BS EN 60700-1:2015

BSI Standards Publication

Thyristor valves for high voltage direct current (HVDC) power transmission

Part 1: Electrical testing

National foreword

This British Standard is the UK implementation of EN 60700-1:2015. It is identical to IEC 60700-1:2015. It supersedes BS EN 60700-1:1998+A2:2008, which will be withdrawn on 1 September 2018.

The UK participation in its preparation was entrusted to Technical Committee PEL/22, Power electronics.

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

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Thyristor valves for high voltage direct current (HVDC) power transmission - Part 1: Electrical testing (IEC 60700-1:2015)

Valves à thyristors pour le transport d'énergie en courant continu à haute tension (CCHT) - Partie 1: Essais électriques (IEC 60700-1:2015)

Thyristorventile für Hochspannungsgleichstrom-Energieübertragung (HGÜ) - Teil 1: Elektrische Prüfung (IEC 60700-1:2015)

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

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European foreword

The text of document 22F/341/CDV, future edition 2 of IEC 60700-1, prepared by SC 22F "Power electronics for electrical transmission and distribution systems" of IEC/TC 22 "Power electronic systems and equipment" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 60700-1:2015.

The following dates are fixed:

• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2016-06-01
• latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2018-09-01

This document supersedes EN 60700-1:1998.

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Endorsement notice

The text of the International Standard IEC 60700-1:2015 was approved by CENELEC as a European Standard without any modification.

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

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

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

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

Publication	Year	Title	EN/HD	Year
IEC 60060	Series	High-voltage test techniques	EN 60060	Series
IEC 60060-1	-	High-voltage test techniques - Part 1: General definitions and test requirements	EN 60060-1	-
IEC 60071-1	-	Insulation co-ordination - Part 1: Definitions, principles and rules	EN 60071-1	-
IEC 60099	Series	Surge arresters	EN 60099	Series
IEC 60270	-	High-voltage test techniques - Partial discharge measurements	EN 60270	-
IEC 61803 +A1	1999 2010	Determination of power losses in high-voltage direct current (HVDC) converter stations	EN 61803 +A1	1999 2010
ISO/IEC Guide 25 [1)]	-	General requirements for the competence of calibration and testing laboratories	-	-

[1)] Withdrawn publication.

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

THYRISTOR VALVES FOR HIGH VOLTAGE DIRECT CURRENT (HVDC) POWER TRANSMISSION –

Part 1: Electrical testing

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 60700-1 has been prepared by subcommittee 22F: Power electronics for electrical transmission and distribution systems, of IEC technical committee 22: Power electronic systems and equipment.

This second edition cancels and replaces the first edition published in 1998, its Amendment 1:2003 and its Amendment 2: 2008. This edition constitutes a technical revision.

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

a) Definitions of terms "redundant thyristor levels", "thyristor level", "valve section" have been changed for clarification.
b) The notes were added to test requirements of dielectric d.c. voltage tests for valve support, MVU, valve, specifying that before repeating the test with opposite polarity, the tested

object may be short-circuited and earthed for several hours. The same procedure may be followed at the end of the d.c. voltage test.

c) Table 1 on thyristor level faults permitted during type tests was supplemented.

d) The alternative MVU dielectric test method was added.

e) It was specified that production tests may include routine tests as well as sample tests.

f) It was added into test requirements for periodic firing and extinction tests that a scaling factor for tests shall be applied when testing with valve sections.

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

CDV	Report on voting
22F/341/CDV	22F/351A/RVC

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

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

A list of all parts in the IEC 60700 series, published under the general title *Thyristor valves for high voltage direct current (HVDC) power transmission*, can be found on the IEC website.

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

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

THYRISTOR VALVES FOR HIGH VOLTAGE DIRECT CURRENT (HVDC) POWER TRANSMISSION –

Part 1: Electrical testing

1 Scope

This part of IEC 60700 applies to thyristor valves with metal oxide surge arresters directly connected between the valve terminals, for use in a line commutated converter for high voltage d.c. power transmission or as part of a back-to-back link. It is restricted to electrical type and production tests.

The tests specified in this standard are based on air insulated valves. For other types of valves, the test requirements and acceptance criteria can be agreed.

2 Normative references

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

IEC 60060, *High-voltage test techniques*

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

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

IEC 60099 (all parts), *Surge arresters*

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

IEC 61803:1999, *Determination of power losses in high-voltage direct current (HVDC) converter stations*
IEC 61803:1999/AMD 1:2010[1]

ISO/IEC Guide 25, *General requirements for the technical competence of testing laboratories*[2]

3 Terms and definitions

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

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1 There exists a consolidated edition 1.1 (2011) that comprises IEC 61803:1999 and its Amendment 1:2010.

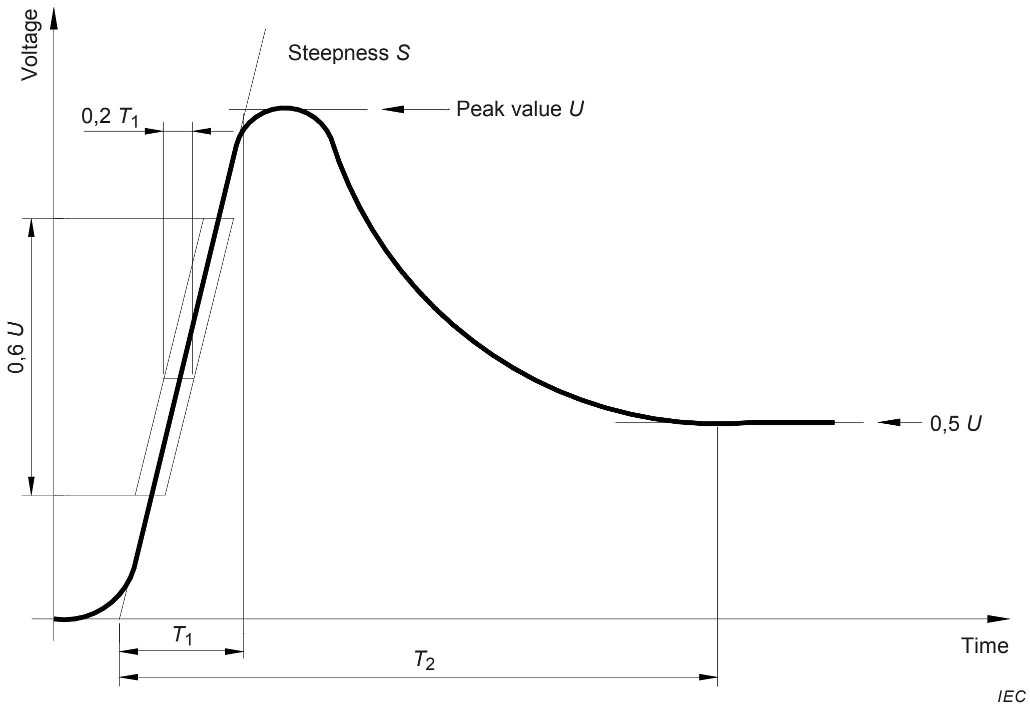
2 Withdrawn.

3.1 Insulation co-ordination terms

3.1.1
test withstand voltage
value of a test voltage of standard waveshape at which a new valve, with unimpaired integrity, does not show any disruptive discharge and meets all other acceptance criteria specified for the particular test, when subjected to a specified number of applications or a specified duration of the test voltage, under specified conditions

3.1.2
steep front impulse
fast-front voltage impulse whose time to peak is less than that of a standard lightning impulse but not less than that of a very-fast-front voltage as defined in IEC 60071-1

Note 1 to entry: For this standard, the steep front impulse voltage for test purposes is as shown in Figure 1.



Key

U specified peak value of steep front impulse test voltage (kV)

S specified steepness of steep front impulse test voltage (kV/μs)

T_1 virtual front time = $\frac{U}{S}$ (μs)

The following conditions shall be satisfied:

a) The peak value of the recorded test voltage shall be $U \pm 3$ %. This tolerance is the same as that in IEC 60060 for standard lightning impulse.

b) Over a voltage excursion of not less than 0,6 *U*, the rising portion of the recorded test voltage shall be entirely contained between two parallel lines of steepness *S* and separation 0,2 T_1.

c) The value of the test voltage at T_2 shall not be lower than 0,5 *U*. T_2 is defined as the time interval between the origin and the instant when the voltage has decreased to half the peak value of the waveform which is obtained from system study. However, it shall be assured that an unintentional d*u*/d*t* switching of the thyristors can be adequately detected.

Figure 1 – Steep front impulse test voltage

3.1.3
internal and external insulation
air external to the components and insulating materials of the valve, but contained within the profile of the valve or multiple valve unit is considered as part of the internal insulation system of the valve

Note 1 to entry: The external insulation is the air between the external surface of the valve or multiple valve unit and its surroundings.

3.1.4
valve protective firing
means of protecting the thyristors from excessive voltage by firing them at a predetermined voltage

3.2 Valve construction terms

3.2.1
valve support
that part of the valve which mechanically supports and electrically insulates from earth the active part of the valve which houses the valve sections

Note 1 to entry: A part of a valve which is clearly identifiable in a discrete form to be a valve support may not exist in all designs of valves.

3.2.2
valve structure
physical structure holding the thyristor levels of a valve which is insulated to the appropriate voltage above earth potential

3.2.3
redundant thyristor levels
maximum number of thyristor levels in a thyristor valve that may be short-circuited externally or internally during service without affecting the safe operation of the thyristor valve as demonstrated by type tests, and which if and when exceeded, would require shutdown of the converter to replace the failed thyristors or acceptance of increased risk of failures

3.2.4
valve base electronics
electronic unit, at earth potential, which is the interface between the control system for the converter and the thyristor valves

3.2.5
thyristor level
part of a thyristor valve comprising a thyristor, or thyristors connected in parallel, together with their immediate auxiliaries, and reactor, if any

3.2.6
valve section
electrical assembly, comprising a number of thyristors and other components, which exhibits pro-rated electrical properties of a complete valve

3.2.7
multiple valve unit
MVU
single physical structure comprising more than one valve with a common mechanical support structure

3.3 Terms related to type tests

NOTE Those tests which are carried out to verify that the valve design will meet the requirements specified. In this standard, type tests are classified under two major categories: dielectric tests and operational tests.

3.3.1
dielectric tests
tests which are carried out to verify the high voltage characteristics of the valve

3.3.2
operational tests
tests which are carried out to verify the turn-on, turn-off and current related characteristics of the valve

3.4 Terms related to production tests

NOTE Those tests which are carried out to verify proper manufacture, so that the properties of a valve correspond to those specified.

3.4.1
routine tests
production tests which are carried out on all valves, valve sections or components

3.4.2
sample tests
production tests which are carried out on a small number of valves, valve sections or components taken at random from a batch

4 General requirements

4.1 Guidelines for the performance of type tests

4.1.1 Evidence in lieu

Each design of valve shall be subjected to the type tests specified in this standard. If the valve is demonstrably similar to one previously tested, the supplier may, in lieu of performing a type test, submit a test report of a previous type test for consideration by the purchaser. This should be accompanied by a separate report detailing the differences in the design and demonstrating how the referenced type test satisfies the test objectives for the proposed design.

4.1.2 Test object

Test object should meet the following requirements:

a) Certain type tests may be performed either on a complete valve or on valve sections, as indicated in Table 2. For those type tests on valve sections, the total number of valve sections tested shall be at least as many as the number in a complete valve.
b) The same valve sections shall be used for all type tests unless otherwise stated.
c) Prior to commencement of type tests, the valve, valve sections and/or the components of them should be demonstrated to have withstood the production tests to ensure proper manufacture.

4.1.3 Sequence of tests

The type tests specified can be carried out in any order.

NOTE Tests involving partial discharge measurement can provide added confidence if performed at the end of the dielectric type test programme.

