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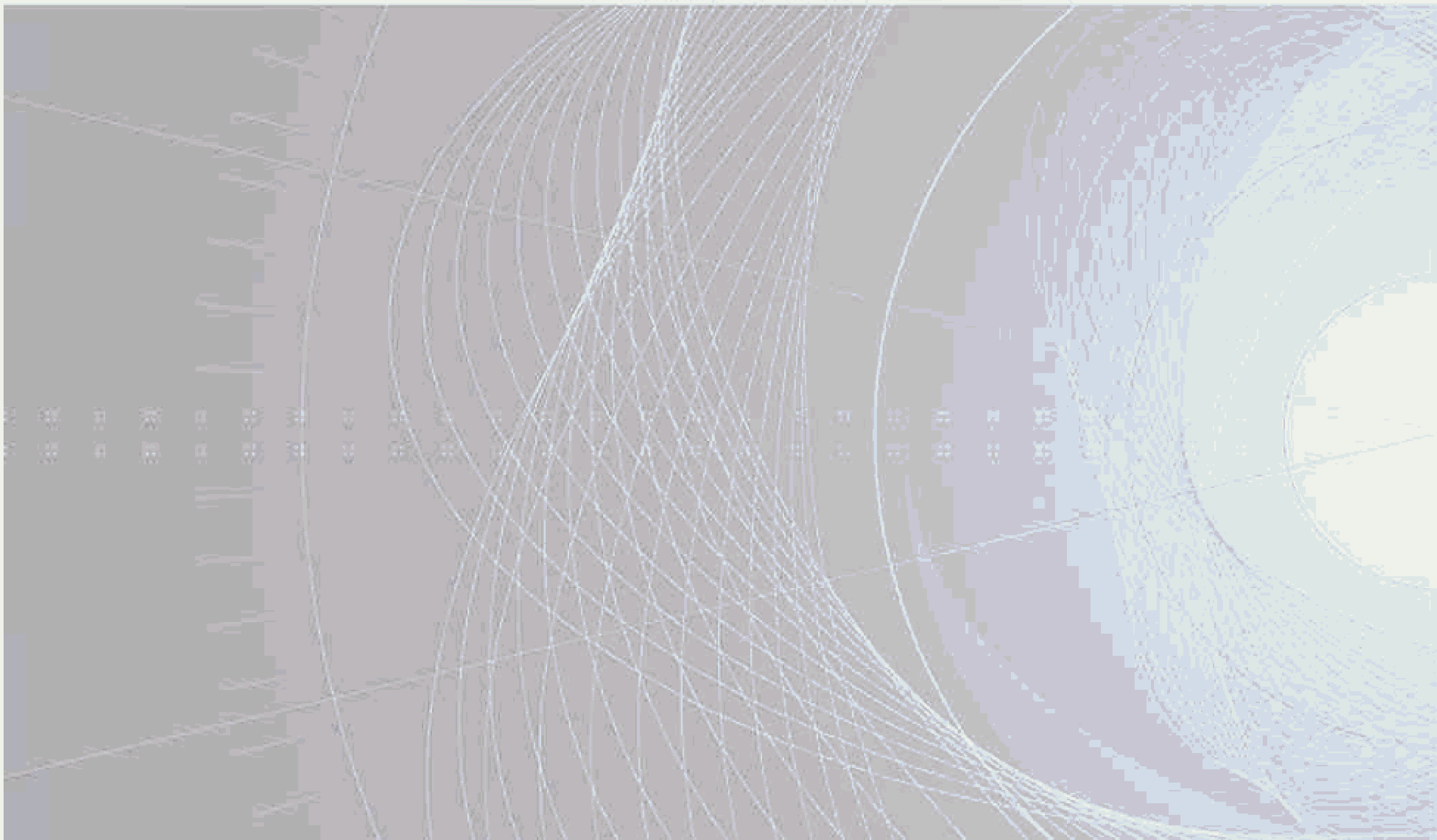
INTERNATIONAL STANDARD

NORME INTERNATIONALE

Static var compensators (SVC) – Testing of thyristor valves

Compensateurs statiques de puissance réactive (SVC) – Essais des valves à thyristors



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INTERNATIONAL ELECTROTECHNICAL COMMISSION

STATIC VAR COMPENSATORS (SVC) – TESTING OF THYRISTOR VALVES

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 61954 has been prepared by subcommittee 22F: Power electronics for electrical transmission and distribution systems, of IEC technical committee 22: Power electronics.

