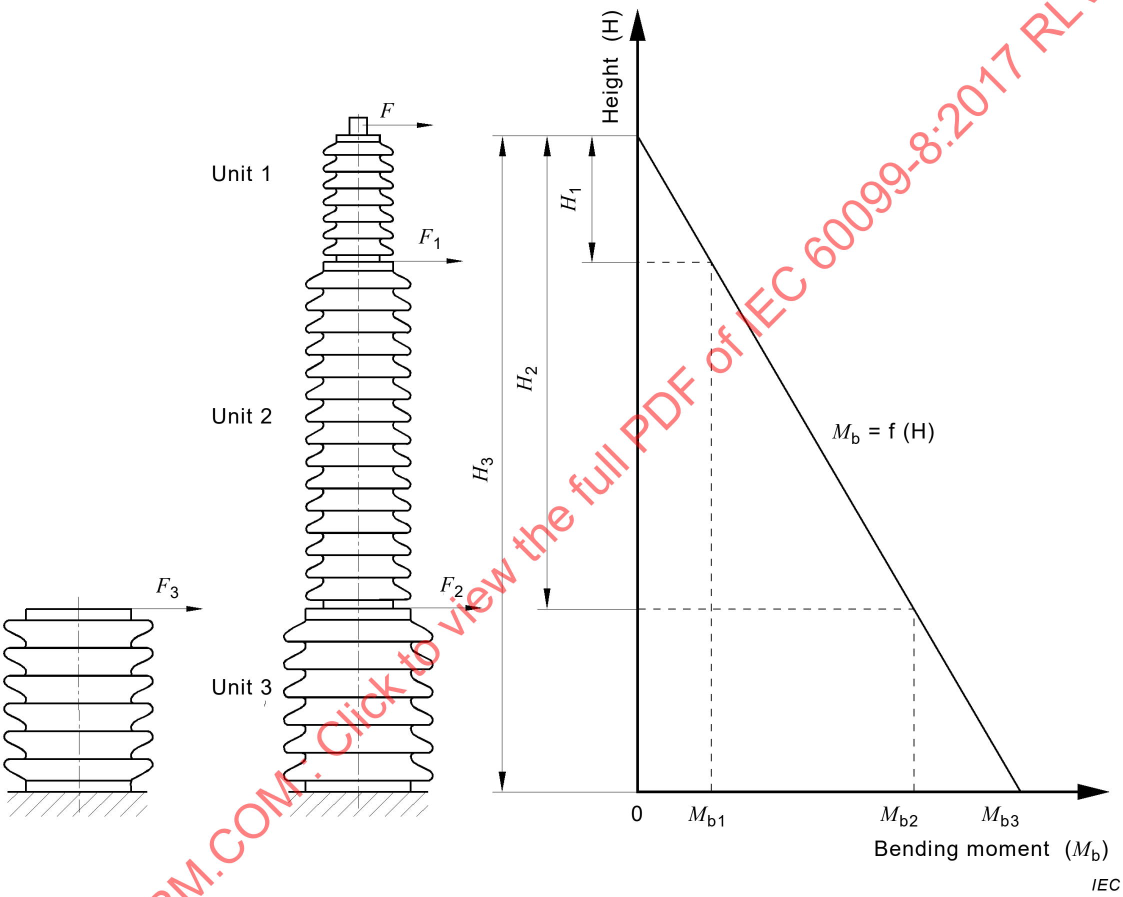


Figure B.1 – Bending moment – Multi-unit SVU

Testing the complete SVU, 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:

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

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

B.2 Definition of mechanical loads

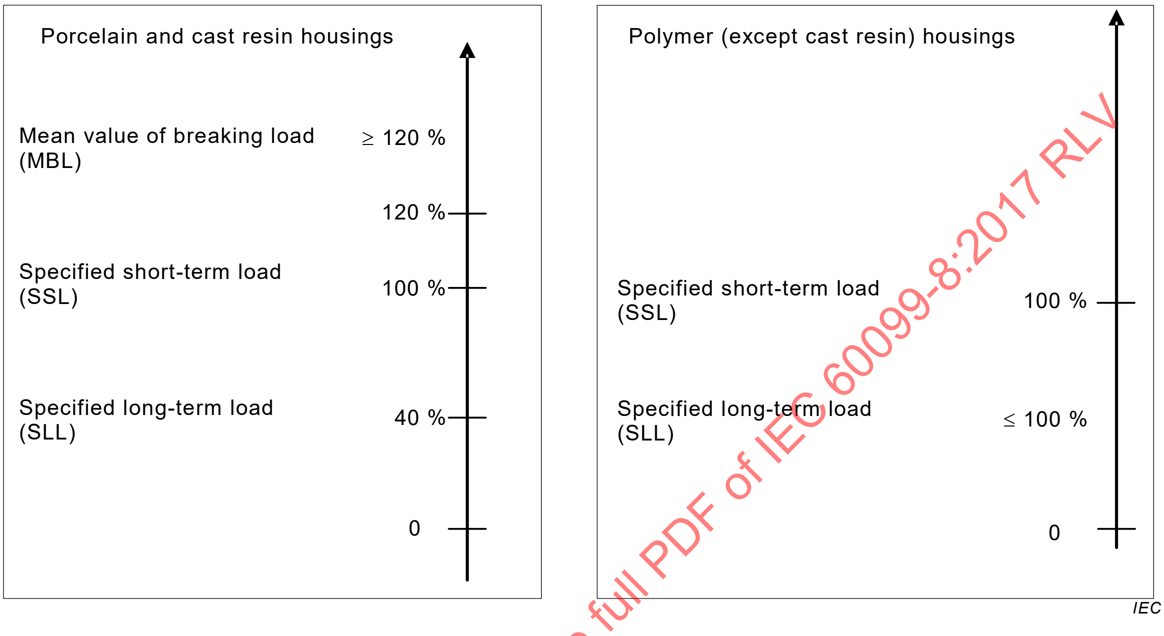


Figure B.2 – Definition of mechanical loads

Figure B.2 shows the definition of mechanical loads.

B.3 Definition of seal leak rate

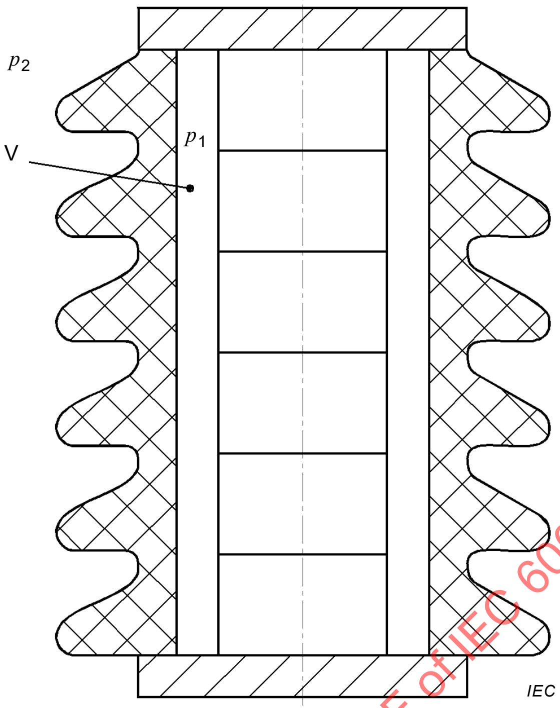


Figure B.3 – SVU unit

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, as shown in Figure B.3.

Seal leak rate $= \frac{\Delta p_1 \times V}{\Delta t}$ at $|p_1 - p_2| \geq 70$ kPa and at a temperature of +20 °C ± 15 K,

where

$\Delta p_1 = p_1(t_2) - p_1(t_1)$;

$p_1(t)$ is the internal gas pressure of the arrester housing as a function of time (Pa);

p_2 is the gas pressure exterior to the arrester (Pa);

t_1 is the start time of the considered time interval (s);

t_2 is the end time of the considered time interval (s);

$\Delta t = t_2 - t_1$;

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

B.4 Calculation of wind-bending-moment

Figure B.4 indicates dimensions of an SVU used for the calculation of wind-bending moment.

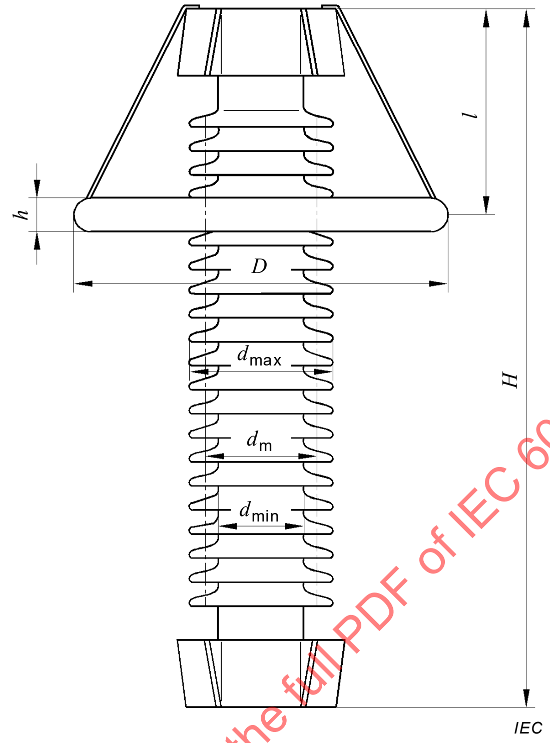


Figure B.4 – SVU dimensions

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

where

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

$d_m = (d_{max} + d_{min})/2$

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

H is the height of the arrester (m);

d_m is the mean value of the insulator diameter (m);

h is the thickness of the grading/corona ring (m);

D is the diameter of the grading/corona ring (m);

l is the grading/corona 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/m²);

P_1 is the density of air at 1,013 bar and 0 °C; equal to 1,29 kg/m³;

V is the wind velocity (m/s).

B.5 Flow chart – Procedures of tests of bending moment for porcelain/cast resin and polymer-housed SVUs

Figure B.5 shows procedures of tests of bending moment for porcelain/cast resin and polymer-housed SVUs.