4.1.4 Test procedures

The tests shall be performed in accordance with IEC 60060, where applicable. The competence of testing and calibration laboratories should correspond to the ISO/IEC Guide 17025.

4.1.5 Ambient temperature for testing

The tests shall be performed at the prevailing ambient temperature of the test facility, unless otherwise specified.

4.1.6 Frequency for testing

AC dielectric tests can be performed at either 50 Hz or 60 Hz. For operational tests, specific requirements regarding the frequency for testing are given in the relevant clauses.

4.1.7 Test reports

At the completion of the type tests, the supplier shall provide type test reports in accordance with Clause 16.

4.2 Atmospheric correction

When specified in the relevant clause, atmospheric correction shall be applied to the test voltages in accordance with IEC 60060-1. The reference conditions to which correction shall be made are the following.

– Pressure:

  a) If the insulation coordination of the tested part of the thyristor valve is based on standard rated withstand voltages according to IEC 60071-1, correction factors are only applied for altitudes exceeding 1 000 m. Hence, if the altitude of the site a_s at which the equipment will be installed is ≤1 000 m, then the standard atmospheric air pressure (b_0 = 101,3 kPa) shall be used with no correction for altitude. If a_s >1 000 m, then the standard procedure according to IEC 60060-1 is used except that the reference atmospheric pressure b_0 is replaced by the atmospheric pressure corresponding to an altitude of 1 000 m ($b_{1\,000\ m}$);
  b) If the insulation coordination of the tested part of the thyristor valve is not based on standard rated withstand voltages according to IEC 60071-1, then the standard procedure according to IEC 60060-1 is used with the reference atmospheric pressure b_0 (b_0=101,3 kPa);

– Temperature: design maximum valve hall air temperature (°C).;

– Humidity: design minimum valve hall absolute humidity (g/m^3).

The values to be used shall be specified by the supplier.

4.3 Treatment of redundancy

4.3.1 Dielectric tests

For all dielectric tests between valve terminals, the redundant thyristor levels shall be short circuited, with the possible exception of the valve non-periodic firing test (see 8.4). The location of thyristor levels to be short circuited shall be agreed by the purchaser and supplier.

NOTE Depending on the design, limitations can be imposed upon the distribution of short-circuited thyristor levels. For example, there may be an upper limit to the number of short-circuited thyristor levels in one valve section.

4.3.2 Operational tests

For operational tests, redundant thyristor levels shall not be short circuited. The test voltages used shall be adjusted by means of a scaling factor k_n:

$$k_n = \frac{N_{tut}}{N_t - N_r}$$

where

N_{tut} is the number of series thyristor levels in the test object;

N_t is the total number of series thyristor levels in the valve;

N_r is the total number of redundant series thyristor levels in the valve.

4.4 Criteria for successful type testing

4.4.1 General

Experience in industry shows that, even with the most careful design of valves, it is not possible to avoid occasional random failures of thyristor level components during service operation. Even though these failures may be stress-related, they are considered random to the extent that the cause of failure or the relationship between failure rate and stress cannot be predicted or is not amenable to precise quantitative definition. Type tests subject valves or valve sections, within a short time, to multiple stresses that generally correspond to the worst stresses that can be experienced by the equipment not more than a few times during the life of the valve. Considering the above, the criteria for successful type testing set out below therefore permit a small number of thyristor levels to fail during type testing, providing that the failures are rare and do not show any pattern that is indicative of inadequate design.

4.4.2 Criteria applicable to thyristor levels

The following criteria are applicable to thyristor levels:

a) If, following a type test as listed in Clause 5, more than one thyristor level (alternatively more than 1 % of the series-connected thyristor levels in a complete valve, if greater) has become short circuited, then the valve shall be deemed to have failed the type tests.

b) If, following a type test, one thyristor level (or more if still within the 1 % limit) has become short circuited, then the failed level(s) shall be restored and this type test repeated.

c) If the cumulative number of short-circuited thyristor levels during all type tests is more than 3 % of the series-connected thyristor levels in a complete valve, then the valve shall be deemed to have failed the type test programme.

d) When type tests are performed on valve sections, the criteria for acceptance above also apply since the number of valve sections tested shall be not less than the number of sections in a complete valve (see 4.1.2 a)).

e) The valve or valve sections shall be checked after each type test to determine whether or not any thyristor levels have become short-circuited. Failed thyristors or auxiliary components found during or at the end of a type test may be replaced before further testing.

f) At the completion of the test programme, the valve or valve sections shall undergo a series of check tests, which shall include as a minimum:
   - check for voltage withstand of thyristor levels in both forward and reverse direction;
   - check of the gating circuits where applicable;
   - check of the monitoring circuits;
   - check of the thyristor level protection circuits by application of transient voltages above and below the protection setting(s) where applicable;
   - check of the voltage grading circuits.

g) Thyristor level short circuits occurring during the check tests shall be counted as part of the criteria for acceptance defined above. In addition to short-circuited levels, the total number of thyristor levels exhibiting faults which do not result in thyristor level short circuit, which are discovered during the type test programme and the subsequent check tests, shall not exceed 3 % of the series-connected thyristor levels in a complete valve. If the total number of such levels exceeds 3 %, then the nature of the faults and their cause shall be reviewed and additional action, if any, agreed between purchaser and supplier.

h) When applying the percentage criteria to determine the permitted maximum number of short-circuited thyristor levels and the permitted maximum number of levels with faults which have not resulted in a thyristor level becoming short-circuited, it is usual practice to round off all fractions to the next highest integer, as illustrated in Table 1.

Table 1 – Thyristor level faults permitted during type tests

Number of thyristor levels in a complete valve minus the number of redundant levels ($N_t - N_r$)	Number of thyristor levels permitted to become short-circuited in any one type test	Total number of thyristor levels permitted to become short-circuited in all type tests	Additional number of thyristor levels, in all type tests, which have experienced a fault but have not become short-circuited
Up to 33	1	1	1
34 to 67	1	2	2
68 to 100	1	3	3
101 to 133	2	4	4
etc.			

The distribution of short-circuited levels and of other thyristor level faults at the end of all type tests shall be essentially random and not show any pattern that may be indicative of inadequate design.

4.4.3 Criteria applicable to the valve as a whole

Breakdown of or external flashover across common electrical equipment associated with more than one thyristor level of the valve, or disruptive discharge in dielectric material forming part of the valve structure, cooling ducts, light guides or other insulating parts of the pulse transmission and distribution system shall not be permitted.

Component and conductor surface temperatures, together with associated current-carrying joints and connections, and the temperature of adjacent mounting surfaces shall at all times remain within limits permitted by the design.

5 List of type tests

Table 2 below lists the type tests given in Clauses 6 to 13.

Table 2 – List of type tests

Type test	Clause or subclause	Test object
Valve support d.c. voltage test	6.3.2	Valve support
Valve support a.c. voltage test	6.3.3	Valve support
Valve support switching impulse test	6.3.4	Valve support
Valve support lightning impulse test	6.3.5	Valve support
MVU d.c. voltage test to earth	7.3.1	MVU
MVU a.c. voltage test	7.3.2	MVU
MVU switching impulse test	7.3.3	MVU
MVU lightning impulse test	7.3.4	MVU
Valve d.c. voltage test	8.3.1	Valve
Valve a.c. voltage test	8.3.2	Valve
Valve switching impulse test	8.3.4	Valve
Valve lightning impulse test	8.3.5	Valve
Valve steep front impulse test	8.3.6	Valve
Valve non-periodic firing test	8.4	Valve
Maximum continuous operating duty tests	9.3.2	Valve or valve-section
Maximum temporary operating duty test (α = 90°)	9.3.3	Valve or valve-section
Minimum a.c. voltage tests	9.3.4	Valve or valve-section
Temporary undervoltage test	9.3.5	Valve or valve-section
Intermittent direct current tests	9.3.6	Valve or valve-section
Tests with transient forward voltage during the recovery period	10	Valve or valve-section
One-loop fault current test with re-applied forward voltage	11.3.2	Valve or valve-section
Multiple-loop fault current test without re-applied forward voltage	11.3.3	Valve or valve-section
Tests for valve insensitivity to electromagnetic disturbance	12	Valve or valve-section
Testing of special features and fault tolerance	13	Valve or valve-section

6 Dielectric tests on valve support

6.1 Purpose of tests

The principal objectives of these tests are:

a) to verify the voltage withstand capability of the insulation of the valve support, cooling ducts, light guides and other insulating components associated with the valve support. If there is insulation to earth other than the valve support then additional tests may be necessary.

b) to verify that the partial discharge inception and extinction voltages are above the maximum operating voltage appearing on the valve support.

NOTE Depending upon the application, it can be possible to eliminate some of the tests on the valve support, subject to agreement between purchaser and supplier.

6.2 Test object

The valve support to be used for the tests may be a representative separate object including representation of the adjacent parts of the valve, or may form part of the assembly used for single valve or multiple valve unit tests. It shall be assembled with all ancillary components in place and shall have the adjacent earth potential surfaces properly represented. The coolant shall be in a condition representative of the most onerous service condition for the purpose of the test.

6.3 Test requirements

6.3.1 General

All test levels given below are subject to atmospheric correction as described in 4.2.

6.3.2 Valve support d.c. voltage test

The two main terminals of the valve or the MVU shall be connected together and the d.c. voltage then applied between the two main terminals thus connected and earth. Starting from a voltage not higher than 50 % of the maximum test voltage, the voltage shall be raised to the specified 1 min test voltage in approximately 10 s, kept constant for 1 min, reduced to the specified 3 h test voltage, kept constant for 3 h and then reduced to zero. During the last hour of the specified 3 h test, the number of partial discharges exceeding 300 pC shall be recorded as described in Annex B.

The number of pulses exceeding 300 pC shall not exceed 15 pulses per minute, averaged over the recording period. Of these, no more than seven pulses per minute shall exceed 500 pC, no more than three pulses per minute shall exceed 1 000 pC and no more than one pulse per minute shall exceed 2 000 pC.

NOTE 1 If an increasing trend in the magnitude or rate of partial discharge is observed the test duration can be extended by mutual agreement between the purchaser and supplier.

The test shall then be repeated with the voltage of opposite polarity.

NOTE 2 Before repeating the test with opposite polarity, the valve support may be short-circuited and earthed for several hours. The same procedure may be followed at the end of the d.c. voltage test.

The valve support d.c. test voltage U_{tds} shall be determined in accordance with the following:

$$U_{tds} = \pm U_{dmS} \times k_1 \times k_t$$

where

U_{dmS} is the maximum value of the d.c. component of the steady-state operating voltage appearing across the valve support;

k_1 is a test safety factor, equaling 1,6 for the 1 min test and 1,3 for the 3 h test;

k_t is the atmospheric correction factor, equaling the value according to 4.2 for the 1 min test and 1,0 for the 3 h test.

6.3.3 Valve support a.c. voltage test

To perform the test, the two main terminals of the valve or the MVU shall be connected together, and the a.c. test voltage then applied between the two main terminals thus connected and earth. Starting from a voltage not higher than 50 % of the maximum test voltage, the voltage shall be raised to the specified 1 min test voltage U_{tas1} within approximately 10 s, kept constant for 1 min, reduced to the specified 30 min test voltage U_{tas2}, kept constant for 30 min and then reduced to zero. During the last 1 min of the specified 30 min test, the level of partial discharge shall be monitored and recorded. If the value of partial discharge is below 200 pC, the design may be accepted unconditionally. If the value of partial discharge exceeds 200 pC, the test results shall be evaluated (see Clause B.4).