This second edition cancels and replaces the first edition published in 1999, amendment 1 (2003) and constitutes a technical revision.

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

a) Definitions of terms "thyristor level", "valve section", "valve base electronics" and ""redundant thyristor levels" have been changed for clarification.
b) Conditions of testing thyristor valve sections instead of a complete thyristor valve have been defined.
c) The requirement has been added that if, following a type test, one thyristor level has become short-circuited, then the failed level shall be restored and this type test repeated.
d) The time period of increasing the initial test voltage from 50 % to 100 % during type a.c. dielectric tests on TSC, TCR or TSR valves has been set equal to approximately 10 s.

e) The duration of test voltage U_{ts2} during type a.c.-d.c. dielectric tests between TSC valve terminals and earth as well as the duration of test voltage U_{tvv2} during dielectric tests between TSC valves (for MVU only) has been changed from 30 min to 3 h.

f) The reference on the number of pulses per minute of the periodic partial discharge recorded during a.c.-d.c. dielectric tests on TSC valves and exceeding the permissible level has been deleted.

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

CDV	Report on voting
22F/217/CDV	22F/231A/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.

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

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

STATIC VAR COMPENSATORS (SVC) – TESTING OF THYRISTOR VALVES

1 Scope

This International Standard defines type, production and optional tests on thyristor valves used in thyristor controlled reactors (TCR), thyristor switched reactors (TSR) and thyristor switched capacitors (TSC) forming part of static VAR compensators (SVC) for power system applications. The requirements of the standard apply both to single valve units (one phase) and to multiple valve units (several phases).

Clauses 4 to 7 detail the type tests, i.e. tests which are carried out to verify that the valve design meets the requirements specified. Clause 8 covers the production tests, i.e. tests which are carried out to verify proper manufacturing. Clauses 9 and 10 detail optional tests, i.e. tests additional to the type and production tests.

2 Normative references

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

IEC 60060 (all parts), *High-voltage test techniques*

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

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

IEC 60071 (all parts), *Insulation co-ordination*

IEC 60071-1:2006, *Insulation co-ordination – Part 1: Definitions, principles and rules*

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

IEC 60700-1:2008, *Thyristor valves for high-voltage direct current (HVDC) power transmission – Part 1: Electrical testing*

3 Terms and definitions

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

3.1
thyristor level
part of a thyristor valve comprising a thyristor, or thyristors connected in parallel or antiparallel, together with their immediate auxiliaries and reactor, if any

3.2
thyristor (series) string
series connected thyristors forming one direction of a thyristor valve

3.3
valve reactor
reactor incorporated within some valves for limitation of stresses

NOTE For testing purposes it is considered an integral part of the valve.

3.4
valve section
electrical assembly, comprising a number of thyristors and other components, which exhibits pro-rated electrical properties of a complete thyristor valve but only a portion of the full voltage blocking capability of the thyristor valve and which can be used for tests

3.5
thyristor valve
electrically and mechanically combined assembly of thyristor levels, complete with all connections, auxiliary components and mechanical structures, which can be connected in series with each phase of the reactor or capacitor of a SVC

3.6
valve structure
physical structure which insulates the valves to the appropriate level above earth potential and from each other

3.7
valve base electronics
VBE
electronic unit, at earth potential, which is the interface between the control system of the SVC and the thyristor valves

3.8
multiple valve unit
MVU
assembly of several valves in the same physical structure which cannot be separated for test purposes (e.g. three-phase valves)

3.9
redundant thyristor levels
the maximum number of thyristor levels in the 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 either the shutdown of the thyristor valve to replace the failed thyristors, or the acceptance of increased risk of failures

3.10
voltage breakover (VBO) protection
means of protecting the thyristors from excessive voltage by firing them at a predetermined voltage

4 General requirements for type, production and optional tests

4.1 Summary of tests

Table 1 lists the tests given in the following clauses and subclauses.