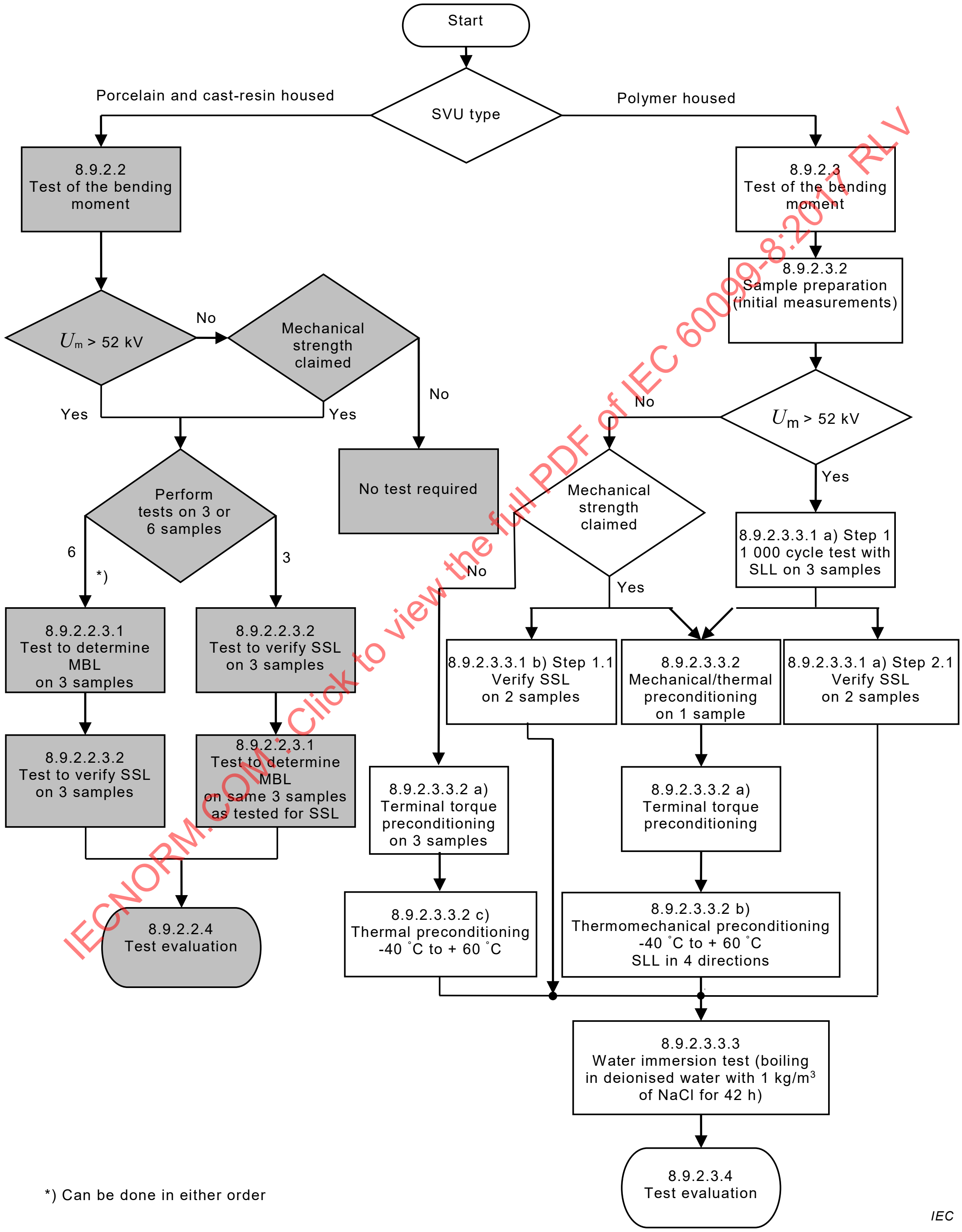


Figure B.5 – Procedures of tests of bending moment for porcelain/cast resin and polymer-housed SVUs

Annex C
(normative)

Special service conditions

C.1 General

A list of possible special service conditions is given in Annex A of IEC 60099-4:2014, referred to as abnormal service conditions in that Annex. A short guidance on the topics is given as follows:

C.2 Temperature in excess of +40 °C or below –40 °C

Low temperature may give problems with the sealing for arresters with enclosed gas volume. Polymer-housed arresters may be sensitive to very low temperatures close to and below –50 °C. Polymer material may become brittle at such low temperatures. The manufacturer must be consulted before use at lower temperatures than given by the IEC and verification tests requested.

C.3 Application at altitudes higher than 1 000 m

The external insulation strength decreases with altitudes. In particular this requires that the arcing distance of the housing and the series gap distance must be considered regarding the decreased insulation strength of the air. Guidance is found in IEC 60071-2.

C.4 Fumes or vapours that may cause deterioration of insulating surface or mounting hardware

For particular fumes or vapours, consult the manufacturer.

C.5 Excessive contamination by smoke, dirt, salt spray or other conducting materials

Severe air pollution such as salt spray smoke and dirt may affect the spark-over voltage of the gap.

C.6 Excessive exposure to moisture, humidity, dripping water, or steam

The manufacturer shall be consulted. However, most polymer arresters should be able to withstand if their performance has been verified in moisture and weather ageing tests as per IEC 60099-4.

C.7 Live washing of arrester

The manufacturer should be consulted if live washing is requested.

C.8 Unusual transportation or storage

The manufacturer shall be consulted and in particular cases tests shall be performed to verify an acceptable performance of the arrester.

C.9 Non-vertical erection and suspended erection

Non-vertical erections introduce a bending moment therefore this erection shall be checked with and accepted by the manufacturer. Suspended erection may also result in a bending moment if the connection is not made moment-free.

C.10 Wind speed > 34 m/s

The additional mechanical stress on the arrester shall be considered. The manufacturer shall be consulted.

C.11 Earthquake

The stress on the arrester approximately can be estimated from standard seismic data and arrester data on resonance frequency and damping and compared with mechanical withstand standards for the arrester. The installation methods are important as pedestals may magnify the stresses while e.g. flexible hanging will lower the stresses.

For more accurate information different seismic tests could be applied. (See IEC 62271-300, IEEE 693 or national standards such as from Japan, China or Chile).

C.12 Torsional loading of the arrester

The manufacturer shall be consulted.

Bibliography

IEEE C62.11, *Standard for metal-oxide surge arrester for alternating current power circuits (> 1 kV)*

ISO 3274, *Geometrical Product Specifications (GPS) – Surface texture: Profile method – Nominal characteristics of contact (stylus) instruments*

SOMMAIRE

COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

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PARAFOUDRES –

Partie 8: Parafoudres à oxyde métallique avec éclateur extérieur en série (EGLA) pour lignes aériennes de transmission et de distribution de réseaux à courant alternatif de plus de 1 kV

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La Norme internationale IEC 60099-8 a été établie par le comité d'études 37 de l'IEC: Parafoudres.

La présente version bilingue (2018-10) correspond à la version anglaise monolingue publiée en 2017-11.

Cette deuxième édition annule et remplace la première édition parue en 2011. Cette édition constitue une révision technique.

Cette édition inclut les modifications techniques majeures suivantes par rapport à l'édition précédente:

a) L'essai de la capacité de décharge aux chocs de foudre a été complètement reformulé et renommé en «Essai de vérification des caractéristiques assignées de transfert de charges répétitives, Qrs, avec décharges de foudre» pour refléter les modifications apportées à l'IEC 60099-4 Éd. 3 (2014) concernant les nouvelles méthodes de classification de la capacité à supporter une énergie ou une charge des parafoudres à oxyde métallique. En plus des essais permettant d'évaluer les performances des résistances MO, des procédures permettant d'évaluer les performances des éclateurs en série des EGLA ont été introduites.

b) Les omissions de l'Éd. 1 de la présente norme ont été rétablies, en particulier un essai aux tensions perturbatrices RF et un moyen de déterminer la constante de temps thermique du bloc de varistances en série de l'EGLA.

c) De nouveaux termes et définitions ont été ajoutés.

d) Un certain nombre de NOTES de l'Éd. 1 ont été converties en exigences normatives.

Un certain nombre de modifications rédactionnelles ont été apportées au document en vue d'en améliorer la grammaire et le flux général des informations.

Le texte anglais de cette norme est issu des documents 37/436/FDIS et 37/438/RVD.

Le rapport de vote 37/438/RVD donne toute information sur le vote ayant abouti à l'approbation de cette norme.

La version française de cette norme n'a pas été soumise au vote.

Ce document a été rédigé selon les Directives ISO/IEC, Partie 2.

Une liste de toutes les parties de la série IEC 60098, publiées sous le titre général *Parafoudres*, peut être consultée sur le site web de l'IEC.

Le comité a décidé que le contenu de ce document ne sera pas modifié avant la date de stabilité indiquée sur le site web de l'IEC sous "http://webstore.iec.ch" dans les données relatives au document recherché. À cette date, le document sera

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INTRODUCTION

La présente partie de l'IEC 60099 concerne les parafoudres de ligne avec éclateur extérieur (EGLA[1]).

Ce type de parafoudre est directement branché en parallèle à un ensemble isolateur. Il est constitué d'un bloc de varistances en série (SVU[2]), réalisé à partir de résistances non linéaires à oxyde métallique enrobées dans une enveloppe en polymère ou en porcelaine et d'un éclateur extérieur en série (voir la Figure 1).

Le but d'un EGLA est de protéger l'ensemble isolateur monté en parallèle contre les surtensions provoquées par la foudre. Par conséquent, il convient que l'éclateur extérieur en série ne s'amorce qu'en présence de surtensions à front rapide. Il convient que l'éclateur supporte toutes les surtensions à fréquence industrielle et à front lent apparaissant sur le réseau.

En cas de défaillance du SVU, il convient que l'éclateur extérieur en série soit en mesure d'isoler le SVU du réseau.

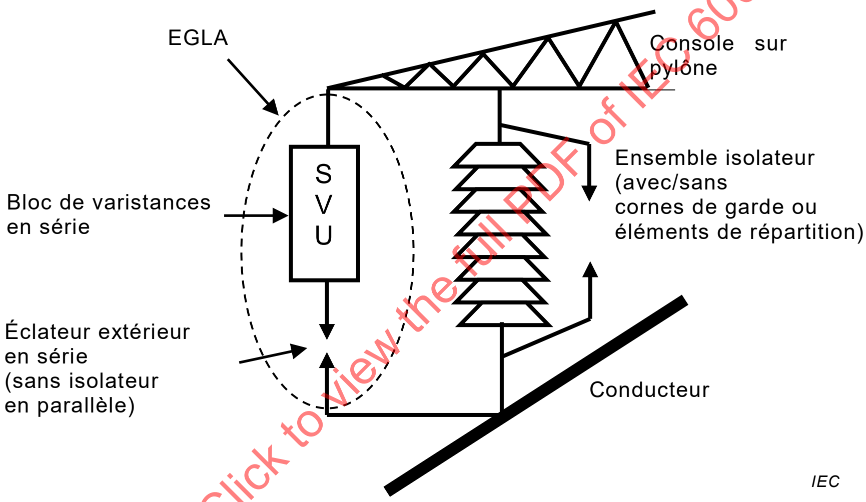

Figure 1 – Configuration d'un EGLA avec isolateur et corne de garde

1 EGLA = *externally gapped line arrester*.

2 SVU = *series varistor unit*.

PARAFOUDRES –

Partie 8: Parafoudres à oxyde métallique avec éclateur extérieur en série (EGLA) pour lignes aériennes de transmission et de distribution de réseaux à courant alternatif de plus de 1 kV

1 Domaine d'application

La présente partie de l'IEC 60099 concerne les parafoudres à oxyde métallique avec éclateur extérieur en série (parafoudres de ligne avec éclateur extérieur) utilisés sur les lignes aériennes de transmission et de distribution, uniquement pour protéger les ensembles isolateurs contre les contournements provoqués par la foudre.

Le présent document définit des parafoudres destinés à protéger l'ensemble isolateur uniquement contre les surtensions provoquées par la foudre. Par conséquent, et sachant que les résistances à oxyde métallique ne sont pas connectées en permanence à la ligne, les éléments suivants ne sont pas pris en compte dans le présent document:

- la tension d'amorçage au choc de manœuvre;
- la tension résiduelle au choc de courant à front raide et au choc de courant de manœuvre;
- la stabilité thermique;
- la tenue au choc de courant de longue durée en fonctionnement;
- la caractéristique de tension à fréquence industrielle en fonction du temps, d'un parafoudre;
- les essais portant sur les dispositifs de déconnexion;
- le fonctionnement et le vieillissement sous tension à fréquence industrielle.

Compte tenu de la conception particulière et du caractère unique de l'application aux lignes aériennes de transmission et de distribution, certaines exigences et certains essais spécifiques ont été introduits, tels que l'essai de vérification de la coordination entre la tenue de l'isolateur et le niveau de protection de l'EGLA, l'essai de coupure du courant de suite, les essais d'efforts mécaniques, etc.