The r.m.s. value of the valve support a.c. test voltage U_{tas} shall be determined in accordance with the following:

$$U_{tas} = \frac{U_{ms}}{\sqrt{2}} \times k_2 \times k_t \times k_r$$

where

U_{ms} is the peak value of the maximum repetitive operating voltage across the valve support during steady-state operation, including commutation overshoot;

U_{tas1} is the 1 min test voltage;

U_{tas2} is the 30 min test voltage;

k_2 is a test safety factor equaling 1,3 for the 1 min test and 1,15 for the 30 min test;

k_t is the atmospheric correction factor equaling the value according to 4.2 for the 1 min test and 1,0 for the 30 min test;

k_r is the temporary overvoltage factor equaling the value determined from system studies for the 1 min test and 1,0 for the 30 min test.

6.3.4 Valve support switching impulse test

The test shall comprise three applications of positive polarity and three applications of negative polarity switching impulse voltages between the main terminals, which are in common, and earth.

A standard switching impulse voltage waveshape in accordance with IEC 60060 shall be used.

The test voltage shall be selected in accordance with the insulation co-ordination of the HVDC substation.

6.3.5 Valve support lightning impulse test

The test shall comprise three applications of positive polarity and three applications of negative polarity lightning impulse voltages between the main terminals, which are in common, and earth.

A standard lightning impulse voltage waveshape in accordance with IEC 60060 shall be used.

The test voltage shall be selected in accordance with the insulation co-ordination of the HVDC substation.

NOTE If new insulating materials without proven service experience are employed, consideration is given to an additional steep front impulse test.

7 Dielectric tests for multiple valve units (MVU)

7.1 Purpose of tests

The principal objectives of these tests are:

a) to verify the voltage withstand capability of the external insulation of the MVU, with respect to its surroundings, especially for the valve/MVU connected at pole potential;
b) to verify the voltage withstand capability between single valves in a MVU structure;
c) to verify that the partial discharge levels are within specified limits.

NOTE Depending upon the application, it can be possible to eliminate some of the tests on the MVU, subject to agreement between purchaser and supplier.

7.2 Test object

There are many possible arrangements of valves and multiple valve units. The test object(s) shall be chosen to reflect, as accurately as possible, the service configuration of valves insofar as is necessary for the test in question. The test object shall be fully equipped unless it can be shown that some components can be simulated or omitted without reducing the significance of the results.

Individual valves may have to be short-circuited depending on the configuration of the MVU and the objectives of the test. As an example, for the most common arrangement of four identical, vertically stacked valves (quadruple valve), one valve should be short-circuited in the position which results in the most onerous conditions.

When the low-voltage terminal of the MVU is not connected at d.c. neutral potential, care shall be taken to suitably terminate the low voltage terminal of the MVU during tests to correctly simulate the voltage appearing at this terminal. Earth planes shall be used, whose separation shall be determined by the proximity of other valves or MVU and earth potential surfaces.

NOTE When the low voltage terminal of the MVU is not connected at d.c. neutral potential, the following test method can be used as an alternative provided that the voltage withstand capability between the inner parts of a MVU is checked adequately during other tests (e.g. the tests between the valve terminals) and the MVU low voltage terminal is capable of withstanding the increased voltage stress. In this case the MVU dielectric tests could be performed on a short-circuited MVU.

The test voltage is applied between the MVU with its terminal short-circuited and earth.

7.3 Test requirements

7.3.1 MVU d.c. voltage test to earth

The d.c. test voltage shall be applied between the highest potential d.c. terminal of the MVU and earth.

Starting from a voltage not higher than 50 % of the maximum test voltage, the voltage shall be raised to the specified 1 min test voltage in approximately 10 s, kept constant for 1 min, reduced to the specified 3 h test voltage, kept constant for 3 h and then reduced to zero.

During the last hour of the specified 3 h test, the number of partial discharges exceeding 300 pC shall be recorded as defined in Annex B.

The number of pulses exceeding 300 pC shall not exceed 15 pulses per minute, averaged over the recording period. Of these, no more than seven pulses per minute shall exceed 500 pC, no more than three pulses per minute shall exceed 1 000 pC, and no more than one pulse per minute shall exceed 2 000 pC.

NOTE 1 If an increasing trend in the magnitude or rate of partial discharge is observed, the test duration can be extended by mutual agreement between the purchaser and supplier.

The test shall then be repeated with the voltage of opposite polarity.

NOTE 2 Before repeating the test with opposite polarity, the MVU can be short-circuited and earthed for several hours. The same procedure can be followed at the end of d.c. voltage test.

The MVU d.c. test voltage U_{tdm} shall be determined in accordance with the following:

$$U_{tdm} = \pm U_{dmm}\, k_3 \times k_t$$

where

U_{dmm} is the maximum value of the d.c. component of the steady-state operating voltage appearing between the high-voltage terminal of the MVU and earth;

k_3 is a test safety factor;

k_3 = 1,6 for the 1 min test;

k_3 = 1,3 for the 3 h test;

k_t is the atmospheric correction factor;

k_t is the value according to 4.2 for the 1 min test;

k_t = 1,0 for the 3 h test.

7.3.2 MVU a.c. voltage test

If a MVU experiences a.c. or composite a.c. plus d.c. voltage stresses between any two terminals, the withstand capability of which is not adequately demonstrated by other tests, then it will be necessary to perform an a.c. voltage test between these terminals of the MVU.

To perform the test, the test voltage source shall be connected to the pair of MVU terminals in question. The point of earth connection is dependent on the test circuit arrangement.

Starting from a voltage not higher than 50 % of the 1 min test voltage, the voltage shall be raised to the specified 1 min test voltage in approximately 10 s, kept constant for 1 min, then reduced to the 30 min value, kept constant for 30 min and then reduced to zero.

During the last 1 min of the specified 30 min test, the level of partial discharge shall be monitored and recorded. If the value of partial discharge is below 200 pC, the design may be accepted unconditionally. If the value of partial discharge exceeds 200 pC, the test results shall be evaluated (see Clause B.4).

The r.m.s. value of the MVU a.c. test voltage U_{tam} shall be determined in accordance with the following:

$$U_{tam} = \frac{U_{mm}}{\sqrt{2}} \times k_4 \times k_r \times k_t$$

where

U_{mm} is the peak value of the maximum repetitive operating voltage appearing between the terminals of the MVU during steady-state operation, including commutation overshoot;

k_4 is a test safety factor;

k_4 = 1,3 for the 1 min test;

k_4 = 1,15 for the 30 min test;

k_r is the temporary overvoltage factor;

k_r is the value determined from system studies for the 1 min test;

k_r = 1,0 for the 30 min test;

k_t is the atmospheric correction factor;

k_t is the value according to 4.2 for the 1 min test;

k_t = 1,0 for the 30 min test.

7.3.3 MVU switching impulse test

A standard switching impulse voltage waveshape in accordance with IEC 60060 shall be used.

The MVU switching impulse test voltage shall be applied between the high voltage terminal of the MVU and earth.

The test shall comprise three applications of positive polarity and three applications of negative polarity switching impulse voltage of a specified amplitude.

The MVU switching impulse test voltage U_{tsm} shall be determined in accordance with the following:

$$U_{tsm} = SIPL_m \times k_5 \times k_t$$

where

$SIPL_m$ is the switching impulse protective level determined by insulation coordination taking into account the arrester(s) connected between the MVU high voltage terminal and earth;

k_5 is a test safety factor;

k_5 = 1,15;

k_t is the atmospheric correction factor;

k_t is the value according to 4.2.

If the test prescribed above does not adequately test the switching impulse withstand between all terminals of the MVU, then consideration shall be given to performing extra tests to check the insulation.

NOTE Subject to agreement between the purchaser and supplier, the MVU switching impulse test cannot be performed if it can be shown by other means that:

a) the external air clearances to other valves and to earth are adequate for the switching impulse voltage withstand level required, and

b) the switching impulse withstand between any two terminals of the MVU is adequately demonstrated by other tests.

7.3.4 MVU lightning impulse test

A standard lightning impulse voltage waveshape in accordance with IEC 60060 shall be used.

The MVU lightning impulse test voltage shall be applied between the high voltage terminal of the MVU and earth.

The test shall comprise three applications of positive polarity and three applications of negative polarity lightning impulse voltage of specified amplitude.

The MVU lightning impulse test voltage U_{tlm} shall be determined in accordance with the following:

$$U_{tlm} = \pm LIPL_m \times k_6 \times k_t$$

where

$LIPL_m$ is the lightning impulse protective level determined by insulation co-ordination, taking into account the arrester(s) connected between the MVU high voltage terminal and earth;

k_6 is a test safety factor;

k_6 is 1,15;

k_t is the atmospheric correction factor;

k_t is the value according to 4.2.

If it cannot be demonstrated that the test prescribed above adequately tests the lightning impulse withstand voltage between all terminals of the MVU, then consideration shall be given to performing extra tests to check this insulation.

NOTE 1 Subject to agreement between the purchaser and supplier, the MVU lightning impulse test can be performed if it can be shown by other means that:

a) the external air clearances to other valves and to earth are adequate for the lightning impulse voltage withstand level required, and

b) the lightning impulse withstand voltage between any two terminals of the MVU is adequately demonstrated by other tests.

NOTE 2 In some circumstances, consideration is given to a separate steep front impulse voltage test in order to supplement the valve steep front impulse test (see 8.3.6).

8 Dielectric tests between valve terminals

8.1 Purpose of tests

These tests are intended to verify the design of the valve regarding its voltage-related characteristics for various types of overvoltages (d.c., a.c., switching impulse, lightning impulse and steep-front impulse overvoltages). The tests should demonstrate that:

a) the valve will withstand the specified overvoltages;

b) any internal overvoltage protective circuits are effective;

c) partial discharges will be within specified limits under specified test conditions;

d) the internal d.c. grading circuits have sufficient power rating;

e) the valve electronic circuits are immune to interference and function correctly;

f) the valve can be fired from specified high overvoltage conditions without damage.

It should be noted that the tests described in this clause are based on standard wave shapes and standard test procedures as developed for the testing of high-voltage a.c. systems and components. This approach offers great advantages to the industry because it allows much of the existing technology of high-voltage testing to be carried over to the qualification of HVDC valves. On the other hand, it shall be recognized that a particular HVDC application may result in wave shapes different from the standards and, in this case, the test may be modified so as to realistically reflect expected conditions.

8.2 Test object

The test object shall be a complete valve which shall be assembled with all auxiliary components except for the valve surge arrester. The valve may form part of a multiple valve unit. For all impulse tests, the valve electronics shall be energized unless otherwise specified. For the a.c. and d.c. voltage tests, the valve electronics need not be energized.

The coolant shall be in a condition that represents service conditions except for flow rate which can be reduced. If any object external to the structure is necessary for proper representation of the stresses during tests it shall be included or simulated in the test. Earth planes shall be used, whose separation shall be determined by the proximity of other adjacent valves and earth potential surfaces.

The test object used for the valve dielectric tests will normally not permit the application of atmospheric correction to the specified test voltages without overstressing the thyristors or other internal components. For this reason, no atmospheric correction factor is applied to any of the dielectric tests between valve terminals. The supplier shall demonstrate that the effects of atmospheric conditions on the valve internal withstand have been allowed for adequately. Separate tests to verify that capability may be carried out on a case-by-case basis.

8.3 Test requirements

8.3.1 Valve d.c. voltage test

The d.c. test voltage source shall be connected so that the voltage is applied between one main terminal of the valve and earth, with the other main terminal of the valve earthed.

Starting from a voltage not higher than 50 % of the maximum test voltage, the voltage shall be raised to the specified 1 min test level within approximately 10 s, kept constant for 1 min, reduced to the specified 3 h test voltage, kept constant for 3 h and then reduced to zero. During the last hour of the specified 3 h test, the number of partial discharges exceeding 300 pC shall be recorded as described in Annex B.

The number of pulses exceeding 300 pC shall not exceed 15 pulses per minute averaged over the recording period. Of these, no more than seven pulses per minute shall exceed 500 pC, no more than three pulses per minute shall exceed 1 000 pC, and no more than one pulse per minute shall exceed 2 000 pC.