Table 1 – List of tests

Test	Clause or subclause		Test object
	TCR/TSR	TSC	
Dielectric tests between valve terminals and earth (type tests)			
AC test	5.1.2		Valve
AC-DC test		6.1.2	Valve
Lightning impulse test	5.1.3	6.1.3	Valve
Dielectric tests between valves (MVU only) (type tests)			
AC test	5.2.2		MVU
AC-DC test		6.2.2	MVU
Lightning impulse test	5.2.3	6.2.3	MVU
Dielectric tests between valve terminals (type tests)			
AC test	5.3.2		Valve
AC-DC test		6.3.2	Valve
Switching impulse test	5.3.3	6.3.3	Valve
Operational tests (type tests)			
Periodic firing and extinction test	5.4.1		Valve or valve section
Overcurrent test		6.4.1	Valve or valve section
Minimum a.c. voltage test	5.4.2	6.4.2	Valve or valve section
Temperature rise test	5.4.3	6.4.3	Valve or valve section
Electromagnetic interference tests (type tests)			
Switching impulse test	7.2.2	7.2.2	Valve
Non-periodic firing test	7.2.3	7.2.3	Valve
Production tests			
Visual inspection	8.2	8.2	
Connection check	8.3	8.3	
Voltage dividing/damping circuit check	8.4	8.4	
Voltage withstand check	8.5	8.5	
Check of auxiliaries	8.6	8.6	
Firing check	8.7	8.7	
Cooling system pressure test	8.8	8.8	
Partial discharge tests	8.9	8.9	
Optional tests			
Overcurrent test	9.1		Valve or valve section
Positive voltage transient during recovery test	9.2	10.1	Valve or valve section
Non-periodic firing test	9.3	10.2	Valve

4.2 Objectives of tests

4.2.1 General

The tests described apply to the valve (or valve sections), the valve structure and those parts of the coolant distribution system and firing and monitoring circuits which are contained within the valve structure or connected between the valve structure and earth. Other equipment, such as valve control and protection and valve base electronics may be essential for demonstrating the correct function of the valve during the tests but are not in themselves the subject of the tests.

4.2.2 Dielectric tests

4.2.2.1 General

Tests for the following dielectric stresses are specified:

– a.c. voltage;

– combined a.c. and d.c. voltage (TSC only);

– impulse voltages.

In the interest of standardization with other equipment, lightning impulse tests between valve terminals and earth and between phases of an MVU are included. For tests between valve terminals, the only impulse test specified is a switching impulse.

4.2.2.2 Tests on valve structure

Tests are defined for the voltage withstand requirements between a valve (with its terminals short-circuited) and earth, and also between valves for MVU. The tests shall demonstrate that

– sufficient clearances have been provided to prevent flashovers;

– there is no disruptive discharge in the insulation of the valve structure, cooling ducts, light guides and other insulation parts of the pulse transmission and distribution systems;

– partial discharge inception and extinction voltages under a.c. and d.c. conditions are above the maximum steady-state operating voltage appearing on the valve structure.

4.2.2.3 Tests between valve terminals

The purpose of these tests is to verify the design of the valve with respect to its capability to withstand overvoltages between its terminals. The tests shall demonstrate that

– sufficient internal insulation has been provided to enable the valve to withstand specified voltages;

– partial discharge inception and extinction voltages under a.c. and d.c. conditions are above the maximum steady-state operating voltage appearing between valve terminals;

– the protective overvoltage firing system (if provided) works as intended;

– the thyristors have adequate du/dt capability for in-service conditions. (In most cases the specified tests are sufficient; however in some exceptional cases additional tests may be required).

4.2.3 Operational tests

The purpose of these tests is to verify the valve design for combined voltage and current stresses under normal and abnormal repetitive conditions as well as under transient fault conditions. They shall demonstrate that, under specified conditions:

– the valve functions properly;

– the turn-on and turn-off voltage and current stresses are within the capabilities of the thyristors and other internal circuits;
– the cooling provided is adequate and no component is overheated;
– the overcurrent withstand capability of the valve is adequate.

4.2.4 Electromagnetic interference tests

The principal objective of these tests is to demonstrate the immunity of the valve to electromagnetic interference from within the valve and from outside the valve. Generally, immunity to electromagnetic interference is demonstrated by monitoring of the valve during other tests.