Les conceptions avec des EGLA à éclateur extérieur en série montés en parallèle sur un isolateur ne sont pas couvertes par le présent document.

2 Références normatives

Les documents suivants cités dans le texte constituent, pour tout ou partie de leur contenu, des exigences du présent document. Pour les références datées, seule l'édition citée s'applique. Pour les références non datées, la dernière édition du document de référence s'applique (y compris les éventuels amendements).

IEC 60060-1:2010, *Technique des essais à haute tension – Partie 1: Définitions et exigences générales*

IEC 60060-2:2010, *Techniques des essais à haute tension – Partie 2: Systèmes de mesure*

IEC 60068-2-11:1981, *Essais fondamentaux climatiques et de robustesse mécanique – Partie 2-11: Essais – Essai Ka: Brouillard salin*

IEC 60068-2-14:2009, *Essais d'environnement – Partie 2-14: Essais – Essai N: Variation de température*

IEC 60099-4:2014, *Parafoudres – Partie 4: Parafoudres à oxyde métallique sans éclateur pour réseaux à courant alternatif*

IEC 60270:2000, *Techniques des essais à haute tension – Mesures des décharges partielles*

IEC 60507:2013, *Essais sous pollution artificielle des isolateurs haute tension en céramique et en verre destinés aux réseaux à courant alternatif*

IEC TS 60815-1:2008, *Selection and dimensioning of high-voltage insulators intended for use in polluted conditions – Part 1: Definitions, information and general principles* (disponible en anglais seulement)

IEC 62217:2012, *Isolateurs polymériques à haute tension pour utilisation à l'intérieur ou à l'extérieur – Définitions générales, méthodes d'essai et critères d'acceptation*

ISO 4287, *Spécification géométrique des produits (GPS) – État de surface: Méthode du profil – Termes, définitions et paramètres d'état de surface*

ISO 4892-1, *Plastiques – Méthodes d'exposition à des sources lumineuses de laboratoire – Partie 1: Lignes directrices générales*

ISO 4892-2, *Plastiques – Méthodes d'exposition à des sources lumineuses de laboratoire – Partie 2: Lampes à arc au xénon*

ISO 4892-3, *Plastiques – Méthodes d'exposition à des sources lumineuses de laboratoire – Partie 3: Lampes fluorescentes UV*

3 Termes et définitions

Pour les besoins du présent document, les termes et définitions suivants s'appliquent.

L'ISO et l'IEC tiennent à jour des bases de données terminologiques destinées à être utilisées en normalisation, consultables aux adresses suivantes:

- IEC Electropedia: disponible à l'adresse http://www.electropedia.org/
- ISO Online disponible à l'adresse http://www.iso.org/obp

3.1
parafoudre de ligne avec éclateur extérieur en série
EGLA
parafoudre conçu pour être installé sur les lignes aériennes de manière à protéger un ensemble isolateur uniquement contre les surtensions à front rapide provoquées par la foudre

Note 1 à l'article: Cette protection est réalisée en élevant la valeur de la tension d'amorçage de l'éclateur extérieur en série à un niveau qui permet d'isoler le parafoudre des surtensions à fréquence industrielle et à front lent les plus défavorables dues aux chocs de manœuvre et aux événements de défaut prévus sur la ligne à laquelle elle est appliquée.

Note 2 à l'article: L'abréviation «EGLA» est dérivée du terme anglais développé correspondant «externally gapped line arrester».

3.2
bloc de varistances en série
SVU
pièce comportant des résistances non linéaires à oxyde métallique, contenue dans une enveloppe, et qui doit être reliée à un éclateur extérieur en série pour réaliser le parafoudre complet

Note 1 à l'article: Le bloc de varistances en série peut être constitué de plusieurs éléments.

Note 2 à l'article: L'abréviation «SVU» est dérivée du terme anglais développé correspondant «series varistor unit».

3.3
fraction d'un EGLA
partie complète d'un EGLA complet, correctement assemblée, nécessaire pour représenter le comportement d'un EGLA complet lors d'un essai particulier

3.4
fraction d'un SVU
partie complète d'un élément de SVU, correctement assemblée, nécessaire pour représenter le comportement d'un SVU lors d'un essai particulier

3.5
élément d'un SVU
partie d'un SVU, entièrement contenue dans une enveloppe, qui peut être connectée en série et/ou en parallèle avec d'autres éléments d'un SVU pour réaliser, en association avec l'éclateur extérieur en série, un EGLA ayant des valeurs assignées de tension et/ou de courant plus élevées

3.6
tension assignée d'un EGLA
U_r
valeur maximale de la tension efficace à fréquence industrielle admissible pouvant être appliquée de manière permanente entre les bornes d'un EGLA et à laquelle il est prévu qu'il fonctionne correctement

Note 1 à l'article: La tension assignée est utilisée comme paramètre de référence pour la spécification des caractéristiques de fonctionnement et de coupure du courant.

Note 2 à l'article: La tension assignée d'un EGLA est comparable à Uc de tous les autres types de parafoudres MO.

3.7
tension de référence d'un SVU
U_{ref}
valeur de crête divisée par √2 de la tension à fréquence industrielle qu'il convient d'appliquer aux bornes du SVU pour que celui-ci soit parcouru par le courant de référence

Note 1 à l'article: La tension de référence d'un SVU à plusieurs éléments est la somme des tensions de référence de chaque élément.

3.8
courant de référence d'un SVU
I_{ref}
valeur de crête (la plus grande des deux polarités si le courant est dissymétrique) de la composante résistive du courant à fréquence industrielle utilisée pour déterminer la tension de référence d'un SVU

Note 1 à l'article: Il convient que le courant de référence soit suffisamment élevé pour rendre négligeables les effets des capacités parasites à la tension de référence mesurée des éléments de SVU. Il doit être spécifié par le fabricant.

Note 2 à l'article: En fonction du courant nominal de décharge de l'EGLA, le courant de référence est typiquement dans la plage de 0,05 mA à 1,0 mA par centimètre carré de surface d'une résistance à oxyde métallique pour les SVU à colonne unique.

3.9
courant assigné de court-circuit d'un SVU
I_s
valeur efficace du courant de court-circuit le plus élevé à laquelle le SVU ne subit pas une défaillance telle qu'elle occasionne une rupture explosive de l'enveloppe et à laquelle l'autoextinction de flammes nues (éventuelles) se produit dans un délai défini

3.10
tension résiduelle d'un EGLA
valeur de crête de la tension entre la longueur de borne à borne de l'EGLA, y compris l'éclateur en série et les connexions pendant le passage du courant de décharge

3.11
tension résiduelle d'un SVU
valeur de crête de la tension entre les bornes d'un SVU pendant le passage du courant de décharge

3.12
courant de fuite à la surface d'un SVU
courant circulant à la surface du SVU

3.13
courant de suite
I_{follow}
courant qui suit immédiatement un choc à travers un EGLA, avec la tension à fréquence industrielle comme source

3.14
effort à long terme spécifié d'un SVU
SLL
force mécanique perpendiculaire à l'axe longitudinal d'un SVU qu'il est admis d'appliquer de manière permanente en service sans provoquer de dommages mécaniques au SVU

Note 1 à l'article: L'abréviation «SLL» est dérivée du terme anglais développé correspondant «specified long-term load».

3.15
effort à court terme spécifié d'un SVU
SSL
force mécanique la plus élevée perpendiculaire à l'axe longitudinal d'un SVU qu'il est admis d'appliquer en service pendant de courtes périodes et en cas d'événements relativement rares (par exemple des efforts dus à des courants de court-circuit et à des vents très élevés) sans provoquer de dommages mécaniques au SVU

Note 1 à l'article: L'abréviation «SSL» est dérivée du terme anglais développé correspondant «specified short-term load».

3.16
effort moyen à la rupture d'un SVU
MBL
valeur moyenne de l'effort à la rupture de SVU à enveloppe en porcelaine ou en résine moulée, déterminée sur la base d'essais

Note 1 à l'article: L'abréviation «MBL» est dérivée du terme anglais développé correspondant «mean breaking load».

3.17
choc de courant de grande amplitude
valeur de crête du courant de décharge de forme d'onde 4/10 ou 2/20 utilisée pour vérifier la capacité de tenue du SVU à des cas de foudre extrêmes

3.18
densité de dépôt de sels
SDD
quantité de sels déposée sur une surface donnée de l'enveloppe d'un SVU, divisée par l'aire de cette surface; généralement exprimée en mg/cm^2

Note 1 à l'article: L'abréviation «SDD» est dérivée du terme anglais développé correspondant «salt deposit density».

3.19
essai de vérification de la coordination entre la tenue de l'isolateur et le niveau de protection de l'EGLA
essai permettant de vérifier que l'EGLA aura un comportement d'amorçage correct et écrêtera les surtensions dues à la foudre à des valeurs bien inférieures à la tension de contournement de l'ensemble isolateur monté en parallèle

3.20
essai de tenue aux vibrations
essai permettant de vérifier que le SVU et ses connecteurs peuvent supporter les niveaux spécifiés de vibrations mécaniques

3.21
décharge au choc de foudre
choc de courant de demi-onde pratiquement sinusoïdal dont la durée est comprise entre 200 µs et 230 µs, période au cours de laquelle la valeur instantanée du courant de choc est comprise entre 5 % et 100 % de sa valeur de crête

3.22
caractéristiques assignées de transfert de charges répétitives
Q_{rs}
capacité de transfert de charges spécifiée maximale d'un EGLA, sous la forme d'un événement simple ou d'un groupe de surtensions qui peut être transmise par un EGLA sans provoquer de défaillance mécanique ou de dégradation électrique inacceptable des résistances MO

Note 1 à l'article: La charge est calculée comme la valeur absolue du courant intégré dans le temps. Pour les besoins de la présente norme, il s'agit de la charge accumulée dans un événement simple ou d'un groupe de surtensions ne durant pas plus de 2 s et qui peut être suivie par un événement ultérieur à un intervalle de temps pas plus court que 60 s.

4 Identification et classification

4.1 Identification des EGLA

Un EGLA doit être au moins défini au moyen des informations suivantes qui doivent figurer sur une plaque signalétique fixée à demeure sur le parafoudre:

- la tension assignée U_r, en kV;
- la fréquence assignée en Hz, uniquement si elle est inférieure à 48 Hz ou supérieure à 62 Hz;
- les informations relatives à la série de classification (par exemple: «X1», «Y2»);
- le courant assigné de court-circuit I_s, en kA;
- le nom du fabricant ou la marque de fabrique;

- l'année de construction;
- le numéro de série (au moins pour les parafoudres de tension U_s > 52 kV);
- la capacité de décharge aux chocs de foudre (valeur de charge uniquement), en C; par exemple: «0.4 C».

Les informations concernant l'écartement exigé des éclateurs, y compris les tolérances applicables, doivent être fournies de manière appropriée, par exemple dans le manuel.

4.2 Classification des EGLA

Les EGLA sont classés en fonction des valeurs nominales de leurs courants de décharge et de leurs capacités de tenue aux chocs de courant de grande amplitude tels que définis dans le Tableau 1; de même, ils doivent au moins satisfaire aux exigences d'essai et caractéristiques de fonctionnement spécifiées dans le Tableau 3. Ces parafoudres ne font l'objet d'aucun essai de fonctionnement aux surtensions à front lent et à fréquence industrielle.