NOTE 1 If an increasing trend in the rate or magnitude of partial discharge is observed, the test duration can be extended by mutual agreement between the purchaser and supplier.

The test shall then be repeated with the voltage of opposite polarity.

NOTE 2 Before repeating the test with opposite polarity, the valve terminals can be short-circuited and earthed for several hours. The same procedure can be followed at the end of d.c. voltage test.

The valve d.c. test voltage U_{tdv} shall be determined in accordance with the following:

$$U_{tdv} = \pm U_{dn} \pm k_7$$

where

U_{dn} is the rated six-pulse bridge voltage;

k_7 is a test safety factor;

k_7 = 1,6 for the 1 min test;

k_7 = 0,8 for the 3 h test.

8.3.2 Valve a.c. voltage test

To perform the test, the test voltage source(s) shall be connected to the valve terminals. The point of earth connection is dependent on the test circuit arrangement. Starting from a voltage not higher than 50 % of the maximum test voltage, the voltage shall be raised to the specified 15 s test voltage within approximately 10 s, kept constant for 15 s, reduced to the specified 30 min test voltage, kept constant for 30 min, and then reduced to zero. During the last 1 min of the specified 30 min test, the level of partial discharge shall be monitored and recorded. The value of partial discharge shall not exceed 200 pC (see Annex B).

The 15 s test voltage of the valve U_{tav1} shall be determined as follows:

$$U_{tav1r} = \sqrt{2} U_{v0max} \times k_r \times k_c \times k_8$$

and

$$U_{tav1d} = \sqrt{2} U_{v0max} \times k_r \times k_8$$

where

U_{tav1r} is the peak value of the required 15 s test voltage in the reverse direction;

U_{tav1d} is the peak value of the required 15 s test voltage in the forward direction;

U_{v0max} is the maximum steady-state no-load phase-to-phase voltage on the valve side of the transformer;

k_r is the temporary overvoltage factor;

k_r is the value determined from system studies;

k_c is the commutation overshoot factor in the reverse direction, calculated for recovery at the crest of the load rejection overvoltage (α = 90°) including the increase arising from the reverse recovery charge of the thyristors. k_c shall allow for the limiting effect of the parallel connected valve arrester;

k_8 is a test safety factor;

k_8 = 1,10.

NOTE Since the value of U_{tav1r} is greater than or equal to U_{tav1d}, the 15 s test can be achieved either with a symmetrical a.c. test voltage of r.m.s. value equal to $U_{tav1r}/\sqrt{2}$ or by a combined a.c. plus d.c. test voltage which satisfies both requirements.

The r.m.s. value of the 30 min test voltage U_{tav2} shall be determined as follows:

$$U_{\mathrm{tav2}} = \frac{U_{\mathrm{ppv}}}{2\sqrt{2}} \times k_9$$

where

U_{ppv} is the maximum value of the peak-to-peak steady-state operating voltage appearing across the valve, including commutation overshoot;

k_9 is a test safety factor;

k_9 = 1,15.

Where U_{tav2} exceeds the maximum effective r.m.s. content of the valve operating voltage U_{vrms} by more than 15 %, the following alternative test procedure may be adopted:

Apply the test voltage U_{tav1} for 15 s and then U_{tav2} for 10 min. The value of partial discharge during the last minute of the 10 min test shall not exceed 200 pC.

At the end of the 10 min test, reduce the test voltage to U_{tav3} and maintained at this level for 30 min, where:

$$U_{\mathrm{tav3}} = k_9 \times U_{\mathrm{vrms}}$$

where

U_{vrms} is the maximum r.m.s. content of the valve voltage under the most severe continuous operating conditions.

8.3.3 Valve impulse tests (general)

Valve impulse tests should meet the following requirements:

a) This standard permits selection between two valve impulse test programmes depending upon the cost-benefit considerations for the application.

   In the first alternative, the test safety factor for lightning and switching impulse tests is 1,1 and for steep front impulse tests 1,15 with the thyristors present, plus 1,15 and 1,2 respectively with the thyristors replaced by insulating blocks.

   In the second alternative, the test safety factor for lightning and switching impulse tests is 1,15 and for steep front impulse tests 1,2 with the thyristors present.

   Further information is given in Annex A.

b) If the valve utilises protective firing, impulse test voltages applied in the forward direction will be prospective only. It shall be demonstrated that any such protective firing circuits behave as intended.

c) Unless otherwise specified, the valve electronics shall be energized.

d) It shall be demonstrated that the voltage across the valve at the initiation of the impulse satisfies the following relationship:

$$-0{,}01 \times V_{\mathrm{DSM}} \times (N_{\mathrm{t}} - N_{\mathrm{r}}) \leq \text{valve voltage} \leq +0{,}01 \times V_{\mathrm{DSM}} \times (N_{\mathrm{t}} - N_{\mathrm{r}})$$

   where

   V_{DSM} is the non-repetitive peak forward surge voltage rating of the thyristors;

   N_{t} is the total number of series thyristor levels in the valve;

   N_{r} is the total number of redundant series thyristor levels in the valve.

e) During the impulse tests, the valve shall be monitored for correct behaviour with regard to electromagnetic interference (see Clause 12). For this to be possible, those parts of the valve base electronics that are necessary for the proper exchange of information with the test valve shall be included.

8.3.4 Valve switching impulse test

A standard switching impulse voltage waveshape in accordance with IEC 60060 shall be used.

The test shall comprise three applications of positive polarity and three applications of negative polarity switching impulse voltages of specified amplitude with the valve electronics initially energized.

The positive polarity test shall be repeated with the valve electronics initially de-energized.

If the valve incorporates protective firing against overvoltages in the forward direction, which operates during the forward test, three additional applications of positive switching impulses of an agreed amplitude, so that the valve does not fire, shall be made. For the additional tests, the valve electronics shall be energized.

The valve switching impulse test withstand voltage U_{tsv} shall be determined in accordance with the following:

$$U_{tsv} = \pm SIPL_v \times k_{10}$$

where

$SIPL_v$ is the switching impulse protective level of the valve arrester;

k_{10} is a test safety factor (see 8.3.3 a)).

8.3.5 Valve lightning impulse test

A standard lightning impulse voltage waveshape in accordance with IEC 60060 shall be used.

The test shall comprise three applications of positive polarity and three applications of negative polarity of a lightning impulse of specified amplitude.

If the valve incorporates protective firing against overvoltages in the forward direction, which operates during the forward test, three additional applications of positive impulses of an agreed amplitude and front time, so that the valve does not fire, shall be made.

The valve lighting impulse test withstand voltage U_{tlv} shall be determined in accordance with the following:

$$U_{tlv} = \pm LIPL_v \times k_{11}$$

where

$LIPL_v$ is the lightning impulse protective level of the valve arrester;

k_{11} is a test safety factor (see 8.3.3 a)).

8.3.6 Valve steep front impulse test

For the steep front impulse test, a voltage waveshape as defined by Figure 1 shall be used. The virtual steepness S and crest value of the worst case valve steep front impulse voltage stress shall be determined from system studies. The virtual steepness shall be evaluated from the study results as the maximum $\mathrm{d}u/\mathrm{d}t$, in kV/µs, averaged over 60 % of the total voltage excursion.

When deriving the test voltage, the virtual steepness and amplitude derived from the system studies shall both be multiplied by the relevant test safety factor, i.e. the virtual front time shall be held constant.

NOTE If overvoltages with wavefronts shorter than 0,1 μs are expected to occur in service, the purchaser and supplier can agree on an appropriate very fast front voltage test in place of the steep front impulse test described above.

The test shall comprise three applications of positive polarity and three applications of negative polarity of a steep front impulse of specified amplitude.

If the valve incorporates protective firing against overvoltages or excessive d*u*/d*t* in the forward direction, which operates during the forward test, three additional applications of positive impulses of an agreed amplitude and front time, so that the valve does not fire, shall be made.

The valve steep front impulse test withstand voltage U_{tsfv} shall be determined in accordance with the following:

$$U_{tsfv} = \pm STIPL_v \times k_{12}$$

where

$STIPL_v$ is the steep front impulse protective level of the valve arrester as determined by the coordinating current from system studies;

k_{12} is a test safety factor (see 8.3.3 a)).

8.4 Valve non-periodic firing test

8.4.1 Purpose of test

The principal objective of the valve non-periodic firing tests is to check the adequacy of the thyristors and the associated electrical circuits with regard to current and voltage stresses at turn-on under specified high-voltage conditions. This test can usually be performed as part of the valve switching impulse test (see 8.3.4).

8.4.2 Test object

Test object should be as in 8.2. The test can be made on the valve section instead of complete valve for the surge arrester method B in 8.4.3. In this case, supplier shall show the equivalency between the valve section test and the complete valve test.

If immunity to electromagnetic disturbance due to coupling between adjacent valves in a MVU is to be demonstrated by approach one as in 12.3.2, then in addition to the test valve, an auxiliary valve (or sufficient portion thereof) shall be included in the test. This auxiliary valve is the test object in so far as the demonstration of immunity to electromagnetic disturbance by coupling is concerned. The electromagnetic disturbance test object shall be configured geometrically in accordance with the service arrangement. The electromagnetic disturbance test object shall be forward biased at the triggering instant of the valve subjected to non-periodic firing. The electronics of the electromagnetic disturbance test object shall be energized. Those parts of the valve base electronics that are necessary for the proper exchange of information with the electromagnetic disturbance test object shall be included.

NOTE The specific geometric arrangement to be used and the magnitude of the forward voltage for the electromagnetic disturbance test object are agreed, based on the design of MVU.

8.4.3 Test requirements

The test shall comprise three applications of positive switching impulse voltage and the valve triggered into conduction at the crest of the impulse.

The impedance of the impulse generator shall be selected to reproduce not only the turn-on current arising from the discharge of the circuit stray capacitance, but also that arising from commutation of the maximum value of surge arrester current determined from system studies.

The test shall be performed at room temperature.

Two methods for achieving this are acceptable as described below.

A **Parallel capacitor method**. In this method, a capacitor shall be connected in parallel with the test valve, the value of which will result in a current discharge at least as severe as the first 10 μs of the predicted value. Longer times may be important if system studies show that the turn-on current is oscillatory and that there is a risk of current extinction in the thyristors. The peak value of current shall be determined from system studies, taken into account all the following conditions:

– valve voltage at firing;

– non-linear behaviour of valve reactors;

– damping effect of thyristor conduction resistance;

– valve stray capacitance and inductance.

B **Surge arrester method**. In this method, an arrester shall be connected between the valve terminals, and the test voltage applied from behind an inductance equal to that of the commutating inductance. Capacitance equal to the maximum value of valve terminal-to-terminal stray capacitance expected in service shall be connected between the valve terminals. When the current through and voltage across the arrester reaches the prescribed levels, the valve shall be triggered into conduction.

The valve voltage at firing shall be the lowest of:

a) the switching impulse protective level of the valve arrester;

b) the protective firing level of the valve;

c) the firing inhibit level of the valve (see Note 3).

If the valve is triggered by protective firing below the switching impulse protective level of the valve arrester, then the test shall be repeated with the redundant thyristor levels operational. If the valve still triggers by protective firing below the switching impulse protective level, the test shall again be repeated with the impulse level reduced to just below the protective firing threshold and the valve triggered by the normal firing circuits.

NOTE 1 A voltage test safety factor at least equal to the difference between the maximum tolerance and minimum tolerance of the valve arrester (typically about 5 %) is already included in this test resulting in a corresponding increase in current. Therefore, no separate test safety factor is applied to the test voltage and current.

NOTE 2 Because of limitations in the practical size of impulse generators, method B is suitable only for valves of low voltage rating. Therefore, when system studies show a need for accurate turn-on current representation at times longer than 10 μs, the valve non-periodic firing test can be performed using method A and be supplemented by separate tests on valve sections using method B.