4.2.5 Production tests

The objective of tests is to verify proper manufacture. The production tests shall demonstrate that

– all materials, components and sub-assemblies used in the valve have been correctly installed;
– the valve equipment functions as intended, and predefined parameters are within prescribed acceptance limits;
– thyristor levels and valve or valve sections have the necessary voltage withstand capability;
– consistency and uniformity in production is achieved.

4.2.6 Optional tests

Optional tests are additional tests which may be performed, subject to agreement between the purchaser and the supplier. The objectives are the same as for the operational tests specified in 4.2.2. The test object is normally one valve or appropriate equivalent number of valve sections.

4.3 Guidelines for the performance of type and optional tests

The following principles shall apply:

– type tests shall be performed on at least one valve or on an appropriate number of valve sections, as indicated in Table 1 (see 4.1), to verify that the valve design meets the specified requirements. All type tests shall be performed on the same valve(s) or valve section(s);
– provided that the valve is demonstrably similar to one previously tested, the supplier may submit a certified report of any previous type test, at least equal to the requirements specified in the contract, in lieu of the type test;
– for type tests performed on valve sections, the total number of thyristor levels subjected to such type tests shall be at least equal to the number of thyristor levels in a valve;
– the valve or valve sections used for type tests shall first pass all production tests. On completion of the type test programme, the valve or valve sections shall be checked again for compliance with the production test criteria;
– material for the type tests shall be selected at random;
– the dielectric tests shall be performed in accordance with IEC 60060-1 and IEC 60060-2 where applicable;
– individual tests may be performed in any order.

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

4.4 Test conditions

4.4.1 General

4.4.1.1 Dielectric test objects

Dielectric tests shall be performed on completely assembled valves, whereas some operational tests may be performed on either complete valves or valve sections. Tests that may be performed on valve sections are identified in 4.1.

The valve shall be assembled with all auxiliary components except for the valve arrester, if used. Unless otherwise specified, the valve electronics shall be energized. The cooling and insulating fluids in particular shall be in a condition that represents service conditions such as conductivity, except for the flow rate and antifreezing media content, which can be reduced. If any object or device external to the structure is necessary for proper representation of the stresses during the test, it shall also be present or simulated in the test. Metallic parts of the valve structure (or other valves in a MVU) which are not part of the test shall be shorted together and connected to earth in a manner appropriate to the test in question.

4.4.1.2 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:

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 less than 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 ($b_{1\,000m}$).

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.

Where non-standard test levels are defined by this standard, a site air density correction factor k_d, defined below shall be applied where stated.

The value of k_d shall be determined from the following expression:

$$k_d = \frac{b_1}{b_2} \times \frac{273 + T_2}{273 + T_1} \tag{1}$$

where

b_1 is the laboratory ambient air pressure, expressed in pascals (Pa);

T_1 is the laboratory ambient air temperature, expressed in degrees Celsius (°C);

b_2 is the standard reference atmosphere of 101,3 kPa (i.e. 1 013 mbar), corrected to the altitude of the site at which the equipment will be installed;

T_2 is the design maximum valve hall air temperature, expressed in degrees Celsius (°C).

Correction factors should not be applied either to the dielectric tests between valve terminals or to the long duration dielectric tests whose primary purpose is to check for the internal insulation and partial discharges.

4.4.1.3 Operational tests

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

Sometimes, operational tests may be performed at a power frequency different from the service frequency, e.g. 50 Hz instead of 60 Hz. Some operational stresses such as switching losses or I^2t of short-circuit current are affected by the actual power frequency during tests. When this situation occurs, the test conditions shall be reviewed and appropriate changes made to ensure that the valve stresses are at least as severe as they would be if the tests were performed at the service frequency.

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. Antifreezing media content should, preferably, be equivalent to the service condition; however, where this is not practicable, a correction factor agreed between the supplier and the purchaser shall be applied.

4.4.2 Valve temperature at testing

4.4.2.1 Valve temperature for dielectric tests

Unless specified otherwise, tests shall be performed at room temperature.

4.4.2.2 Valve temperature for operational tests

Unless specified otherwise, tests shall be carried out under the conditions that produce the highest component temperature that may occur in real operation.

If several components are to be verified by a test, it may be necessary to carry out the same test under different conditions.