Tableau 1 – Classification des EGLA – «Série X» et «Série Y»

Série X					Série Y				
Désignation de la classe	X1	X2	X3	X4	Désignation de la classe	Y1	Y2	Y3	Y4
Courant nominal de décharge (kA), 8/20	5	5	10	20	Courant nominal de décharge (kA), 2/20	5	10	15	20
Choc de courant de grande amplitude (kA), 4/10	40	65	100	100	Choc de courant de grande amplitude (kA), 2/20	10	25	40	65

La «Série X» correspond à la classification de l'IEC 60099-4. Les normes IEC et IEEE utilisent un courant nominal de décharge de forme d'onde 8/20 et un choc de courant de grande amplitude de forme d'onde 4/10. La «Série Y» correspond à la classification utilisée au Japon (par exemple) pour les applications de lignes protégées (blindées). La spécification d'une forme d'onde 2/20 à la fois pour le courant nominal de décharge et le choc de courant de grande amplitude se fonde sur cette application particulière.

En fonction des conditions de service, des valeurs de choc de courant de grande amplitude autres que celles spécifiées dans ce tableau peuvent être appliquées.

5 Caractéristiques assignées et conditions de service

5.1 Tensions assignées normalisées

Les valeurs normalisées de tension assignée (valeurs efficaces) des parafoudres sont spécifiées dans le Tableau 2 en échelons de tension constants dans les plages de tensions spécifiées.

Tableau 2 – Échelons de tension assignée (valeurs efficaces)

Plage de tensions assignées (kV)	**Échelons de tension assignée** (kV)
3 à 30	1
> 30 à 54	3
> 54 à 96	6
> 96 à 288	12
> 288 à 396	18
> 396	24

NOTE Des valeurs de tension assignée autres que celles indiquées ci-dessus peuvent être admissibles à condition qu'elles soient des multiples de 6.

5.2 Fréquences assignées normalisées

Les fréquences assignées normalisées vont de 48 Hz à 62 Hz.

5.3 Valeurs normalisées du courant nominal de décharge

Les valeurs normalisées du courant nominal de décharge pour des formes d'onde 8/20 ou 2/20 sont les suivantes: 5 kA, 10 kA, 15 kA et 20 kA.

5.4 Conditions de service

5.4.1 Conditions normales de service

Les EGLA conformes au présent document doivent être en mesure de fonctionner dans les conditions normales de service suivantes:

a) température ambiante de l'air comprise entre –40 °C et +40 °C;
b) altitude ne dépassant pas 1 000 m;
c) fréquence de la source d'alimentation en courant alternatif comprise entre 48 Hz et 62 Hz maximum;
d) tension à fréquence industrielle appliquée de façon continue entre les bornes de l'EGLA ne dépassant pas sa tension assignée;
e) conditions mécaniques: non spécifiées (voir NOTE);
f) vitesse du vent: non spécifiée (voir NOTE);
g) conditions de pollution: il peut y avoir pollution par la poussière, la fumée, les gaz corrosifs, les vapeurs ou le sel; cependant, elle ne dépasse pas le niveau de pollution «fort» tel que défini dans l'IEC TS 60815-1.

NOTE Il est admis que les questions mécaniques et d'environnement sont déterminantes pour le service; cependant, du fait de la grande variété de configurations d'installation possibles, il n'est pas possible de fournir des valeurs normalisées pour les points e) et f).

5.4.2 Conditions particulières de service

Les parafoudres destinés à des utilisations différentes ou soumis à des conditions de service autres que les conditions normales peuvent exiger une étude spéciale pour leur conception, leur fabrication ou leur utilisation. L'utilisation du présent document en cas de conditions particulières de service fait l'objet d'un accord entre le fabricant et l'acheteur. Une liste des conditions particulières de service existantes est fournie dans l'Annexe C.

6 Exigences

6.1 Tenue de l'isolation du SVU et de l'EGLA complet

6.1.1 Tenue de l'isolation de l'enveloppe du SVU

L'enveloppe du SVU doit supporter une tension de choc de foudre de

a) pour la «Série X»: 1,4 fois la tension résiduelle au courant nominal de décharge
b) pour la «Série Y»: 1,13 fois la tension résiduelle au choc de courant de grande amplitude, mais au moins 1,3 fois la tension résiduelle au courant nominal de décharge

NOTE Le facteur de 1,4 du cas a) tient compte des variations des conditions atmosphériques jusqu'à 1 000 m d'altitude et de valeurs du courant de décharge jusqu'à trois fois égales au courant nominal de décharge.

6.1.2 Tenue de l'isolation de l'EGLA avec SVU en court-circuit (défectueux)

L'EGLA doit avoir les performances suivantes de tenue de l'isolation:

a) l'EGLA doit supporter le niveau spécifié de tension de tenue au choc de manœuvre du système même si le SVU a été mis en court-circuit du fait d'une surcharge (défaillance);

b) l'EGLA doit être en mesure de supporter les valeurs et durées maximales de surtensions temporaires entre phase et terre même si le SVU a été mis en court-circuit du fait d'une surcharge (défaillance).

6.2 Tensions résiduelles

Le mesurage des tensions résiduelles a pour objet de connaître les valeurs maximales de ces tensions résiduelles pour une conception donnée et pour tous les courants et formes d'onde spécifiés. Ces valeurs sont déduites du résultat des essais de type ainsi que de la valeur spécifiée et publiée par le fabricant pour la tension résiduelle maximale sous le courant de choc de foudre utilisé lors des essais individuels de série.

La tension résiduelle maximale d'une conception d'EGLA donnée, quels que soient le courant et la forme d'onde, est calculée en multipliant la tension résiduelle des fractions de SVU soumises aux essais de type par un facteur d'échelle spécifique et en ajoutant une valeur calculée de la chute de tension inductive aux bornes du SVU, de l'éclateur et des connexions. Le facteur d'échelle est égal au rapport entre la tension résiduelle maximale déclarée, telle que vérifiée pendant les essais individuels de série, et la tension résiduelle mesurée sur les fractions pour le même courant et la même forme d'onde.

La valeur de la tension résiduelle de l'EGLA au courant nominal de décharge et au choc de courant de grande amplitude, respectivement, multipliée par un facteur comme indiqué en 6.1.1, doit être inférieure à la tension de contournement minimale de l'ensemble isolateur à protéger.

6.3 Fonctionnement aux chocs de courant de grande amplitude

La capacité de décharge du SVU doit être démontrée par l'injection de deux chocs de courant de grande amplitude.

6.4 Capacité de décharge aux chocs de foudre

La capacité des résistances à oxyde métallique, y compris des éclateurs en série de l'EGLA, à supporter des décharges de foudre ayant des formes d'onde de courant d'une durée de plusieurs dizaines de microsecondes pour des parafoudres utilisés sur des lignes avec câble de garde et de plusieurs centaines de microsecondes pour des parafoudres utilisés sur des lignes sans câble de garde, doit être démontrée. L'essai correspondant couvre également les effets de coups de foudre multiples.

6.5 Comportement du SVU aux courants de court-circuit

Le fabricant doit déclarer les caractéristiques assignées du SVU concernant la tenue en court-circuit. Ces caractéristiques assignées de courant de court-circuit ne doivent pas occasionner de rupture explosive du SVU, et l'autoextinction d'éventuelles flammes nues doit avoir lieu dans des délais définis.

L'éclateur ne fait pas l'objet d'essais de court-circuit sur le SVU et il est recommandé de vérifier ses performances de tenue aux courts-circuits de manière séparée. Il convient que l'éclateur soit en mesure de conserver son intégrité mécanique après avoir été soumis au courant assigné de court-circuit de l'EGLA et que sa tension d'amorçage n'en soit pas diminuée.

6.6 Performances mécaniques

Pour les EGLA qui doivent être montés sur des pylônes ou des poteaux de transmission, les performances mécaniques permettant de supporter les efforts de traction, de flexion et/ou les charges de vibration dus à la pression du vent, les charges anormales de vibration des conducteurs lors des travaux d'installation et la pénétration d'humidité doivent être démontrées.

Les valeurs applicables d'efforts de traction et de flexion doivent être convenues entre le fabricant et l'acheteur.

Le SVU doit être en mesure de supporter les charges de vibration à prévoir en service.

Il convient que l'EGLA complet, y compris l'ensemble éclateur et la structure de montage, soit au moins en mesure de supporter les mêmes contraintes mécaniques.

6.7 Vieillissement climatique du SVU

Le SVU doit être en mesure de supporter les contraintes climatiques prévues en service. Les essais d'environnement démontrent par des procédures d'essai accéléré que le système d'étanchéité et les interfaces métalliques exposées du SVU ne sont pas affectés par les conditions climatiques. En outre, la résistance aux rayonnements ultraviolets doit être démontrée pour les SVU à enveloppe en polymère (composite et résine moulée).

6.8 Tension de référence du SVU

La tension de référence (U_{ref}) du SVU doit être mesurée au courant de référence sur des fractions et des éléments quand cela est exigé. Ce mesurage doit être effectué à une température ambiante de 20 °C ± 15 K et la température réelle doit être enregistrée.

NOTE Le remplacement de la valeur de crête de la composante résistive du courant par la valeur instantanée du courant au moment de la crête de tension peut donner une approximation acceptable.

6.9 Décharges partielles internes

Le niveau des décharges partielles internes dans le SVU, lors des essais réalisés selon 9.1 et 10.3, ne doit pas dépasser 10 pC.

6.10 Coordination entre la tenue de l'isolateur et le niveau de protection de l'EGLA

La coordination correcte entre, d'une part, les caractéristiques de contournement de l'ensemble isolateur, la tension d'amorçage de l'EGLA en présence de chocs de foudre normaux et sur front d'onde et, d'autre part, la tension résiduelle de l'EGLA au courant nominal de décharge ainsi que, pour les parafoudres de «Série Y», au choc de courant de grande amplitude, doit être démontrée.

Tout amorçage à la tension de choc de foudre doit avoir lieu dans l'éclateur extérieur en série de l'EGLA, sans entraîner un éventuel contournement de l'ensemble isolateur à protéger.

La valeur de

- pour la «Série X»: 1,4 fois la tension résiduelle au courant nominal de décharge conformément au Tableau 1 et à 8.3.3;
- pour la «Série Y»: 1,13 fois la tension résiduelle au choc de courant de grande amplitude, mais au moins 1,3 fois la tension résiduelle au courant nominal de décharge, conformément au Tableau 1 ainsi qu'à 8.3.3 et 8.3.4.

doit être inférieure à $U_{50,\ \text{Isolateur}}$ moins X fois l'écart type ($U_{50,\ \text{Isolateur}} - X \times \sigma$) de l'ensemble isolateur à protéger, où σ = 0,03 et X doit être convenu entre le fabricant et l'utilisateur. Une valeur de 2,5 est recommandée pour X.

6.11 Coupure du courant de suite

La coupure du courant de suite par l'EGLA, dans des conditions d'humidité et de pollution, doit être démontrée par une procédure d'essai tenant compte de ces conditions de fonctionnement. L'essai de coupure du courant de suite est obligatoire, soit comme essai de type conformément à 8.8, soit comme essai de réception conformément à 10.6.

6.12 Compatibilité électromagnétique

Les parafoudres ne sont pas sensibles aux perturbations électromagnétiques et aucun essai d'immunité n'est donc nécessaire.