NOTE 3 In some designs, firing of the valve from high voltage can be inhibited by a voltage measurement across the valve, or by a current measurement in the parallel valve arrester. If this is the case, the details of the non-periodic firing test are agreed by the purchaser and the supplier taking into account the characteristics of the inhibiting circuits employed.

9 Periodic firing and extinction tests

9.1 Purpose of tests

The principal objectives of the periodic firing and extinction tests are:

a) to check the adequacy of the thyristor levels and associated electrical circuits in a valve with regard to current, voltage and temperature stresses at turn-on and turn-off under the worst repetitive stress conditions;

b) to demonstrate correct performance of the valve at minimum repetitive voltage, coincident with minimum delay and extinction angles, at maximum temperature.

9.2 Test object

The tests may be performed on either the complete valve or on valve sections. The choice depends mainly upon the valve design and the test facilities available. The tests specified in this standard are valid for valve sections containing five or more series-connected thyristor levels. If tests with fewer than five levels are proposed, additional test safety factors shall be agreed. Under no circumstances shall the number of series-connected levels for tests be less than three.

The valve or valve sections under test shall be assembled with all auxiliary components. When required, a proportionally scaled valve arrester shall be included. The arrester shall be scaled to the number of series-connected levels under test to give a protective level which corresponds at least to the maximum characteristic of the service arrester.

9.3 Test requirements

9.3.1 General

The tests shall be performed using suitable test circuits giving stresses equivalent to the appropriate service conditions such as two six-pulse bridges in back-to-back connection or an appropriate synthetic test circuit.

The coolant shall be in a condition representative of service conditions. Flow and temperature, in particular, shall be set to the most unfavourable values appropriate to the test in question.

The equivalent service conditions to be reproduced are specified in 9.3.2 to 9.3.6. Subclauses 9.3.2, 9.3.3 and 9.3.4 are defined for operation with maximum continuous operating thyristor junction temperature. If higher firing or recovery voltages, alternatively lower delay or extinction angles, are possible under loading conditions which do not coincide with maximum continuous operating thyristor junction temperature, then these shall also be reproduced. Examples where this may be the case include winter overload operation, and the use of the converters to limit the export of surplus reactive power into the a.c. network at light load conditions. When tests are performed to reproduce such conditions, the test current and coolant temperature may be adjusted to reflect the worst case thermal conditions appropriate to the service conditions being represented in the test.

To obtain voltage and current stresses representative of service conditions, it is important that the total stray capacitance associated with the valve and the inductances contributing to the commutating reactance be properly represented in the circuit. In a deblocked six-pulse bridge circuit, each valve experiences a parallel impedance equal to 1,5 times that of a single off-state valve. If a test circuit other than a six-pulse bridge is used, then it is important that this feature is also properly represented in the circuit.

When testing with valve sections, the scaling factor for tests shall be applied.

Test voltages and test circuit resistances and inductances shall be determined from the full scale values by being multiplied by a scaling factor, while test circuit capacitances shall be determined from the full scale values by being divided by a scaling factor.

In order to reproduce correct heating effects, the periodic firing and extinction tests should be performed at the service frequency. When this is not possible and the service frequency is different from the test frequency, then the test conditions shall be adjusted so as to approximately compensate the difference in frequency dependent losses, as necessary to demonstrate the proper stressing of the equipment. Guidance on the sensitivity to frequency of the various loss producing mechanisms can be found in IEC 61803.

During the tests, the temperature rise of the most critical heat producing components and their adjacent mounting surfaces shall be monitored to verify that the maximum temperatures reached are within limits permitted by the design (see 4.4.3). The number and location of the components to be monitored shall be agreed, but shall be not less than three examples each of: thyristor case temperature, damping resistor surface temperature, and valve saturable reactor surface temperature. If less than three items of a type of component are installed in a valve, all components of this type in the valve shall be monitored.

9.3.2 Maximum continuous operating duty tests

9.3.2.1 General

The test current shall be based on the maximum continuous direct current at maximum ambient temperature.

The test current shall incorporate a test safety factor of 1,05.

The test voltage U_{tpv1} corresponding to the no-load phase-to-phase value in a six-pulse bridge converter shall be determined as follows:

$$U_{tpv1} = U_{v0max} \times k_n \times k_{13}$$

where

U_{v0max} is the maximum steady-state no-load phase-to-phase voltage on the valve side of the transformer;

k_n is a test scaling factor according to 4.3.2;

k_{13} is a test safety factor;

k_{13} = 1,05.

Three maximum operating duty test conditions shall be satisfied as detailed in 9.3.2.2, 9.3.2.3 and 9.3.2.4 below. These conditions can be satisfied singly or in any combination.

NOTE Subject to agreement between the purchaser and supplier, consideration can be given to apply the current and voltage stresses separately, provided it can be demonstrated that the objectives of the tests are met.

9.3.2.2 Maximum continuous firing voltage test

Operate the valve or valve sections at a delay angle α so that the valve (section) firing voltage u_f is not lower than the greater of:

a) $u_{fr} = U_{tpv1} \times \sqrt{2} \times \sin\alpha$

b) $u_{fi} = U_{tpv1} \times \sqrt{2} \times \sin(\gamma + \mu)$

where

α is the steady-state delay angle corresponding to the rectifier service condition that leads to the highest value of $u_{fr,}$ coincident with operation at maximum continuous operating thyristor junction temperature;

$(\gamma + \mu)$ is the sum of the steady-state extinction angle and overlap angle corresponding to the inverter service condition that leads to the highest value of $u_{fi,}$ coincident with operation at maximum continuous operating thyristor junction temperature.

The duration of the test shall be not less than 30 min after the exit coolant temperature has stabilized.

9.3.2.3 Maximum continuous recovery voltage test

Operate the valve or valve sections at a delay angle α so that the prospective step voltage at recovery at current zero u_r is not lower than the greater of:

a) $u_{rr} = U_{tpv1} \times \sqrt{2} \times \sin(\alpha + \mu)$

b) $u_{ri} = U_{tpv1} \times \sqrt{2} \times \sin\gamma$

where

$(\alpha + \mu)$ is the sum of the steady-state delay angle and overlap angle corresponding to the rectifier service condition that leads to the highest value of u_{rr}, coincident with operation at maximum continuous operating thyristor junction temperature;

γ is the steady-state extinction angle corresponding to the inverter service condition that leads to the highest value of u_{ri}, coincident with operation at maximum continuous operating thyristor junction temperature.

The duration of the test shall be not less than 30 min after the exit coolant temperature has stabilized.

9.3.2.4 Heat-run test

To simulate the maximum combined losses in thyristors and damping circuits during continuous operation, operate the valve or valve sections at a delay angle α so that the sum of the squares of the jump voltages in the valve voltage waveshape, measured over one cycle (excluding the commutation overshoot transients) is not lower than:

$$\sum \Delta V^2 = \left(1{,}75 + 1{,}5m^2\right) \times 2 \times U^2{}_{tpv1}\left[\sin^2\alpha + \sin^2(\alpha + \mu)\right]$$

where

m is the electromagnetic notch factor (see 5.1.4 of IEC 61803, 1999);

α and μ correspond to the rectifier or inverter steady-state service condition for which $U^2{}_{tpv1}$ $[\sin^2 \alpha + \sin^2 (\alpha + \mu)]$ is maximum, coincident with operation at maximum continuous operating thyristor junction temperature.

If a two × six-pulse back-to-back test circuit is used, the conditions required for this test are automatically met when performing 9.3.2.2 and 9.3.2.3. However, differences to twelve-pulse operation shall be considered.

The duration of the test shall be not less than 1 h after the exit coolant temperature has stabilized.

9.3.3 Maximum temporary operating duty test (α = 90°)

The test voltage U_{tpv2} corresponding to the no-load phase-to-phase value in a six-pulse bridge converter shall be determined as follows:

$$U_{tpv2} = U_{v0max} \times k_n \times k_r \times k_{14}$$

where

U_{v0max} is the maximum steady-state no-load phase-to-phase voltage on the valve side of the transformer;

k_n is a test scaling factor according to 4.3.2;

k_r is the temporary overvoltage factor;

k_r is a value determined from system studies;

k_{14} is a test safety factor;

k_{14} = 1,05.

Prior to the test, the valve or valve sections, shall be brought to thermal equilibrium under the conditions of 9.3.2.2. Operate the valve or valve sections, for the specified time, at a delay angle α = 90° so that the firing and prospective recovery voltages are not less than $U_{tpv2} \times \sqrt{2}$.

The sum of the squares of the jump voltages in the valve voltage waveshape shall be not less than that obtained from the expression given in 9.3.2.4 using α = 90° and U_{tpv1} as defined in this clause. The current during the period of α = 90° operation shall be at least equal to the maximum value for α = 90° operation, determined from system studies, multiplied by a test safety factor of 1,05. After the specified time at α = 90°, return to the conditions corresponding to 9.3.2.2 and maintain constant for at least 15 min.

The duration of operation at α = 90° shall be at least twice the normal permitted time in service at this delay angle.

Depending on the temporary overvoltage control strategy for the scheme, tests of different duration, with different values of k_r, may be required.

9.3.4 Minimum a.c. voltage tests

9.3.4.1 General

The test current and coolant temperature shall be selected as defined in 9.3.2.

The test voltage U_{tpv3} corresponding to the no-load phase-to-phase value in a six-pulse bridge converter shall be determined as follows:

$$U_{tpv3} = U_{v0min} \times \frac{N_{tut}}{N_t} \times k_{15}$$

where

U_{v0min} is the lowest steady-state no-load phase-to-phase voltage on the valve side of the transformer;

N_{tut} is the number of series-connected thyristor levels under test;

N_t is the total number of series-connected thyristor levels in a complete valve, including redundant levels;

k_{15} is a test safety factor;

k_{15} = 0,95.

9.3.4.2 Minimum delay angle test

Operate the valve or valve sections at a rectifier delay angle α so that the valve (section) firing voltage u_{fr} is not higher than:

$$u_{fr} = U_{tpv3} \times \sqrt{2} \times \sin\alpha$$

where α is the smallest steady-state rectifier delay angle in service coincident with operation at maximum continuous operating thyristor junction temperature.

The duration of the test shall be not less than 15 min after the exit coolant temperature has stabilized.

If the operating strategy of the converter permits temporary operation with α below the minimum steady-state value, then operation at this reduced value shall also be demonstrated. The duration of operation at the transient α value shall be at least twice the normal permitted time in service at this delay angle.

It shall be demonstrated that the valve (sections) fire regularly at both the steady-state and transient values of α.

9.3.4.3 Minimum extinction angle test

Operate the valve or valve sections at an inverter extinction angle γ so that the prospective step voltage at recovery at current zero u_{ri} is not higher than:

$$u_{ri} = U_{tpv3} \times \sqrt{2} \times \sin\gamma$$

and the time from current zero to positive-going voltage zero crossing t_{off} is not greater than:

$$t_{off} = \frac{\gamma}{360 \times f}$$

where

γ is the smallest steady-state extinction angle in service coincident with operation at maximum operating thyristor junction temperature;

f is the service frequency.

The duration of the test shall be not less than 15 min after the exit coolant temperature has stabilized.

If the operating strategy of the converter permits temporary operation with γ below the minimum steady-state value, then operation at this reduced value shall also be demonstrated. The duration of operation at the transient minimum γ value shall be at least twice the normal permitted time in service at this extinction angle.

It shall be demonstrated that no commutation failures occur at either the steady-state or transient minimum values of γ.

9.3.5 Temporary undervoltage test

The purpose of this test is to verify the correct performance of those valve designs in which energy for the firing circuits is extracted from the voltage appearing between the valve terminals.