4.4.3 Redundant thyristor levels

4.4.3.1 Dielectric tests

All dielectric tests on a complete valve shall be carried out with redundant thyristor levels short-circuited, except where otherwise indicated.

4.4.3.2 Operational tests

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

$$k_n = \frac{N_{tot}}{N_t - N_r} \quad (2)$$

where

N_{tot} is the total 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.

NOTE In thyristor valves with a small number of thyristor levels, where the redundancy is a significant portion of the total, this may cause certain valve components to be overstressed. As an alternative, it is therefore acceptable to perform the operational test with redundant thyristor levels short-circuited and without scaling the test voltages and impedances by k_n.

4.5 Permissible component failures during type testing

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 essentially random and do not show any pattern that is indicative of inadequate design.

The valves or valve sections shall be checked before each test, after any preliminary calibration tests, and again after each type test to determine whether or not any thyristors or auxiliary components have failed during the test. Failed thyristors or auxiliary components found at the end of a type test shall be remedied before further testing of a valve.

One thyristor level is permitted to fail due to short-circuiting in any type test. If, following a type test, one thyristor level has become short-circuited, then the failed level shall be restored and this type test repeated (see 4.4.1b) in IEC 60700-1, Amendment 1). The total number of thyristor levels allowed to fail during all tests are given in Table 2.

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

4.6 Documentation of test results

4.6.1 Test reports to be issued

The supplier shall provide certified test reports of all type tests performed on the valves or valve sections.

Test records on the results of routine tests shall be provided by the supplier.

Table 2 – Number of thyristor levels permitted to fail during type tests

Number of thyristor levels in a complete valve	Number of thyristor levels permitted to fail to short circuit in any one type test	Total number of thyristor levels permitted to fail to short circuit in all type tests	Additional number of thyristor levels, in all type tests, permitted to have experienced a fault but have not become short circuited
<34	1	2	2
34 < n < 68	1	3	3
68 < n < 101	1	4	4

4.6.2 Contents of a type test report

A report on the type tests conducted on the thyristor valves shall be produced. The report shall include the following:

a) general data such as:
   - identification of the equipment tested (e.g. type and ratings, drawing number, serial number, etc.);
   - identification of major parts of the test objects (e.g. thyristors, valve reactors, printed circuit cards, etc.);
   - name and location of the facility where the test was carried out;
   - relevant circumstances wherever necessary (e.g. temperature, humidity and barometric pressure during the dielectric tests, etc.);
   - reference to the test specification;
   - dates of the tests;
   - name(s) and signature(s) of the personnel responsible;
   - signature of the purchaser's inspector (if present) and the sign of his approval (if required);

b) description of power sources (i.e. impulse voltage generator, d.c. voltage source, etc.) used for the particular test, such as the name of the manufacturer, ratings, characteristics, etc.;

c) description of the measuring instrumentation, including information on guaranteed accuracy and date of the last calibration;

d) detailed information on the arrangement for each test (e.g. circuit diagramme);

e) description of the test procedures;

f) any agreed deviations or waivers;

g) tabulated results including photographs, oscillograms, graphs, etc.;

h) reports on component failures or other unusual events;

i) conclusions and recommendations, if any.

5 Type tests on TCR and TSR valves

5.1 Dielectric tests between valve terminals and earth

5.1.1 General

For these tests, each thyristor valve shall be short-circuited across valve terminals or individual thyristor levels.

For valves belonging to a MVU, all valves in the same structure shall be short-circuited and connected together. The test voltage shall be applied between all the valves and earth.

See 4.4.1.1 for other detailed requirements of the test object.

5.1.2 AC test

5.1.2.1 Objectives

See 4.2.2.1.

5.1.2.2 Test values and waveshapes

U_{ts1} and U_{ts2} have sinusoidal waveshapes with a frequency of 50 Hz or 60 Hz, depending on the test facilities. U_{ts1} is the standard short-duration power-frequency withstand voltage according to IEC 60071-1, Table 2. U_{ts2} shall be calculated from the following:

$$U_{ts2} = \frac{k_{s2} \times U_{ms2}}{\sqrt{2}} \qquad (3)$$

where

U_{ms2} is the peak value of the maximum steady-state operating voltage, including extinction overshoot, appearing between any valve terminal and earth;

k_{s2} is a test safety factor;

k_{s2} = 1,2.