Dans des conditions normales de fonctionnement, l'EGLA ne doit pas émettre de perturbations significatives. L'EGLA complet doit faire l'objet d'un essai aux tensions perturbatrices RF réalisé comme essai de réception (voir 10.4). Le niveau maximal de perturbations RF de l'EGLA, soumis à la tension maximale permanente phase-terre du réseau ($U_s/\sqrt{3}$), ne doit pas dépasser 2 500 μV.

6.13 Fin de vie

À la demande des utilisateurs, chaque fabricant doit fournir des informations suffisantes pour que tous les composants du parafoudre puissent être mis au rebut et/ou recyclés conformément aux règlements nationaux ou internationaux.

7 Conditions générales d'exécution des essais

7.1 Appareillage de mesure et incertitude

L'appareillage de mesure doit être conforme aux exigences de l'IEC 60060-2 et de l'IEC 60099-4. L'incertitude des valeurs obtenues doit répondre aux exigences relatives aux essais.

Sauf indication contraire, tous les essais aux tensions à fréquence industrielle doivent être effectués sous une tension alternative ayant une fréquence comprise entre 48 Hz et 62 Hz et une forme d'onde pratiquement sinusoïdale.

7.2 Échantillons d'essai

Sauf spécification contraire, pour chaque entité soumise à l'essai, la séquence complète d'essais doit être effectuée sur le même échantillon d'essai. Le nombre d'échantillons est donné dans le Tableau 3. Les échantillons d'essai doivent être neufs, propres, entièrement assemblés et disposés de manière à simuler les conditions de service.

Lorsque les essais portent sur des fractions ou des éléments, les conditions suivantes doivent être remplies:

a) Le rapport entre la tension assignée de l'EGLA complet et la tension assignée de la fraction ou de l'élément est appelé n.

b) Le volume des éléments de résistance utilisés comme échantillons d'essai ne doit pas être supérieur au volume minimal de tous les éléments de résistance utilisés dans l'EGLA complet divisé par n.

c) Il convient que la tension de référence U_{ref} du SVU de la fraction d'essai soit égale à la tension minimale de référence du SVU de l'EGLA, divisée par n. Si la tension de référence du SVU de la fraction d'essai est supérieure à la tension minimale de référence du SVU de l'EGLA complet, divisée par n, le facteur n doit être réduit en conséquence. Si la tension de référence du SVU de la fraction d'essai est inférieure à la tension minimale de référence du SVU de l'EGLA complet, divisée par n, l'utilisation de la fraction d'essai n'est pas autorisée.

Le facteur *n* de l'échantillon d'essai doit être consigné dans le rapport d'essai.

8 Essais de type

8.1 Généralités

Le Tableau 3 identifie les essais de type qui doivent être réalisés sur l'EGLA complet ou sur des composants de l'EGLA.

Tableau 3 – Essais de type (tous les essais à réaliser avec ou sans l'ensemble isolateur sur décision du fabricant)

Intitulé de l'essai	Nombre d'échan-tillons d'essai	EGLA	Fraction d'EGLA	Élément de SVU	Fraction de SVU	Numéro d'article
Essais de tenue de l'isolation						
1.1 Essai de tenue de l'enveloppe du SVU	1			Essai		8.2.2
1.2 Essai de tenue de l'EGLA avec SVU défectueux	1	Essai				8.2.3
2. Essais de tensions résiduelles	3				Essai	8.3
3. Essai d'amorçage au choc de foudre normal a)	1	Essai				8.4
4. Essai de tenue aux chocs de courant de grande amplitude	3				Essai	8.5
5. Essai de vérification des caractéristiques assignées de transfert de charges répétitives, Q_{rs}, avec décharges de foudre: Résistances MO	10 (20)				Essai	8.6.1
6. Essai de vérification des caractéristiques assignées de transfert de charges répétitives, Q_{rs}, avec décharges de foudre: Éclateurs en série	1				Essai	8.6.2
7. Essais de court-circuit	4 ou 5			Essai		8.7
8. Essai de coupure du courant de suite b)	1	Essai c)	Essai c)			8.8
9. Essai de flexion	3 ou 6			Essai		8.9.2
10. Essai de vibrations d)	1			Essai e)		8.9.3
11. Essais de vieillissement climatique	1			Essai		8.10
12. Essai aux tensions perturbatrices RF	1	Essai f)				8.11

a) Cet essai est obligatoire s'il n'est pas réalisé comme un essai de réception conformément à 10.5.

b) Cet essai est obligatoire s'il n'est pas réalisé comme un essai de réception conformément à 10.6.

c) Cet essai est réalisé soit sur un EGLA complet soit sur une fraction d'EGLA; voir 8.8.2.

d) Cet essai est obligatoire s'il n'est pas réalisé comme un essai de réception conformément à 10.7.

e) L'essai de vibrations est réalisé sur un SVU complet, voir 8.9.3.1.

f) Cet essai est obligatoire s'il n'est pas réalisé comme un essai de réception conformément à 10.4.

8.2 Essais de tenue de l'isolation de l'enveloppe du SVU et de l'EGLA avec SVU défectueux

8.2.1 Généralités

Ces essais démontrent la tension de tenue aux chocs de foudre de l'enveloppe du SVU, dans des conditions sèches, ainsi que la tension de tenue de l'EGLA à la tension maximale de choc de manœuvre prévue et aux surtensions à la fréquence industrielle dans le système sous la pluie, en cas de défaillance et de court-circuit du SVU.

8.2.2 Essai de tenue de l'isolation de l'enveloppe du SVU

8.2.2.1 Généralités

Cet essai démontre la rigidité diélectrique de l'enveloppe extérieure du SVU vis-à-vis des tensions de choc de foudre.

8.2.2.2 Procédure d'essai

L'enveloppe du SVU doit être soumise à une tension de choc de foudre normalisée en condition sèche conformément à la procédure B de 7.3.1.2 de l'IEC 60060-1:2010.

L'essai doit être effectué sur l'enveloppe du SVU, à la contrainte spécifique de tension par unité de longueur la plus élevée. Les résistances non linéaires à oxyde métallique doivent être retirées ou remplacées par des éléments en matière isolante.

Quinze chocs consécutifs à la valeur de la tension d'essai doivent être appliqués pour chaque polarité.

Tension d'essai:

a) pour la «Série X»: 1,4 fois la tension résiduelle au courant nominal de décharge conformément au Tableau 1 et à 8.3.3.

b) pour la «Série Y»: 1,13 fois la tension résiduelle au choc de courant de grande amplitude, mais au moins 1,3 fois la tension résiduelle au courant nominal de décharge, conformément au Tableau 1 ainsi qu'à 8.3.3 et 8.3.4.

Si la distance de formation d'arcs sur bandes sèches ou la somme des distances partielles de formation d'arcs sur bandes sèches est supérieure à la tension d'essai divisée par 500 kV/m, cet essai n'est pas exigé.

Évaluation: Le SVU doit être déclaré avoir satisfait à l'essai si le nombre de décharges disruptives externes ne dépasse pas deux pour chaque série de 15 chocs.

8.2.3 Essais de tenue de l'isolation de l'EGLA avec SVU défectueux

8.2.3.1 Généralités

Un essai de tension de tenue aux chocs de manœuvre sous pluie et un essai de tension de tenue à fréquence industrielle sous pluie doivent être réalisés afin de simuler un SVU défectueux. Ces essais ont pour but de démontrer qu'il n'y aura pas d'amorçage en cas de surtensions de choc de manœuvre et à fréquence industrielle si, dans le scénario le plus défavorable, le SVU est mis en court-circuit par une défaillance.

8.2.3.2 Essai de tension de tenue aux chocs de manœuvre sous pluie

Procédure d'essai

La procédure d'essai doit être la suivante:

Échantillon d'essai: EGLA avec SVU en court-circuit. La défaillance du SVU doit être simulée en mettant en court-circuit le SVU au moyen d'un fil métallique, tandis que l'état de l'électrode doit être spécifié par accord entre le fabricant et l'acheteur. La longueur minimale de l'éclateur extérieur en série utilisé pour l'essai doit être spécifiée par le fabricant.

Tension et conditions d'essai:

a) La valeur de la tension de tenue doit être déclarée par le fabricant ou déterminée par accord entre le fabricant et l'acheteur, en tenant compte du niveau maximal de la surtension présumée de tenue aux chocs de manœuvre de la ligne. L'altitude de l'installation et du laboratoire d'essai doit être prise en considération lors de la détermination des tensions d'essai.
b) La tension de contournement à 50 % ($U_{50,\ \mathrm{EGLA}}$) est mesurée par la méthode de montée et descente conformément à l'IEC 60060-1, pour chaque polarité de l'EGLA, le SVU étant en court-circuit. La forme d'onde de la tension d'essai doit être 250/2500.
c) Les caractéristiques de pluie doivent être conformes aux exigences de l'IEC 60060-1.

Évaluation: La tension de tenue de l'EGLA est déterminée par l'expression suivante:

$$U_{10,\ \mathrm{EGLA}} = U_{50,\ \mathrm{EGLA}}\ (1 - 1{,}3\ \sigma),$$

calculée à partir de la tension de contournement à 50 % mesurée et de l'écart type σ qui est par hypothèse égal à 6 % (σ = 0,06) pour la tension de tenue aux chocs de manœuvre. L'EGLA est considéré comme ayant satisfait à l'essai si sa valeur de tenue est supérieure ou égale à la valeur déclarée ou convenue.

NOTE Pour la distribution normale prise pour hypothèse dans le cas présent, la valeur de probabilité de 10 % résulte de la valeur de probabilité de 50 % moins 1,3 fois l'écart type.

8.2.3.3 Essai de tension de tenue à fréquence industrielle sous pluie

La procédure d'essai doit être la suivante:

Échantillon d'essai: EGLA avec SVU en court-circuit. La défaillance du SVU doit être simulée en mettant le SVU en court-circuit au moyen d'un fil métallique. La longueur minimale de l'éclateur extérieur en série et les conditions des électrodes de l'éclateur doivent être spécifiées par le fabricant ou être convenues entre le fabricant et l'utilisateur.

Tension et conditions d'essai:

a) L'essai de tension de tenue à fréquence industrielle sous pluie doit être réalisé conformément à l'IEC 60060-1, le SVU de l'EGLA étant en court-circuit.
b) La tension d'essai doit être de 1,2 fois la tension assignée de l'EGLA.
c) Les caractéristiques de pluie doivent être conformes aux exigences de l'IEC 60060-1.

Évaluation: Le résultat est positif si l'échantillon d'EGLA supporte la tension d'essai pendant une minute.

8.3 Essais de tensions résiduelles

8.3.1 Généralités

Cet essai démontre que les tensions résiduelles du SVU et de l'EGLA complet, soumis à des chocs de foudre, sont conformes aux valeurs déclarées. Tous les essais de vérification de la tension résiduelle doivent être effectués sur les trois mêmes fractions d'un SVU. Le temps entre décharges doit être suffisant pour permettre aux échantillons de revenir à une température approximativement égale à la température ambiante. La tension résiduelle de l'EGLA est calculée à partir de la tension résiduelle mesurée des fractions de SVU multipliée par un facteur d'échelle et en ajoutant au résultat une valeur calculée de la chute de tension inductive aux bornes du SVU, de l'éclateur et des connexions. La tension résiduelle du SVU est calculée à partir de la tension résiduelle mesurée des fractions de SVU multipliée par un facteur d'échelle et en ajoutant au résultat une valeur calculée de la chute de tension inductive aux bornes du SVU.