Prior to the test, the valve or valve sections shall be operated under conditions corresponding to 9.3.4.2 (steady-state minimum α) except for the test current which may be reduced. Operate the valve or valve sections, for the specified time at minimum transient value of α, coincident with a test voltage U_{tpv4}, which shall be determined as follows:

$$U_{tpv4} = U_{v0N} \times \frac{N_{tut}}{N_t} \times k_u \times k_{16}$$

where

U_{v0N} is the nominal value of the no-load phase-to-phase voltage on the valve side of the transformer;

N_{tut} is the number of series-connected thyristor levels under test;

N_t is the total number of series-connected thyristor levels in a complete valve, including redundant levels;

k_u is the temporary undervoltage factor (fundamental frequency) for which the converters shall remain controllable;

k_{16} is a test safety factor;

k_{16} = 0,95.

The duration of operation with temporary undervoltage shall be not less than the back-up fault clearing time for the a.c. system, including, where appropriate, any dead-time arising from auto-reclose sequences in the a.c. system.

After the specified time, return to the conditions corresponding to 9.3.4.2.

It shall be demonstrated that the valve (sections) remain controllable over the full duration of the temporary undervoltage.

Depending on the level of temporary undervoltage and the method of test adopted, it may not be possible to maintain normal operation of the test circuit during the test. If this occurs, it shall be demonstrated that this is an inherent consequence of the abnormal voltage conditions during the test and not a result of a failure of the valve (sections) to respond correctly to the firing control signals.

9.3.6 Intermittent direct current tests

The test shall be performed with the valve coolant at its maximum temperature. The stresses arising from intermittent direct current operation for two operating conditions shall be reproduced:

a) α = 90° operation with maximum a.c. voltage and k_r = 1,0 (see 9.3.3);
b) rectifier minimum α operation with minimum a.c. voltage (see 9.3.4.1).

The duration of the test shall be at least twice the normal permitted time in service for operation with intermittent direct current under the specified conditions.

The tests shall demonstrate safe turn-on of the thyristors, in accordance with the design, at the requisite number of firings per cycle. For an effective demonstration, the behaviour of the valve (sections) should be explored with an adjustable intermittent direct current in which the duration of the periods of zero current can be varied from zero to a value which is long, compared with the turn-off time of the thyristors.

NOTE The maximum number of current pulses per cycle in a valve during intermittent direct current operation is normally four for valves used in HVDC transmission applications and eight for valves used in back-to-back schemes.

10 Tests with transient forward voltage during the recovery period

10.1 Purpose of tests

The principal objective of the tests with transient forward voltage during the recovery period is to check that, at maximum temperature, the valve will tolerate the application of transient forward voltages in the period immediately following current extinction. The tests shall demonstrate that the valve will either withstand the transient forward voltage or will turn on safely.

A second objective is to demonstrate that, for transients in the forward direction applied after the recovery interval, the protective firing level and d*u*/d*t* withstand of a valve containing operating thyristors at their maximum steady-state junction temperature are consistent with the design.

10.2 Test object

See 9.2.

10.3 Test requirements

The test requirements are the same as for the periodic firing and extinction tests, Clause 9, except that an impulse generator, connected across an inverter valve or valve section, is also required. Triggering of the impulse generator shall be synchronized with the normal operating waveshapes to apply forward impulses to the valve or valve sections under test in the interval immediately following current extinction.

The test current and coolant temperature shall be selected to produce the maximum continuous operating thyristor junction temperature. The operating conditions for the valve (sections) under test shall be those of 9.3.4.3 for steady-state minimum γ.

The impulse generator shall be set so that the prospective peak voltage in the forward direction U_{tvtd} is determined by:

$$U_{tvtd} = U_{IMPLv} \times k_n$$

where

U_{IMPLv} is the impulse protective level of the valve arrester, alternatively the guaranteed non-firing level for protective firing with a switching impulse waveshape, if lower;

k_n is a scaling factor according to 4.3.2.

NOTE 1 U_{SIPLv} is used as U_{IMPLv} in 100 µs front time waveshape and U_{LIPLv} is used as U_{IMPLv} in 1,2 and 10 µs front time waveshapes.

The test shall be performed with three different impulse waveshapes:

– type 1: 100 µs front time ± 30 %;
– type 2: 10 µs front time ± 30 %;
– type 3: 1,2 µs front time ± 30 %.

The time from voltage crest to half value of the impulse is not critical, but shall be not less than 10 µs for any waveshape when applied under conditions for which the valve does not turn on due to the impulse.

NOTE 2 The sensitivity of the equipment to impulses of different waveshapes is design dependent. Subject to agreement between purchaser and supplier, consideration can be given to restricting the test to a single impulse waveshape, provided it can be shown that the objectives of the test are met.

Not less than five impulses of each type shall be applied singly, at various times in the interval from current zero to the end of the negative recovery period. Three additional impulses of each type shall be applied after the recovery period has ended.

NOTE 3 The recovery period is considered to have ended when the thyristors have regained their full off-state voltage and d*u*/d*t* withstand capabilities. This can be marked, in some designs, by the ending of a time window during which protection circuits have increased sensitivity. The relevant time is stated by the supplier.

The valve or valve sections shall either withstand the impulses or turn-on safely.

If the valve incorporates protective firing against transient forward voltages in the recovery period then it shall be demonstrated that the protection operates as intended.

The valve shall not fire for any impulse applied after the recovery period has ended, unless firing can be shown to be due to a legitimate response of the protective firing circuits during the off-state (see Note 3 above). If protective firing occurs with the specified waveshapes, when applied after the recovery period has ended, then three additional applications of positive impulses of revised amplitude and front time, such that the valve does not fire, shall be made. It shall be demonstrated that the revised amplitude and front times for non-firing are consistent with the protective firing strategy for the valve.

11 Valve fault current tests

11.1 Purpose of tests

The principal objectives of the fault current tests are to demonstrate proper design of the valve to withstand the maximum current, voltage and temperature stresses arising from short-circuit currents.

The tests shall demonstrate that the valve is capable of:

a) suppressing a one-loop fault current of maximum amplitude, commencing from maximum temperature and blocking the ensuing reverse and forward voltages, including any overvoltage due to load rejection;
b) surviving, to circuit breaker trip, a multiple-loop fault current, under conditions similar to the one-loop test, but with no re-applied forward voltage. This test covers the – normally rare – case where phase shifts or transients in the AC system prevent the conditions needed for the valve to block the fault at the end of the first cycle.

11.2 Test object

See 9.2.

11.3 Test requirements

11.3.1 General

The tests shall be performed using test circuits which are capable of reproducing, as closely as possible, the most severe fault current conditions specified.

For the one-loop fault current test, the principal requirement is to reproduce the worst combination of forward voltage and thyristor junction temperature at the time of the crest of the first positive half cycle of re-applied voltage following one loop of fault current.

For the multiple-loop fault current test, the principal requirement is to reproduce the worst combination of reverse voltage and thyristor junction temperature at negative recovery following the penultimate loop of a multiple-loop fault current.

A second requirement of the one-loop fault current test is to demonstrate that the thyristors have adequate turn-off time to be able to withstand the re-application of forward voltage at the positive-going voltage zero crossing immediately following the fault current. The time interval between current zero and positive-going voltage zero crossing is dependent on the damping factor of the test circuit and on the test supply frequency. These should either be made equal to the service values or adjusted so as to produce a representative value for the hold-off interval. Where this is not possible, the supplier shall demonstrate by other means, that the turn-off time of the thyristors, after one loop of fault current, is adequately short.

In order to reproduce the correct transient reverse voltages during the multiple-loop fault current test, it is important that the total stray capacitance associated with the valve and inductances contributing to the commutating reactance be properly represented in the circuit. It is important that the effective parallel impedance of the other valves of a six-pulse bridge is properly represented, taking into account the location of the presumed short circuit and the control strategy adopted during overcurrents. The valve or valve sections need not be subjected to any recovery voltage after the final loop of fault current.

When testing with valve sections, the test voltages and test circuit component values shall be scaled according to the number of series-connected thyristor levels under test as described in 9.3.

NOTE The fault current tests specified in 11.3.2 and 11.3.3 are based on the normal worst case condition of the maximum value of fault current arising from a short circuit across a rectifier valve. If the worst combination of voltage and junction temperature for the thyristors does not coincide with the maximum fault current arising from a short circuit across a rectifier valve, then the test conditions are adjusted accordingly.

11.3.2 One-loop fault current test with re-applied forward voltage

Prior to the test, the valve or valve sections shall be operated to produce the maximum continuous operating thyristor junction temperature.

Subject the valve or valve sections to one loop of fault current of the specified peak value and conduction duration, followed by re-application of forward voltage. The crest value of the first half cycle of re-applied forward voltage U_{tfvd} shall be determined as follows:

$$U_{tfvd} = U_{v0max} \times \sqrt{2} \times k_n \times k_r \times k_{17}$$

where

U_{v0max} is the maximum steady-state no-load phase-to-phase voltage on the valve side of the transformer;

k_n is a test scaling factor according to 4.3.2;

k_r is the temporary overvoltage factor;

k_r is the value determined from system studies;

k_{17} is a test safety factor;

k_{17} = 1,05.

The peak value and conduction duration of the fault current shall be determined from system studies, taking into account:

– the maximum a.c. system short-circuit fault level;
– the minimum steady-state a.c. system frequency consistent with the above;
– the minimum tolerance value of the converter transformer reactance referred to the valve side;
– the most critical of the following combinations:
    - the lowest delay angle at fault initiation corresponding to the maximum steady-state operating voltage referred to the valve side,
    - the lowest operating voltage referred to the valve side at fault initiation corresponding to the minimum transient delay angle;
– the minimum damping factors for the a.c. system and converter transformer referred to the valve side;
– a short circuit across a rectifier valve.

The peak value of the fault current so calculated shall not be reduced by half the d.c. current ($Id/2$) unless the supplier can demonstrate that the reduction is valid for the proposed control strategy.

The value of k_r shall be consistent with the a.c. system conditions used for calculating the fault current. The d.c. load rejected shall be that portion of the rated d.c. power of the converter station which is lost due to the fault.

If the parameters of the test circuit prevent the specified fault current amplitude and conduction duration from being achieved, then a current waveshape of equivalent severity may be used. It shall be demonstrated that the equivalent waveshape results in a thyristor junction temperature, at the time of peak voltage stress, which is at least as great as that which would have occurred with the correct current waveshape.

11.3.3 Multiple-loop fault current test without re-applied forward voltage

Prior to the test, the valve or valve sections shall be operated to produce the maximum continuous operating thyristor junction temperature.

Subject the valve or valve sections to one application of the specified number of loops of fault current of the specified peak value and conduction duration. The valve or valve sections shall be subjected to reverse voltage between the loops of fault current, but shall be prevented from experiencing forward blocking voltage by continuously triggering the thyristors.

The prospective value of reverse recovery voltage at current zero of the penultimate fault current loop U_{tfvr} shall be determined as follows:

$$U_{tfvr} = U_{v0max} \times \sqrt{2} \sin \psi \times k_n \times k_r \times k_{18}$$

where

U_{v0max} is the maximum steady-state no-load phase-to-phase voltage on the valve side of the transformer;

ψ is the fraction, in degrees, of one cycle of the service waveform, by which current zero of the penultimate fault current loop precedes positive-going voltage zero crossing;

k_n is a test scaling factor according to 4.3.2;

k_r is the temporary overvoltage factor;

k_r is the value determined from system studies;

k_{18} is a test safety factor;

k_{18} = 1,05.

The number of fault current loops shall be determined from the operating time of the primary circuit-breaker used for terminating short-circuit currents in the converter. The operating time shall include the fault detection and signalling delays as well as the breaker clearing time.

The peak value and conduction duration of the fault current loops shall be determined in the same manner as defined in 11.3.2 except that, for all fault loops after the first, the delay angle of initiation shall be 0°.