5.1.2.3 Test procedures

The test consists of applying the specified test voltages U_{ts1} and U_{ts2} for the specified duration between the two interconnected valve terminals and earth.

a) Raise the voltage from 50 % U_{ts1} to 100 % of U_{ts1} in approximately 10 s.
b) Maintain U_{ts1} for 1 min.
c) Reduce the voltage from 100 % U_{ts1} to U_{ts2}.
d) Maintain U_{ts2} for 10 min, record the partial discharge level and then reduce the voltage from U_{ts2} to zero.
e) The peak value of the periodic partial discharge recorded during the last minute of step d) shall be less than 200 pC, provided that the components which are sensitive to partial discharge in the valve have been separately tested, or alternatively, 50 pC if they have not.
f) The measurement of inception and extinction voltage shall be performed in accordance with IEC 60270.

5.1.3 Lightning impulse test

5.1.3.1 Objectives

See 4.2.2.1.

5.1.3.2 Test values and waveshapes

A standard 1,2/50 μs waveshape in accordance with IEC 60060 shall be used.

The peak value of the test voltage is the standard lightning impulse withstand voltage according to IEC 60071-1, Table 2 or 3.

5.1.3.3 Test procedures

The test shall comprise three applications of positive-polarity and three applications of negative-polarity lightning impulse voltages between the earth and the two valve terminals connected together.

5.2 Dielectric tests between valves (MVU only)

5.2.1 General

For these tests, each thyristor valve shall be short-circuited across valve terminals or individual thyristor levels.

The tests shall be repeated to verify the insulation between any two valves located in the same structure, unless the physical arrangement of the MVU makes it unnecessary.

See 4.4.1.1 for other detailed requirements of the test object.

5.2.2 AC test

5.2.2.1 Objectives

See 4.2.2.1.

5.2.2.2 Test values and waveshapes

U_{ts1} and U_{ts2} have sinusoidal waveshapes with a frequency of 50 Hz or 60 Hz depending on the test facilities. U_{ts1} is the standard short-duration power-frequency withstand voltage according to IEC 60071-1, Table 2. U_{ts2} shall be calculated from the following equation:

$$U_{ts2} = \frac{k_{s2} \times U_{ms3}}{\sqrt{2}} \quad (4)$$

where

U_{ms3} is the peak value of the maximum steady-state operating voltage, including extinction overshoot, appearing between valves;

k_{s2} is a test safety factor;

k_{s2} = 1,2.

5.2.2.3 Test procedures

The test consists of applying the specified test voltages U_{ts1} and U_{ts2} for the specified duration between the valves.

a) Raise the voltage from 50 % to 100 % of U_{ts1} in approximately 10 s.
b) Maintain U_{ts1} for 1 min.
c) Reduce the voltage to U_{ts2}.
d) Maintain U_{ts2} for 10 min, record the partial discharge level and then reduce the voltage to zero.
e) The peak value of the periodic partial discharge recorded during the last minute of step d) shall be less than 200 pC, provided that the components which are sensitive to partial discharge in the valve have been separately, or alternatively 50 pC if they have not.
f) The measurement of inception and extinction voltage shall be performed in accordance with IEC 60270.

5.2.3 Lightning impulse test

5.2.3.1 Objectives

See 4.2.2.1.

5.2.3.2 Test values and waveshapes

A standard 1,2/50 µs waveshape shall be used.

The peak value of the test voltage is the standard lightning impulse withstand voltage according to IEC 60071-1, Table 2 or 3.

5.2.3.3 Test procedures

The test shall comprise three applications of positive-polarity and three applications of negative-polarity lightning impulse voltages between valves.

5.3 Dielectric tests between valve terminals

5.3.1 General

For valves belonging to a multiple valve unit, these tests need only be performed on one valve. Each other valve in the same structure shall be short-circuited across valve terminals or individual thyristor levels and connected to earth.

See 4.4.1.1 for detailed requirements for the test object.

5.3.2 AC test

5.3.2.1 Objectives

See 4.2.2.2.

5.3.2.2 Test values and waveshapes

U_{tv1} and U_{tv2} have sinusoidal waveshapes with a frequency of 50 Hz or 60 Hz depending on the test facilities.