8.3.2 Procédure de correction et de calcul des tensions inductives

Dans le cas d'une forme d'onde 2/20 du courant, la procédure suivante doit être utilisée pour déterminer si une correction des effets inductifs est exigée. Un choc de courant comme décrit ci-dessus doit être appliqué à un bloc métallique de même dimension que les échantillons de résistances en essai. La valeur de crête et la forme d'onde apparaissant aux bornes du bloc métallique doivent être enregistrées. Si la tension de crête sur le bloc métallique est inférieure à 2 % de la tension de crête mesurée sur les échantillons de résistances, aucune correction inductive de la tension mesurée sur les résistances n'est exigée. Si la tension de crête sur le bloc métallique est comprise entre 2 % et 20 % de la tension de crête mesurée sur les échantillons de résistances, alors la forme d'onde de la tension aux bornes du bloc métallique doit être soustraite de la forme d'onde des tensions mesurées sur chacune des résistances, et les valeurs de crête des ondes ainsi obtenues doivent être enregistrées comme valeurs corrigées des tensions des résistances. Si la tension de crête sur le bloc métallique est supérieure à 20 % de la tension de crête sur les échantillons de résistances, le circuit d'essai et le circuit de mesure de la tension doivent être améliorés.

NOTE Une manière possible de réaliser des formes d'onde de courant identiques lors de tous les mesurages consiste à les appliquer en même temps sur l'échantillon et sur le bloc métallique en série dans le circuit d'essai. Seule leur position relative nécessite d'être inversée pour le mesurage de la chute de tension sur l'échantillon ou sur le bloc métallique.

L'onde impulsionnelle de tension aux bornes de l'échantillon (corrigée si nécessaire) ayant la plus grande valeur de crête doit être utilisée pour déterminer la valeur de la tension résiduelle au choc de courant du SVU et de l'EGLA complet, respectivement, selon l'une des procédures a) ou b) suivantes:

Procédure a)

1) Multiplier l'onde impulsionnelle de tension aux bornes de l'échantillon par le facteur d'échelle (voir 6.2).
2) À partir de la forme d'onde du choc de courant, déterminer le taux de variation du courant ($\mathrm{d}i/\mathrm{d}t$) sur l'ensemble de l'onde et le multiplier par l'inductance pour déterminer la chute de tension inductive:

$$u(t) = L \cdot \frac{\mathrm{d}i}{\mathrm{d}t} = L' \cdot h \cdot \frac{\mathrm{d}i}{\mathrm{d}t}$$

où

$u(t)$ est la chute de tension inductive (en kV) en fonction du temps;

L' est l'inductance par unité de longueur (en µH/m); L' = 1 µH/m;

h est la longueur de borne à borne (en m) du SVU ou de l'EGLA complet, y compris l'éclateur en série et les connexions;

$\mathrm{d}i/\mathrm{d}t$ est le taux de variation du courant en fonction du temps (en kA/µs).

3) Ajouter les résultats de 1) et 2) relatifs à la forme d'onde; la valeur de crête de l'onde résultante doit être prise comme étant la tension résiduelle réelle au choc de courant du parafoudre.

Procédure b)

1) Multiplier la valeur de crête de la tension de choc aux bornes de l'échantillon par le facteur d'échelle (voir 6.2).
2) Déterminer la chute de tension inductive aux bornes du parafoudre, en utilisant la formule suivante:

$$U_L = L \cdot \frac{di}{dt} = L' \cdot h \cdot \frac{I_d}{T_f}$$

où

U_L est la valeur de crête de la chute de tension inductive (en kV);

L' est l'inductance par unité de longueur (en µH/m); L' = 1;

h est la longueur de borne à borne (en m) du SVU ou de l'EGLA complet, y compris l'éclateur en série et les connexions;

T_f est la durée du front du choc de courant (en µs); T_f = 2;

I_d est l'amplitude réelle du courant de décharge (en kA).

3) Ajouter les résultats de 1) et 2); la valeur résultante doit être prise comme étant la tension résiduelle réelle au choc de courant du parafoudre.

8.3.3 Essai de la tension résiduelle aux chocs de courant de foudre

Chacun des trois échantillons doit être soumis à un choc de courant de foudre avec des valeurs de crête approximativement égales à 0,5, 1 et 2 fois le courant nominal de décharge de l'EGLA. La forme d'onde du courant doit être 8/20 pour les parafoudres de «Série X» et 2/20 pour les parafoudres de «Série Y», conformément au Tableau 1.

Pour les chocs de courant, il n'existe aucune exigence concernant la durée conventionnelle jusqu'à mi-valeur sur la queue, mais les tolérances de la durée conventionnelle du front des chocs de courant doivent s'inscrire dans les limites suivantes:

a) pour les chocs de courant de forme d'onde 2/20: de 1,7 µs à 2,3 µs en ce qui concerne la durée conventionnelle du front;

b) pour les chocs de courant de forme d'onde 8/20: de 7 µs à 9 µs en ce qui concerne la durée conventionnelle du front.

Pour les parafoudres de «Série Y», la tension résiduelle aux chocs de foudre est déterminée selon la procédure a) ou b) de 8.3.2. Pour les parafoudres de «Série X», il n'est nullement nécessaire de tenir compte de la chute de tension inductive.

Les valeurs maximales des tensions résiduelles déterminées doivent être portées sur une courbe donnant la tension résiduelle en fonction du courant de décharge.

La valeur de

- 1,4 fois la tension résiduelle au courant nominal de décharge conformément au Tableau 1 pour les modèles de «Série X»,
- 1,3 fois la tension résiduelle au courant nominal de décharge conformément au Tableau 1 pour les modèles de «Série Y»,

doit être inférieure à la tension minimale de contournement de l'ensemble isolateur à protéger. Voir également 10.5.3.

Si l'essai individuel d'un SVU complet ne peut être effectué au courant nominal de décharge, des essais complémentaires doivent être effectués à une valeur de courant comprise entre 0,01 et 1 fois le courant nominal de décharge, pour comparaison avec le SVU complet.

8.3.4 Essai de la tension résiduelle aux chocs de courant de grande amplitude

Cet essai s'applique uniquement aux modèles de «Série Y». Il doit être appliqué à chacun des trois échantillons un choc de courant de grande amplitude de forme d'onde 2/20 et d'une valeur de crête conforme au Tableau 1.

Pour les chocs de courant, il n'existe aucune exigence concernant la durée conventionnelle jusqu'à mi-valeur sur la queue, mais les tolérances de la durée conventionnelle du front des chocs de courant doivent s'inscrire dans les limites suivantes:

de 1,7 μs à 2,3 μs en ce qui concerne la durée conventionnelle du front.

La tension résiduelle aux chocs de courant de grande amplitude est déterminée conformément à la procédure a) ou b) de 8.3.2.

La valeur de 1,13 fois la tension résiduelle aux chocs de courant de grande amplitude doit être inférieure à la tension minimale de contournement de l'ensemble isolateur à protéger. Voir également 10.5.3.

8.4 Essai d'amorçage au choc de foudre normal

Il s'agit d'un essai de type obligatoire uniquement s'il n'est pas effectué d'essai de réception pour chaque ensemble isolateur spécifique conformément à 10.5. Lorsqu'il est réalisé comme essai de type, l'ensemble isolateur n'est pas inclus.

Cet essai a pour objet de déterminer la tension d'amorçage à 50 % de l'EGLA soumis à une contrainte de tension de choc de foudre.

L'échantillon d'essai est constitué d'un EGLA à la distance maximale entre éclateurs pour un système désigné donné, sans l'ensemble isolateur.

La forme d'onde doit être 1,2/50. La tension d'amorçage à 50 % ($U_{50,\ \mathrm{EGLA}}$) de l'EGLA doit être vérifiée conformément à la méthode de montée et descente de l'IEC 60060-1.

NOTE 1 La marge de protection entre la tension d'amorçage de l'EGLA et la tension de contournement de l'ensemble isolateur à protéger, peut être évaluée par $U_{50,\ \mathrm{EGLA}}$ plus X fois l'écart type, ($U_{50,\ \mathrm{EGLA}} + X \cdot \sigma$) sans dépasser $U_{50,\ \mathrm{Isolateur}}$ moins X fois l'écart type ($U_{50,\ \mathrm{Isolateur}} - X \cdot \sigma$) de l'ensemble isolateur à protéger, si cela est convenu entre le fabricant et l'utilisateur. X doit être défini par accord entre le fabricant et l'utilisateur. L'écart type (σ) est établi à 3 % pour des formes d'onde 1,2/50.

NOTE 2 2,5 est une valeur type pour X.

NOTE 3 Au cours des essais, l'expérience a montré que la tension d'amorçage de l'EGLA peut être affectée par la proximité de l'ensemble isolateur.

8.5 Essai de tenue aux chocs de courant de grande amplitude

8.5.1 Choix des échantillons d'essai

L'essai doit être effectué sur trois fractions d'un SVU. Les fractions doivent avoir une tension résiduelle au courant nominal de décharge à l'extrémité la plus élevée de la plage de variation déclarée par le fabricant. Pour satisfaire à ces spécifications, les conditions suivantes doivent être remplies:

a) Le rapport entre la tension résiduelle au courant nominal de décharge du SVU complet et la tension résiduelle au courant nominal de décharge de la fraction est défini par n. Le volume des éléments de résistance utilisés comme échantillons d'essai ne doit pas être supérieur au volume minimal de tous les éléments de résistance utilisés dans le SVU complet divisé par n.

b) Il convient que la tension de référence U_{ref} du SVU de la fraction d'essai soit égale à la tension minimale de référence du SVU de l'EGLA, divisée par n. Si la tension de référence du SVU de la fraction d'essai est supérieure à la tension minimale de référence du SVU de l'EGLA complet, divisée par n, le facteur n doit être réduit en conséquence. Si la tension de référence du SVU de la fraction d'essai est inférieure à la tension minimale de référence du SVU de l'EGLA complet, divisée par n, l'utilisation de la fraction d'essai n'est pas autorisée.

8.5.2 Procédure d’essai

Deux chocs de courant de grande amplitude de même polarité, ayant des valeurs de crête et des formes d'onde conformes au Tableau 1, doivent être appliqués aux trois fractions. L'intervalle de temps entre l'application des chocs doit permettre à l'échantillon de refroidir jusqu'à la température ambiante.

Les tolérances de réglage du matériel doivent être telles que les valeurs mesurées de chocs de courant s'inscrivent dans les limites suivantes:

a) pour les chocs de courant de forme d'onde 2/20:
   - de 90 % à 110 % de la valeur de crête spécifiée;
   - de 1,7 μs à 2,3 μs en ce qui concerne la durée conventionnelle du front;
   - de 18 μs à 22 μs en ce qui concerne la durée conventionnelle jusqu'à mi-valeur sur la queue;
   - la valeur de crête de toute onde de courant de polarité opposée doit être inférieure à 20 % de la valeur de crête du courant;
   - de légères oscillations sur le choc sont admissibles à condition que leur amplitude à proximité de la crête du choc soit inférieure à 5 % de la valeur de crête. Dans ces conditions, pour des besoins de mesure, une courbe moyenne doit être acceptée pour la détermination de la valeur de crête.

b) pour les chocs de courant de forme d'onde 4/10:
   - de 90 % à 110 % de la valeur de crête spécifiée;
   - de 3,5 μs à 4,5 μs en ce qui concerne la durée conventionnelle du front;
   - de 9 μs à 11 μs en ce qui concerne la durée conventionnelle jusqu'à mi-valeur sur la queue;
   - la valeur de crête de toute onde de courant de polarité opposée doit être inférieure à 20 % de la valeur de crête du courant;
   - de légères oscillations sur le choc sont admissibles à condition que leur amplitude à proximité de la crête du choc soit inférieure à 5 % de la valeur de crête. Dans ces conditions, pour des besoins de mesure, une courbe moyenne doit être acceptée pour la détermination de la valeur de crête.