The value of k_r shall be determined as described in 11.3.2.

12 Tests for valve insensitivity to electromagnetic disturbance

12.1 Purpose of tests

The principal objective is to demonstrate the insensitivity of the valve to electromagnetic interference (electromagnetic disturbance) arising from voltage and current transients generated within the valve and imposed on it from the outside. The sensitive elements of the valve are generally electronic circuits used for triggering, protection and monitoring of the thyristor levels.

Generally, the valve insensitivity to electromagnetic disturbance can be checked by monitoring the valve during other type tests. Of these, the valve impulse tests (8.3.3 to 8.3.5) and the valve non-periodic firing test (8.4) are the most important because the events reproduced by these tests can be expected during normal operation of the converter station and do not normally cause the converter station to be tripped.

The tests should demonstrate that:

a) out-of-sequence or spurious triggering of thyristors does not occur;

b) the electronic protection circuits installed in the valve operate as intended;

c) false indication of thyristor level faults or erroneous signals sent to the converter control and protection systems by the valve base electronics, arising from receipt of false data from the valve monitoring circuits, does not occur.

For this standard, tests to demonstrate valve insensitivity to electromagnetic disturbance apply only to the thyristor valve and that part of the signal transmission system that connects the valve to earth. Demonstration of the insensitivity to electromagnetic disturbance of equipment located at earth potential, and characterization of the valve as a source of electromagnetic disturbance for other equipment, are not within the scope of this standard.

12.2 Test object

Generally, the test object is the valve or valve sections as used for other tests.

When insensitivity to electromagnetic disturbance arising from coupling between adjacent valves in a MVU is to be demonstrated, two approaches are acceptable as defined in 12.3. In this case, the test object will be a separate valve or valve section according to the approach adopted.

12.3 Test requirements

12.3.1 General

When demonstrating insensitivity to electromagnetic disturbance arising from coupling between adjacent valves of a MVU, the test requirements depend on which of the two recommended approaches is adopted.

12.3.2 Approach one

Approach one is to simulate the source of electromagnetic disturbance directly as part of a test set-up. Such a test set-up will require more than one valve in order to check for interaction between them. The geometric arrangements of the source of the electromagnetic disturbance with respect to the valve under test shall be as close as possible to the service arrangement (or worse from an electromagnetic disturbance point of view).

Subclause 8.4.2 gives further details of requirements if approach one is adopted.

12.3.3 Approach two

Approach two is to determine the intensity of electromagnetic fields under worst operational conditions, either from theoretical considerations or by measurements. In a second step, these fields are simulated by a test circuit which generates correct (or worse) electromagnetic radiation at the respective frequencies. A valve section is then exposed to the fields generated by the test source.

An essential prerequisite to approach two is the determination of the dynamic field strength and direction at key locations in the valve. This can generally be obtained from search coil measurements taken during firing tests on a single valve. Alternatively, the field can be predicted from three-dimensional field modelling programs. A valve section shall then be tested using a separate field coil to produce field intensity, frequency content and direction which is at least as severe as the predicted values.

The following conditions for the valve section under test shall be met:

– the valve section shall have operational voltage (proportionally scaled) between its terminals and be forward biased at the time of energization of the field coil;

– the electronics of the valve section under test shall be energized;

– those parts of the valve base electronics that are necessary for the proper exchange of information with the valve section shall be included.

12.3.4 Acceptance criteria

The criteria for acceptance for both approaches one and two shall be as defined in 12.1.

13 Testing of special features and fault tolerance

13.1 Purpose of tests

13.1.1 General

These tests are intended to verify the design and performance of any special features of the valve. Special features may include, but are not limited to, those in the following two categories.

13.1.2 Circuits to facilitate the proper control, protection and monitoring of the valve

Generally, these features can be demonstrated as part of the other tests.

13.1.3 Features included in the valve to provide fault tolerance

Fault tolerance capability may be defined as the ability of an HVDC thyristor valve to perform its intended function, until a scheduled shutdown, with faulted components or subsystems or overloaded components, and not lead to any unacceptable failure of other components, or extension of the damage due to the faulted condition. Special features may be required in the design to ensure fault tolerance. Examples of faults for which fault tolerance may be required include, but are not limited to, those given below.

a) Short circuit of a thyristor

   Even though a short-circuited thyristor will shunt the other components at the thyristor level, in some designs there may be a danger of overloading gate pulse transformers, overloading of current connections (where parallel thyristors are used), or changing the clamping load.

b) Continuous operation of protective firing at one thyristor level due to loss of normal firing pulses to that level.

   Continuous operation of protective firing can lead to overload of the damping resistor and other components at the affected level.

c) Insulation failure of a pulse transformer (if feeding two or more series-connected thyristors), damping capacitor, damping resistor or grading capacitor.

   Insulation failure of any component in parallel with the thyristors can attract load current into it, leading to a hazardous condition.

d) Leakage of small quantities of valve coolant

   If the valve is liquid cooled, small leaks may not be easily detected. Escaped coolant can contaminate sensitive components, leading to malfunction, and can increase the probability of insulation failure.

The purchaser shall review the design offered with the supplier to determine the probability and likely consequences of certain failures. Where appropriate, consideration shall be given, in the type test programme, to the performance of special tests to verify critical aspects of the fault tolerance capability of the valve. Such tests shall be agreed between the purchaser and supplier on a case-by-case basis.

13.2 Test object

Tests may be performed on a complete valve, valve section or relevant parts of either.

13.3 Test requirements

The test procedures and acceptance criteria shall be chosen having regard to the actual design of the valve. It shall be demonstrated that the components or circuits involved behave as intended.

14 Production tests

14.1 General

This clause covers tests on assemblies of components that are parts of valves, valve sections, or auxiliary circuits for their protection, control and monitoring. It does not cover tests on individual components that are used within the valve, the valve support, or valve structure. Production tests may include routine tests as well as sample tests. In this clause, only routine test objectives are given.

NOTE In some cases it could be necessary to perform sample tests on complete assemblies in addition to the routine tests, for example when modifications are introduced in the course of production to verify that the valve maintains its performance without deviation from its original type tested design. The programme of sample tests is agreed between the purchaser and supplier.

14.2 Purpose of tests

The purpose of the production tests is to verify proper manufacture by demonstrating that:

– all components and subassemblies used in the valve have been correctly installed in accordance with the design;
– the valve equipment functions as intended and predefined parameters are within prescribed acceptance limits;
– the valve sections and thyristor levels (as appropriate) have adequate voltage withstand capability;
– consistency and uniformity in production is achieved.

14.3 Test object

All valve sections or parts thereof manufactured for the project shall be subjected to the routine tests. For sample tests the test object should be agreed between the purchaser and the supplier.

14.4 Test requirements

Uniformity in the specified production tests of different suppliers is unnecessary. The production tests shall take into account the special design characteristics of the valve and its components, the extent to which the components are tested prior to assembly, and the particular manufacturing procedures and techniques involved. In all cases, the supplier shall submit, for approval by the purchaser, a detailed description of the test procedures proposed to meet the production test objectives.

The minimum requirements for routine tests are listed in 14.5. The order in which the tests are listed implies neither ranking of importance nor the order in which the tests should be performed.

14.5 Routine test – minimum requirements

14.5.1 Visual inspection

To check that all materials and components are undamaged and are correctly installed in accordance with the latest approved revision of the production documentation.

14.5.2 Connection check

To check that all the main current-carrying connections have been made correctly.

14.5.3 Voltage-grading circuit check

To check the grading circuit parameters and thereby ensure that voltage division between series-connected thyristors will be correct for applied voltages from d.c. to impulse waveshapes.

14.5.4 Voltage withstand check

To check that the valve components can withstand the voltage corresponding to the maximum value specified for the valve.

14.5.5 Partial discharge tests

To demonstrate correct manufacture, the purchaser and supplier shall agree which components and subassemblies are critical to the design, and appropriate partial discharge tests shall be performed.

14.5.6 Check of auxiliaries

To check that the auxiliaries (such as monitoring and protection circuits) at each thyristor level and those common to the complete valve (or valve section) function correctly.

14.5.7 Firing check

To check that the thyristor in each thyristor level turns on correctly in response to firing signals.

14.5.8 Pressure test

To check that there are no coolant leaks (for liquid cooled valves only).

15 Method for loss determination

The procedure for loss determination of HVDC thyristor valves is specified in IEC 61803.

16 Presentation of type test results

The test report shall be issued in accordance with the general guidelines as given in ISO/IEC Guide 25, and shall include the following information:

– name and address of the laboratory and location where the tests were carried out;
– name and address of the purchaser;
– unambiguous identification of the test object, including type and ratings, serial number and any other information aimed to identify the test object;
– dates of performance of the tests;
– description of test circuits and test procedures used for the performance of the tests;
– reference to the normative documents and clear description of deviations, if any, from procedures stated in the normative documents;
– description of measuring equipment and statement of the measuring uncertainty;
– test results in the form of tables, graphs, oscillograms, and photographs as appropriate;
– description of equipment or component failure.

Annex A
(normative)

Test safety factors

A.1 General

Thyristor valves are designed to withstand the stresses they are likely to experience under specified HVDC operating conditions. To verify the valve design, dielectric and operational type tests are carried out. The type test levels include test safety factors which ensure that the tests conservatively reproduce the worst-case service stresses.

Tests and test levels can have major economic penalties, particularly when unnecessary tests or unrealistic test levels are specified without compensating benefits in valve performance. The test safety factors used in this standard have been established with the objective of reflecting realistic and practical requirements to assure an economical valve design suitable for the intended application.

Test safety factors allow for measurement uncertainties during the test and, where appropriate, a protective margin. The protective margin provides an allowance for the uncertainty in the prediction of the maximum service stress and an allowance for any reduction in the capability of the equipment with time, due to ageing.

When type tests are performed according to IEC 60060-1, measuring uncertainties amount to 3 % for measuring errors and a further 3 % for the test level tolerance.

Uncertainty in the prediction of the maximum service stresses depends on many factors and assumptions, while degradation due to ageing is material and application dependent. No universally applicable quantitative factors exist for these parameters but established practice, supported by acceptable service experience provides a basis for judgement.

A review of the standard practice for high voltage equipment, the current practices for testing of HVDC thyristor valves and the service experience, taking the special characteristics of thyristor valves into account, has resulted in appropriate values of test safety factors to be used. These are discussed in Clauses A.2 and A.3 below.

A.2 Test safety factors for dielectric tests

A.2.1 Impulse tests

A.2.1.1 Basic approach

The impulse test safety factors used in this standard are based on the following assumptions:

a) metal oxide surge arresters are the primary impulse overvoltage protection devices, and are connected directly between the terminals of each valve to minimize impulse separation effects;

b) all redundant thyristors are short-circuited during the tests.

The criterion for valve redundancy is that a new valve, with all of its redundant thyristors short-circuited, shall still be capable of meeting the specified type test performance. The specified performance is established from analytical studies considering the permissible operating modes and requirements.

As with other conventional power equipment, the valve costs are influenced by the type tests and associated test levels. For impulse tests, the cost of a thyristor valve is almost directly proportional to the required impulse withstand test level. In addition, the associated in-service power losses are also almost directly proportional to the impulse test level. Recognizing the benefits in costs and losses of optimizing test levels, 8.3.3 of this standard allows the following alternatives for the impulse tests between valve terminals.

a) Apply a test safety factor of 1,10 for lightning and switching impulse tests and a test safety factor of 1,15 for the steep front impulse test. In addition, the impulse tests are repeated with a test safety factor of 1,15 for lightning and switching impulse tests, and a test safety factor of 1,2 for the steep front impulse test with all thyristors replaced with insulating blocks.
b) Apply a test safety factor of 1,15 for lightning and switching impulse tests and a test safety factor of 1,2 for the steep front impulse test.