The value of the test voltage U_{tv1} depends on the protection system of the valve and is equal to the smaller of U_{tv11} and U_{tv12}. Where neither U_{tv11} nor U_{tv12} can be determined, U_{tv13} shall be used.

U_{tv11} is determined by the VBO protective firing of the valve;

U_{tv12} is determined by the protective action of the arresters;

U_{tv13} is determined by the maximum temporary overvoltage that can occur.

U_{tv11}, U_{tv12} and U_{tv13} shall be evaluated as follows:

$$U_{tv11} = \frac{k_{s11} \times U_1}{\sqrt{2}} \tag{5}$$

where

U_1 is the maximum instantaneous value of the valve terminal-to-terminal voltage that is guaranteed not to initiate the VBO protective firing system, if fitted;

k_{s11} is a test safety factor;

k_{s11} = 0,95.

$$U_{tv12} = \frac{k_{s12} \times U_2}{\sqrt{2}} \qquad (6)$$

where

U_2 is the protective voltage of the arrester, if fitted, connected across the valve terminals;

k_{s12} is a test safety factor;

k_{s12} = 1,1.

$$U_{tv13} = \frac{k_{s13} \times U_3}{\sqrt{2}} \qquad (7)$$

where

U_3 is the peak value of maximum repetitive overvoltage, including extinction overshoot, across the valve terminals for the most severe temporary overvoltage condition specified;

k_{s13} is a test safety factor;

k_{s13} = 1,3.

NOTE The prescribed test may thermally overstress some valve components unrealistically. Where this is the case, subject to agreement between the purchaser and the supplier, the 1 min a.c. voltage withstand test may be replaced by several shorter tests whose minimum duration is determined from the maximum possible duration of the specified overvoltage condition multiplied by 2, but with a total duration of not less than 1 min.

The test voltage U_{tv2} shall be the smaller of U_{tv1} and U_{tv21}:

$$U_{tv21} = \frac{k_{s2} \times U_{mv2}}{\sqrt{2}} \qquad (8)$$

where

U_{mv2} is the peak value of the maximum repetitive voltage, including extinction overshoot, appearing between valve terminals during the most severe steady-state operating condition;

k_{s2} is a test safety factor;

k_{s2} = 1,15.

5.3.2.3 Test procedures

The test procedure consists of applying the specified test voltages, for the specified duration, between the two valve terminals. One terminal of the valve may be earthed.

a) Raise the voltage from 50 % to 100 % of U_{ts1} in approximately 10 s.
b) Maintain U_{tv1} for 1 min.
c) Reduce the voltage to U_{tv2}.
d) Maintain U_{tv2} for 10 min, record the partial discharge level and reduce the voltage to zero.
e) The peak value of the periodic partial discharge recorded during the last minute of step d) shall be less than 200 pC, provided that the components which are sensitive to partial discharge in the valve have been separately tested, or alternatively 50 pC if they have not.
f) The measurement of inception and extinction voltage shall be performed in accordance with IEC 60270.

If protective VBO firing is provided, it shall not operate during this test.

5.3.3 Switching impulse test

5.3.3.1 Objectives

See 4.2.2.2. An additional objective is to verify the electromagnetic interference insensitivity of the valve (see Clause 7).

5.3.3.2 Test values and waveshapes

– Waveshape 1:

  Use a 20/200 µs waveshape, which approximates a typical extinction waveshape, or an alternative approximation if supported by system studies.

– Waveshape 2:

  Use a standard 250/2 500 µs waveshape.

a) Test 1

This test is intended to verify that the protective firing system of the valve (if applicable to the valve design) will not operate for voltage values up to the test voltage.

The test voltage U_{tsv1} is determined as follows:

$$U_{tsv1} = k_s \times U_{pf} \quad \text{(waveshapes 1 and 2)} \tag{9}$$

where

U_{pf} is the value of surge voltage that the valve shall withstand without initiating operation of the protective firing system under service conditions;

k_s is a test safety factor;

k_s = 1,05.

b) Test 2

This test is intended to verify the valve insulation and the proper operation of the protective firing system (if applicable to the valve design).

– **Valves protected by surge arresters:**

The prospective test voltage U_{tsv2} is determined as follows:

$$U_{tsv2} = k_s \times U_{cms} \quad \text{(waveshapes 1 and 2)} \tag{10}$$

where

U_{cms} is the arrester protective level;

k_s is a test safety factor;

k_s = 1,1.