8.5.3 Évaluation de l’essai

a) La tension de référence mesurée avant et après l'essai ne doit pas avoir varié de plus de 10 %.

b) Toute variation de la tension résiduelle au courant nominal de décharge mesurée avant et après l'essai doit s'inscrire dans une plage de (– 2 % à + 5 %).

c) L'examen visuel des échantillons après l'essai ne doit révéler aucune trace de perforation, de contournement et de fissure ou autre dommage significatif de l'échantillon d'essai. Si les résistances à oxyde métallique ne peuvent être retirées des échantillons d'essai pour effectuer un examen visuel, les essais supplémentaires suivants doivent être réalisés afin de s'assurer qu'aucun dommage n'a eu lieu au cours de l'essai. Après l'essai de tension résiduelle (b), il doit être appliqué à l'échantillon d'essai deux chocs au courant nominal de décharge. Le premier doit être appliqué à l'issue d'un délai suffisant permettant à l'échantillon de refroidir jusqu’à température ambiante. Le deuxième est appliqué entre 50 s et 60 s après le premier. Pendant l'application des deux chocs, les oscillogrammes de la tension et du courant ne doivent révéler aucun claquage et la différence de tension résiduelle entre le mesurage initial avant l'essai et l'application du dernier des deux chocs après l'essai doit demeurer dans une plage comprise entre (– 2 % et + 5 %).

8.6 Essai de vérification des caractéristiques assignées de transfert de charges répétitives, Q_{rs}, avec décharges de foudre

8.6.1 Résistances MO

8.6.1.1 Généralités

Cet essai a pour objet de vérifier les caractéristiques assignées de transfert de charges répétitives, Q_{rs}, d'un EGLA.

La capacité de transfert de charges répétitives est spécifiée par une contrainte de courant de choc pouvant être supportée par les résistances MO d'un EGLA vingt fois sans dommage mécanique ou électrique inacceptable. Une contrainte de courant de choc est censée représenter un transfert de charges pouvant se produire dans les conditions réelles d'un système.

Les caractéristiques assignées de transfert de charges répétitives sont liées à une probabilité très faible de défaillance et ne sont par conséquent pas données par une valeur déterministe mais par une valeur statistique. L'essai est effectué sur des résistances MO séparées à une valeur de charge comprise entre 1,1 et 1,2 fois la valeur assignée choisie dans la liste de 8.6.1.5. Cette approche part de l'hypothèse selon laquelle les performances des résistances MO séparées peuvent également être assignées à un EGLA complet fabriqué à partir de ces résistances MO, selon les exigences d'essai et l'approche statistique choisie.

La charge a été choisie pour faire l'objet d'essais afin d'obtenir une meilleure comparaison entre les différentes marques de résistances MO.

Pour cet essai, la forme du choc de courant doit être approximativement sinusoïdale. Le laps de temps pendant lequel la valeur instantanée du courant de choc est comprise entre 5 % et 100 % de sa valeur de crête doit être compris entre 200 µs et 230 µs. La valeur de crête de toute onde de courant de polarité opposée doit être inférieure à 5 % de la valeur de crête du courant. La valeur de crête du courant de chaque choc sur chaque échantillon d'essai doit être comprise entre 90 % et 110 % de la valeur de crête choisie.

Une valeur Q_{rs} tirée de la liste de 8.6.1.5 doit être assignée à un EGLA.

Une première séquence d'essai doit être effectuée sur 10 échantillons de résistances MO choisis conformément à 8.6.1.2. Le résultat de l'essai complet est positif s'il n'y pas plus d'une résistance MO qui échoue à un essai. Si deux résistances MO échouent à un essai, une deuxième séquence identique à la première doit être effectuée sur dix échantillons. Le résultat de l'essai complet doit alors être positif en l'absence de défaillance d'une résistance MO pendant cette deuxième séquence. Si plus de deux résistances MO échouent au cours de la première séquence d'essai ou si une résistance MO quelconque échoue au cours de la deuxième séquence d'essai, le résultat de l'essai complet est négatif.

8.6.1.2 Choix des échantillons d'essai

Les échantillons d'essai doivent comprendre des SVU complets, des fractions de SVU ou des éléments de résistance à oxyde métallique n'ayant été soumis à aucun des essais précédents, sauf dans la mesure nécessaire aux fins d'évaluation du présent essai.

Les échantillons qui doivent être choisis pour l'essai de vérification des caractéristiques assignées de transfert de charges répétitives doivent avoir une tension résiduelle au courant nominal de décharge à l'extrémité la plus élevée de la plage de variation déclarée par le fabricant. De plus, dans le cas de SVU à plusieurs colonnes, la valeur la plus élevée d'une distribution inégale de courant doit être prise en compte. Pour satisfaire à ces spécifications, les conditions suivantes doivent être remplies.

a) Le rapport entre la tension résiduelle au courant nominal de décharge du SVU complet et la tension résiduelle au courant nominal de décharge de la fraction est défini par n. Le volume des éléments de résistance utilisés comme échantillons d'essai ne doit pas être supérieur au volume minimal de tous les éléments de résistance utilisés dans le SVU complet divisé par n.

b) Il convient que la tension de référence U_{ref} du SVU de la fraction d'essai soit égale à la tension minimale de référence du SVU de l'EGLA, divisée par n. Si la tension de référence du SVU de la fraction d'essai est supérieure à la tension minimale de référence du SVU de l'EGLA complet, divisée par n, le facteur n doit être réduit en conséquence. Si la tension de référence du SVU de la fraction d'essai est inférieure à la tension minimale de référence du SVU de l'EGLA complet, divisée par n, l'utilisation de la fraction d'essai n'est pas autorisée.

c) Les échantillons doivent avoir la longueur maximale du type de résistances MO utilisé lors de la conception, et doivent avoir une contrainte de tension résiduelle de 10 kA supérieure ou égale à 0,97 × ($U_{10\ kA}$ par mm de longueur de résistance MO)$_{max}$, où ($U_{10\ kA}$ par mm de longueur de résistance MO)$_{max}$ est la contrainte de tension résiduelle de 10 kA la plus élevée spécifiée par le fabricant pour toute longueur du type de résistances MO utilisé dans le parafoudre. Si seuls des échantillons de contrainte de tension résiduelle de 10 kA inférieure sont disponibles, la charge transférée exigée doit être augmentée pour l'essai au moyen du facteur ($U_{10\ kA}$ par mm de longueur de résistance MO)$_{max}$ / ($U_{10\ kA}$ par mm de longueur de résistance MO)$_{réelle}$.

8.6.1.3 Procédure d'essai

La Figure 2 donne un aperçu de la procédure d'essai.

Essais initiaux

- Essai de tension résiduelle au courant nominal de décharge
- Essai de tension de référence au courant de référence spécifié

Application de 1,1 fois Q_{rs}

- 1re séquence: 20 chocs par échantillon (10 échantillons)
- s'il n'y a pas plus d'une défaillance d'échantillon au cours de la 1re séquence: résultat d'essai positif
- s'il n'y a pas plus de deux défaillances d'échantillons au cours de la 1re séquence: effectuer une 2e séquence avec 10 échantillons, 20 chocs par échantillon
- s'il y a plus de deux défaillances d'échantillons au cours de la 1re séquence ou une défaillance quelconque d'un échantillon au cours de la 2e séquence: résultat d'essai négatif

Évaluation de l'essai: vérification

- de l'absence de dommage mécanique par examen visuel
- de la variation de la tension de référence de ± 5 %
- de la variation de la tension résiduelle de ± 5 % au courant nominal de décharge
- de la capacité de tenue à un choc de courant de forme d'onde 8/20 d'une densité de courant de crête d'au moins 0,5 kA/cm² ou de 2 fois I_n, la valeur la plus faible étant retenue

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Figure 2 – Procédure d'essai de vérification des caractéristiques assignées de transfert de charges répétitives, Q_{rs}

Dix échantillons d'essai doivent être soumis à l'essai au cours de la première séquence. En fonction des résultats, il peut s'avérer nécessaire de soumettre à l'essai dix échantillons supplémentaires lors d'une deuxième séquence.

Les échantillons doivent satisfaire aux exigences de 8.6.1.2.

La procédure suivante doit être suivie:

a) Chaque échantillon doit être soumis à un essai de tension résiduelle au courant nominal de décharge et à un essai de tension de référence au courant de référence spécifié avant et après l'essai.

b) Chaque échantillon doit être soumis à vingt chocs de courant appliqués en dix groupes de deux chocs, avec un intervalle entre les chocs de 50 s à 60 s et un intervalle entre les groupes suffisant pour leur permettre de revenir à la température ambiante.

c) La forme d'onde et la durée des chocs de courant doivent être telles que décrites en 8.6.1.

d) La charge de chaque choc doit être au moins égale aux caractéristiques assignées de transfert de charges répétitives déclarées (choisies à partir de la liste de 8.6.1.5) multipliées par 1,1.

NOTE L'exigence relative à l'essai à au moins 1,1 fois les valeurs assignées de charge est considérée comme suffisante pour conclure que les performances des résistances MO séparées peuvent également être assignées à des parafoudres complets fabriqués à partir de ce type de résistances MO.

8.6.1.4 Évaluation de l'essai

Le résultat de l'essai complet doit être considéré comme positif si:

a) pas plus d'un échantillon a échoué au cours de la première séquence, ou

b) pas plus de deux échantillons ont échoué au cours de deux séquences.

Dans les autres cas, le résultat de l'essai est considéré comme négatif et un niveau inférieur de charge, Q_{rs}, tiré de la liste de 8.6.1.5, doit être choisi, et l'essai doit être répété pour ce niveau inférieur de charge selon la procédure de 8.6.1.3.

NOTE Si une seule défaillance se produit au cours de la première séquence et qu'elle a lieu dans le cas le plus défavorable dès la toute première application de choc, 180 chocs sans défaillance auront été appliqués à la fin de la séquence, ce qui donne une probabilité maximale de défaillance de 1/181 = 0,0056 ou de 0,56 % pour l'essai complet. Si deux défaillances se produisent au cours de la première séquence et qu'elles ont lieu à nouveau dans le cas le plus défavorable dès les premières applications sur deux des échantillons, 360 chocs sans défaillance auront été appliqués à la fin des deux séquences, ce qui donne à nouveau une probabilité maximale de défaillance de 2/362 = 0,0056 ou de 0,56 % pour l'essai complet.

Chaque échantillon séparé doit être considéré comme ayant supporté la série complète de chocs si tous les critères suivants sont remplis:

a) il n'y a aucune trace de dommage mécanique (perforation, contournement, fissure);

b) toute variation de la tension de référence avant et après l'essai, mesurée à la même température ± 3 K, est de ± 5 %;

c) toute variation de la tension résiduelle au courant nominal de décharge avant et après l'essai est de ± 5 %;

d) une application finale d'un choc de courant de forme d'onde 8/20 µs dont l'amplitude se traduit par une densité de courant d'au moins 0,5 kA/cm^2 ou de 2 fois I_n, la valeur la plus faible étant retenue, est effectuée sans dommage mécanique.

NOTE La perforation de la métallisation n'est pas considérée comme un dommage mécanique si tous les autres critères de réussite sont remplis.