Alternative b) reflects the majority practice in industry to date, and corresponds to a raising of the effective test safety margin for thyristors and associated thyristor level equipment compared with the previous edition of this standard. Alternative a) provides for a more economical design by limiting the maximum voltage to be withstood by the thyristors, while retaining the full test safety margins of alternative b) for all insulation in parallel with the thyristors.

The test safety factors adopted for both impulse test alternatives are supported by successful performance of valves presently in service, and by calculations showing that the test safety factors used give adequate margins of safety based on present industry knowledge and experience.

The selection of the impulse test alternative rests with the purchaser and will be based on the cost-benefit considerations for the specific application. Subclauses A.2.1.2 and A.2.1.3 below provide background information.

A.2.1.2 Prior practice and experience

The previous edition of this standard specified a test safety factor of 1,15 for lightning and switching impulse tests with redundant thyristor levels of up to 3 % not short-circuited. The effective test safety factor for the thyristors in valves with 3 % redundancy was therefore 1,117.

A review of the valve in-service performance records and the test safety factors used for impulse tests showed that, for the majority of projects installed world-wide, the valves have been tested with a test safety factor of 1,15 with the redundancy short-circuited. This corresponds to alternative b) in A.2.1.1 above. The service experience for these projects has been very good.

The review also showed that a significant number of projects has been supplied in which either the tests were performed with a test safety factor of 1,15 and redundancy of up to 3 % intact, or the value of the test safety factor was reduced, typically to 1,10. In one case, a test safety factor of 1,10 and intact redundancy of 3 % have been used (corresponding to an effective test safety factor for the thyristors of 1,067). The in-service performance records for these projects are also very good.

Based on in-service experience and other investigations to date, the insulation properties of thyristors do not indicate any tendency for significant ageing in service. On the other hand, industry recognizes that, in general, conventional insulating materials do age in service. Because a thyristor valve contains conventional insulating materials as well as thyristors, the effects of ageing on these materials shall be considered when establishing test safety factors. For this reason, while an alternative test safety factor of 1,10 for the thyristors can be supported, the standard shall require an impulse test on all valve components, except thyristors, at test levels corresponding to the test safety factors of 1,15 for lightning and switching impulses and 1,2 for steep front impulse. This is the basis of alternative a) in A.2.1.1 above.

A.2.1.3 Assessment of test safety factor alternatives for impulse tests

As an independent check, the chosen test safety factors were assessed for their adequacy to cover for the best estimates of the known contributing factors to the measurement uncertainty and protective margin components of the test safety factor.

The adequacy of the test safety factors was assessed by the following means.

a) All the factors relating to measuring uncertainties and the protective margin were considered to be statistically independent.

b) From a probability point of view, it was considered unrealistic to assume that all factors were biased in the same direction and simultaneously at their maximum values.

c) It was assumed that the contributing factors could be combined by a root sum of squares (RSS) approach. A check was then made to ensure that the following relationship was satisfied:

$$k_s \geq 1 + \sqrt{\sum k_n^2} \quad \text{(evaluate } n = 1 \text{ to } n\text{)}$$

where

k_s is the test safety factor;

n is the number of factors;

k_n = per unit value of each n -factor (less than 1,0).

d) The factors considered for lightning and switching impulse tests and their associated values were as follows:

   – test voltage measuring error (0,03 per IEC 60060);
   – tolerance on test voltage (0,03 per IEC 60060);
   – measurement tolerance of arrester characteristic (0,03 per IEC 60060);
   – ageing allowance for arrester (0,05 per IEC 60099);
   – study uncertainties – most onerous case (0,03) estimated;
   – allowance for non-standard waveshapes (0,03) estimated;
   – allowance for insulation ageing (0,10 alternatively 0).

e) Using the RSS relationship of c), then, if an insulation ageing factor of 0,1 is assumed for conventional materials then:

$$1 + \sqrt{\sum k_n^2} = 1{,}13$$

With a test safety factor of 1,15 specified, the contingency for any unallowed factors or for errors in the allowed factors amounts to:

$$\sqrt{0{,}15^2 - 0{,}13^2} = 0{,}075$$

If insulation does not significantly age, as is the case for the thyristors, then:

$$1 + \sqrt{\sum k_n^2} = 1{,}084$$

With a test safety factor of 1,10 specified, the contingency for any unallowed factors or for errors in the allowed factors amounts to:

$$\sqrt{0{,}10^2 - 0{,}084^2} = 0{,}055$$

On the basis of the assumptions made, selection of alternative b) of A.2.1.1 will provide an inherent contingency margin of 7,5 % for both thyristors and other materials, and makes no presumption concerning the different ageing mechanisms for thyristors and conventional insulating materials.

Selection of alternative a) of A.2.1.1 will provide an inherent contingency margin of 7,5 % for all materials except the thyristors, and a contingency allowance of 5,5 % for the thyristors on the presumption that ageing of thyristors can be neglected.

The capital cost and operating losses of thyristor valves designed and tested to alternative a) will each be approximately 4,5 % lower than that of alternative b).

A.2.2 AC and d.c. temporary and long-term voltage tests

The durability of the valve dielectric materials cannot be demonstrated during the valve type tests. This is more appropriately carried out as part of separate design or development testing. However, the a.c and d.c. voltage type tests do demonstrate valve withstand capabilities against temporary and long-term overvoltages. The test levels and durations reflect, to a large extent, the established a.c and d.c. test philosophy and practices for conventional dielectric materials. A commonly used indication of the quality of the insulation is partial discharge performance (see Annex B). The standard therefore requires that the quality of insulation be checked during the a.c and d.c. voltage tests by measurement of partial discharges.

In the case of the short-duration valve a.c. voltage test, the test can unrealistically over-stress valve components in the reverse direction because, for practical reasons, the test shall be performed with a.c. (hence giving a large voltage-time area) but the service condition only results in a short duration at high voltage (commutation overshoot). For this reason, a lower test safety factor than normal practice is used. The test safety factor k_8 is based on voltage measuring error (3 %), tolerance on test voltage (3 %), measuring tolerance of surge arrester characteristics (3 %), ageing allowance for arrester (5 %) and an inherent contingency margin, or allowance for other unknown effects (7,5 %).

A.3 Test safety factors for operational tests

The operational test safety factors apply to the combined voltage and current stresses which occur during steady-state operation, specified overloads and fault conditions. The test voltages and currents to be considered are those obtained from the most onerous steady-state operating conditions. In general, only measurement uncertainties need be considered in the test safety factors:

$$k_s = 1 + \sqrt{0,03^2 + 0,03^2} = 1,042, \text{ rounded up to 1,05}$$

For the minimum a.c. voltage tests, the corresponding test safety factor is:

$$k_s = 1 - \sqrt{0,03^2 + 0,03^2} = 0,957, \text{ rounded down to 0,95}$$

For fault current tests, no special current test safety factor is needed (k_s = 1,0).

This is justified on the basis that:

a) the tests are performed with fault current amplitudes that are at least equivalent in severity to the worst case current as determined from calculations or system studies, using the coincidence of worst case factors as listed in 11.3.2 without statistical averaging;

b) a test safety factor of 1,05 is applied to the voltage to be blocked after the fault current.

Annex B
(normative)

Partial discharge measurements

B.1 Measurement of partial discharge

The quality of insulation in the valve support, between highest potential valve and earth, and between valve terminals shall be checked during the a.c and/or d.c. voltage tests by measurement of partial discharges. Present experience in the application of HVDC valves shows that other techniques such as RIV (radio interference voltage) measurements are less indicative for the given purpose.

Partial discharge measurements shall be performed in accordance with IEC 60270.

B.2 Partial discharge during a.c. tests

The sensitivity of the partial discharge measurements for a.c. voltage depends on the capacitance of the test object and the magnitude of the background noise. In most valves, the capacitance between valve terminals is large (mainly due to the presence of the damping capacitors) compared to stray capacitance between the terminals for other equipment. Typical values for thyristor valves are in hundreds of nanofarads and for other equipment they are in the range of tens of picofarads. Consequently, special measurement techniques may be necessary to fulfil the objectives of the test.

The commonly accepted test circuits for the measurement of partial discharge on a large air-insulated apparatus will not separate the partial discharge into surrounding air (corona), which could be acceptable, from any discharges across or through non-healing insulation. Consequently, setting an absolute limit on the partial discharge value for the complete valve will not alone give a dependable result. For an air-insulated valve, partial discharge of up to 200 pC is normally of no consequence as far as discharge into the surrounding air is concerned, but is above the safe threshold for discharges in organic insulation.

For this reason, and also because the a.c. dielectric test on a complete valve or valve support does not stress all components (e.g. damping resistors, saturable reactors, etc.), it is recommended that the partial discharge measurement is performed on all critical components or subassemblies as identified by the supplier. The purpose of partial discharge measurements on a complete valve or valve support during the dielectric tests is then to verify that there are no adverse interactions between individual components or high levels of partial discharge into air. Except as noted in Clause B.4 below, the maximum value of partial discharge for a complete valve or valve support during a.c. tests shall be 200 pC, provided that the valve is air-insulated and partial discharge of the critical components is within their own individual limits as demonstrated by the component test.

B.3 Partial discharge during d.c. tests

It is noted in IEC 60270, that there is no generally accepted method for the determination of the partial discharge magnitude during tests with direct voltage.

Dielectric stresses under steady-state d.c. conditions are determined by the resistivity of the insulating material rather than by the dielectric constant. Due to the high value of the resistivity, the time constant of the system is rather long, therefore partial discharges under d.c. conditions tend to be characterized by pulses of relatively high amplitude (hundreds to thousands of pC) at low repetition rate (seconds to minutes).

For this standard, the quality of insulation during tests with direct voltage is checked by counting the number of partial discharges per unit of time that exceed specified levels. This means that, in general, test circuits and measuring instruments used with alternating voltages may also be used with direct voltages, however with the addition of a multi-level pulse counting device. The d.c. voltage test levels and durations, together with the acceptance limits for partial discharge given in this standard, are based on the following considerations:

– expected service stresses, both in normal operation and during faults;
– previous service and test experience;
– recognition that thyristor valves contain many different dielectric materials which have time constants spanning the whole range of likely values;
– recognition that tests of shorter duration with higher test safety factors will unrepresentatively overstress those valve components with short time constants;
– recognition that the magnitude of partial discharges and number per period of time when using positive polarity is normally higher than when using negative polarity;
– recognition that, following initial application of opposite polarity, a larger amount of partial discharge than that occurring during steady-state d.c. voltage stress can be expected. The value of partial discharge versus time after selection of opposite polarity should decrease.

B.4 Composite a.c. plus d.c. voltage stress

Equipment in an HVDC converter often experiences a service voltage waveshape which comprises both a.c. and d.c. components.

Due to practical difficulties and the lack of experience of partial discharge measurement with composite voltages, separate a.c. and d.c. voltage tests are specified in this standard. A consequence of this approach is that, in striving to reproduce the correct peak voltage stress, those components which are stressed in service mainly by a d.c. component, with only a small component of a.c., will be stressed during the long duration a.c. voltage test with a much higher peak-to-peak voltage excursion than will be encountered in service. Since partial discharge with a.c. voltage stress is strongly influenced by the peak-to-peak voltage swing, the specified tests will be unrealistic for those cases where the service stress is mainly d.c.

Two cases where this will occur are:

a) across the valve support when the support is attached to another bus than the neutral d.c. busbar or lower six-pulse bridge a.c. connection potential;
b) across any two terminals of an MVU between which there are two or more series-connected valves of the same phase.

For the two cases above, recorded values of partial discharge in excess of 200 pC, during the long duration a.c. voltage test, are not necessarily indicative of inadequate design. For this reason, if values of partial discharge in excess of 200 pC are recorded, the test results shall be evaluated by the purchaser and supplier to assess the significance, if any, that the observed values may have on the durability of the equipment in service.

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