8.6.1.5 Liste des valeurs assignées de charge

Les valeurs suivantes, exprimées en C, sont normalisées comme valeurs assignées de charge: 0,1; 0,2; 0,3; 0,4; 0,6; 0,8; 1; 1,2; 1,4; 1,6; 1,8; 2; 2,4; 2,8; 3,2; 3,6; 4.

Si des valeurs supérieures doivent être spécifiées, ceci doit être effectué par échelons de 0,4 C.

8.6.2 Éclateur en série

8.6.2.1 Généralités

Cet essai s'applique à l'éclateur en série pour parafoudres de ligne avec éclateur extérieur (EGLA) avec un écartement entre les éclateurs de 20 cm ou moins.

Cet essai a pour objet de vérifier la capacité de tenue aux charges répétitives de l'éclateur en série lorsqu'il est soumis à des décharges au choc de foudre. L'essai doit être effectué sur un éclateur en série d'une valeur de Q_{rs} supérieure ou égale à la valeur de Q_{rs} spécifiée pour les résistances MO du SVU.

8.6.2.2 Procédure d'essai

La Figure 3 donne un aperçu de la procédure d'essai.

Essais préliminaires • Détermination de la tension d'amorçage à 50 % de l'éclateur en série soumis à des contraintes de tension de choc de foudre pour les deux polarités. La distance de contournement la plus courte pour la conception doit être utilisée. L'essai peut être effectué sans ensemble isolateur. La tension d'amorçage à 50 % ($U_{50,\ \mathrm{EGLA\ series\ gap}}$) doit être vérifiée par la méthode de montée et descente de l'IEC 60060-1 (voir 8.4). • Pour l'application des décharges au choc de foudre, l'éclateur en série peut être intégré en série avec l'un des dix échantillons utilisés pour l'essai de 8.6.1 pour permettre de vérifier les caractéristiques assignées de transfert de charges répétitives, Q_{rs}. La distance de contournement de l'éclateur en série doit être ajustée à au moins 10 mm pour obtenir un arc.
Application de Q_{rs} • 20 chocs de décharges au choc de foudre
Post-essai • Répéter l'essai préliminaire pour déterminer la tension d'amorçage à 50 % pour les deux polarités

IEC

Figure 3 – Procédure d'essai permettant de vérifier la capacité de tenue aux charges répétitives de l'éclateur en série

8.6.2.3 Évaluation de l'essai

La tension d'amorçage à 50 % pour chaque polarité au cours du post-essai ne doit pas avoir subi de variation de plus de ± 10 % par rapport aux valeurs déterminées au cours de l'essai préliminaire.

8.7 Essais de court-circuit

8.7.1 Généralités

Le fabricant doit déclarer les caractéristiques assignées du SVU en termes de tenue en court-circuit. Les SVU doivent être soumis aux essais conformément au présent paragraphe. L'essai doit être réalisé de manière à montrer qu'une défaillance du SVU ne donne pas lieu à une rupture explosive de l'enveloppe du SVU et que l'autoextinction de flammes nues (éventuelles) se produit dans un délai défini. Chaque type de SVU est soumis à l'essai avec quatre valeurs de courants de court-circuit. Si le SVU est équipé d'un autre dispositif comme substitut d'un limiteur de pression conventionnel, ce dispositif doit être inclus dans l'essai.

La fréquence de l'alimentation du courant d'essai de court-circuit doit être comprise entre 48 Hz et 62 Hz.

En ce qui concerne les performances au courant de court-circuit, il est important de distinguer deux conceptions de SVU:

– Les SVU de «conception A» sont tels qu'un canal utilisé par le gaz suit toute la longueur de l'élément de SVU et remplit ≥ 50 % du volume interne non occupé par les parties actives internes.
– Les SVU de «conception B» sont solides et sans volume interne de gaz ou ont un volume de gaz interne remplissant < 50 % du volume interne non occupé par les parties actives internes.

NOTE 1 En règle générale, les SVU de «conception A» sont des SVU à enveloppe en porcelaine ou en polymère avec un isolateur creux composite, équipés soit de limiteurs de pression soit de points faibles préfabriqués dans l'enveloppe composite qui éclatent ou s'ouvrent à une pression spécifiée, ce qui fait baisser la pression interne.

En règle générale, les SVU de «conception B» ne sont pas équipés de limiteur de pression et sont solides sans volume interne de gaz. Si les résistances connaissent une défaillance électrique, il se produit un arc à l'intérieur du SVU. Cet arc provoque une évaporation importante et éventuellement la combustion de l'enveloppe et/ou du matériau interne. Ces performances de tenue aux courts-circuits des SVU sont déterminées par leur capacité à contrôler l'éclatement ou le déchirement de l'enveloppe dû aux effets de l'arc, évitant ainsi une rupture explosive.

NOTE 2 Dans ce contexte, les «parties actives» sont les résistances non linéaires à oxyde métallique et les éventuelles entretoises métalliques directement connectées en série avec elles.

En fonction du type de SVU et de la tension d'essai, des exigences différentes s'appliquent concernant le nombre d'échantillons d'essai, le début du passage du courant de court-circuit et l'amplitude de la première valeur de crête du courant de court-circuit. Le Tableau 4 donne un résumé de ces exigences qui sont expliquées plus en détail dans les paragraphes suivants.

8.7.2 Préparation des échantillons d'essai

8.7.2.1 Généralités

Pour les essais à courant de forte amplitude, les échantillons d'essai doivent être constitués par l'élément de SVU le plus long utilisé pour la conception avec la tension assignée la plus élevée de cet élément utilisé pour chaque conception de SVU différente.

Pour l'essai à courant de faible amplitude, l'échantillon d'essai doit être constitué par un élément de SVU de toute longueur avec la tension assignée la plus élevée de cet élément utilisé pour chaque conception de SVU différente.

La Figure 4 représente différents exemples d'éléments de SVU.

Lorsqu'un fil fusible est exigé, le matériau de ce fil fusible et ses dimensions doivent être choisis de façon à ce que le fil fonde dans les 30 premiers degrés électriques après le début de l'application du courant d'essai.

Pour que le fil fusible fonde dans les limites de temps spécifiées et qu'il crée une condition appropriée à l'amorçage de l'arc, il est généralement recommandé d'utiliser un fil fusible avec un matériau à faible résistance (par exemple cuivre, aluminium ou argent) d'un diamètre d'environ 0,2 mm à 0,5 mm. Des sections de fil fusible plus importantes sont applicables aux éléments de SVU préparés pour des courants d'essai de court-circuit plus élevés. Lorsqu'il y a des difficultés pour amorcer l'arc, un fil fusible de dimensions plus importantes, mais d'un diamètre inférieur à 1,5 mm, peut être utilisé dans la mesure où il contribue à l'établissement de l'arc. Dans de tels cas, un fil fusible spécialement préparé, ayant une section plus importante sur la plus grande partie de la hauteur du SVU avec une courte section plus mince au milieu, peut également aider.

8.7.2.2 SVU de «conception A»

Les échantillons doivent être préparés avec des moyens pour conduire le courant de court-circuit exigé en utilisant un fil fusible. Le fil fusible doit être en contact direct avec les résistances MO et il doit être positionné à l'intérieur ou aussi près que possible du canal utilisé par le gaz et il doit court-circuiter la partie active interne complète. L'emplacement réel du fil fusible au cours de l'essai doit être consigné dans le rapport d'essai.

Il n'est pas fait de différence entre les enveloppes en polymère et celles en porcelaine dans la préparation des échantillons d'essai. Toutefois, des différences s'appliquent partiellement dans la procédure d'essai (voir 8.7.4.3). Dans ce cas, les SVU de «conception A» avec des ailettes polymères qui ne sont pas en porcelaine ou avec d'autres isolateurs creux et qui sont aussi fragiles que la céramique, doivent être pris en compte et soumis aux essais comme des SVU sous enveloppe en porcelaine.

8.7.2.3 SVU de «Conception B»

8.7.2.3.1 Généralités

Les SVU de «conception B» avec des ailettes polymères qui ne sont pas en porcelaine ou avec d'autres structures de support mécanique et qui sont aussi fragiles que la céramique, doivent être pris en compte et soumis aux essais comme des SVU sous enveloppe en porcelaine.

8.7.2.3.2 SVU à enveloppe en polymère

Aucune préparation spéciale n'est nécessaire. Des éléments de SVU normaux doivent être utilisés. Les éléments de SVU doivent être électriquement prédégradés par l'application d'une surtension à fréquence industrielle. La surtension doit être appliquée à des éléments d'essai complètement assemblés. Aucune modification physique ne doit être apportée aux éléments entre la prédégradation et l'essai au courant de court-circuit réel.

Il convient que la surtension donnée par le fabricant soit une tension supérieure à la tension de référence. Elle doit entraîner la défaillance du SVU en l'espace de (5 ± 3) min. Les résistances sont considérées comme ayant subi une défaillance lorsque la tension qui les traverse tombe en dessous de 10 % de la tension appliquée au départ. Le courant de court-circuit du circuit d'essai de prédégradation ne doit pas être supérieur à 30 A.

Le délai entre la prédégradation et l'essai de court-circuit assigné ne doit pas dépasser 15 min.

NOTE La prédégradation peut être obtenue en appliquant soit une source de tension soit une source de courant aux échantillons:

– Méthode avec la source de tension: Il convient que le courant initial soit normalement compris entre 5 mA/cm^2 et 10 mA/cm^2. Il convient que le courant de court-circuit soit normalement compris entre 1 A et 30 A. La source de tension n'a pas besoin d'être ajustée après son réglage initial, bien que de petits réglages puissent être nécessaires pour dégrader les résistances dans le délai imparti.

– Méthode avec la source de courant: Normalement, une densité de courant d'environ 15 mA/cm^2 avec une variation de ± 50 %, provoque une défaillance des résistances dans le délai imparti. Il convient que le courant de court-circuit soit normalement compris entre 10 A et 30 A. La source de courant n'a pas besoin d'être ajustée après son réglage initial, bien que de petits réglages puissent être nécessaires pour dégrader les résistances dans le délai imparti.

8.7.2.3.3 SVU à enveloppe en porcelaine

Les échantillons doivent être préparés avec des moyens pour conduire le courant de court-circuit exigé en utilisant un fil fusible. Le fil fusible doit être en contact direct avec les résistances MO et il doit être situé aussi loin que possible du canal utilisé par le gaz et il doit court-circuiter la partie active interne complète. L'emplacement réel du fil fusible au cours de l'essai doit être consigné dans le rapport d'essai.

8.7.3 Montage de l'échantillon d'essai

Les éléments de SVU à soumettre aux essais peuvent être soit montés directement sur une embase conformément aux dispositifs représentés à la Figure 5a et à la Figure 5b, soit suspendus conformément aux recommandations d'installation du fabricant. Le choix de l'installation d'essai est à la discrétion du fabricant. En cas de montage suspendu, l'extrémité inférieure du SVU doit être à la même hauteur que le bord supérieur de l'enveloppe circulaire.

Pour un SVU monté sur embase, le dispositif de montage est représenté à la Figure 5a et à la Figure 5b. La distance entre le sol et la plate-forme isolante et les conducteurs doit être comme représentée à la Figure 5a et à la Figure 5b.

Pour les SVU qui ne sont pas montés sur embase (par exemple SVU montés sur poteau), l'échantillon d'essai doit être monté sur un poteau non métallique en utilisant des consoles de montage et des dispositifs normalement utilisés pour leur installation en service. Pour les