– **Valves protected by VBO:**

The prospective test voltage U_{tsv2} is determined as follows:

$$U_{tsv2} = k_s \times U_{VBO} \quad \text{(waveshapes 1 and 2)} \tag{11}$$

where

U_{VBO} is the maximum VBO protective voltage level with redundant thyristor levels operational;

k_s is a test safety factor;

k_s = 1,1.

The upper and lower limits of the protective VBO firing threshold, with the redundant thyristor levels operational, shall be stated by the manufacturer and a check made that the observed voltage at firing lies between the two limits.

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

NOTE In valve designs where the regular firing circuits are energized independently of the main power circuit, this additional test is not applicable.

c) Test 3

This test is intended to verify the valve insulation when neither arresters nor VBOs are used.

$$U_{tsv2} = k_s \times U_{cms} \text{ (waveshapes 1 and 2)} \quad (12)$$

where

U_{cms} is the switching impulse prospective voltage according to IEC 60071, or as determined by insulation coordination studies;

k_s is a test safety factor;

k_s = 1,3.

The valve shall withstand the test voltage without switching or insulation breakdown.

5.3.3.3 Test procedures

For any of these tests, three applications of switching impulse voltages of each polarity shall be applied between the valve terminals, with one terminal earthed.

Instead of reversing the polarity of the surge generator, the test may be performed with one polarity of the surge generator and reversing the valve terminals.

5.4 Operational tests

5.4.1 Periodic firing and extinction test

5.4.1.1 Objectives

The main objective of this test is to demonstrate the valve switching capability, at elevated voltage and current, during periodic turn-on and turn-off operation. This test also verifies the proper operation of the dividing/damping network provided to ensure uniform voltage distribution.

If the valve design allows continuous operation of individual protective firing (such as VBO), this test shall be used to verify reliable operation of the protective firing circuit itself and the damping circuit at the affected thyristor level.

5.4.1.2 Test values and waveshapes

The valve should be shown to withstand the combined voltage and current stresses resulting from temporary overvoltage. Therefore, the test conditions shall correspond to the specified worst-case, time-dependent system overvoltage (load cycle) for which the SVC must remain in service, taking into account the control and protection characteristics of the scheme. In particular, it shall be demonstrated that the valve can block the highest voltage (including extinction overshoot) combined with the maximum thyristor junction temperature given by the load cycle.

The valve or valve sections shall be subjected to current and voltage waveshapes as close as possible to those experienced by the valve during firing and extinction, for the most critical operating conditions specified below. The time interval of principal interest for firing is the first 10 to 20 μs after firing while, for extinction, the interval of interest is between 0,2 ms before and 1 ms after current zero at thyristor turn-off.

In particular, the following conditions shall be no less severe than in service:

– voltage magnitudes at turn-on and turn-off;
– the d*i*/d*t* at turn-on and at least for 0,2 ms before current zero;
– the thyristor junction temperature.

The following factors shall also be considered:

– the representation of stray capacitance between valve terminals;
– sufficient magnitude and duration of the load current to achieve full area conduction of the thyristor junction.

5.4.1.3 Test procedures

The tests shall be performed using suitable test circuits giving turn-on and turn-off stresses equivalent to the appropriate service conditions, such as a power frequency source feeding a reactor in series with the valve section, or an appropriate synthetic test circuit.

All the auxiliary systems which may influence the behaviour of the valve in the operating conditions specified below (e.g. forced firing) shall be in operation.

Ideally, the test would be performed by reproducing the specified time-dependent source voltage. For practical reasons, a modified test procedure may be adopted as follows:

a) establish maximum steady-state conditions for voltage and current and maintain them until thermal equilibrium is reached;
b) raise the source voltage to the highest value according to the overload characteristic or to the highest value for which phase angle control is guaranteed. A test safety factor of 1,05 shall be applied;
c) keep the firing angle constant close to 90° until the thyristor temperature has reached the maximum temperature given by the specified temporary overvoltage cycle;
d) return to the steady-state operating conditions.

The extinction overshoot, corresponding to the maximum step recovery voltage, shall be measured and checked to ensure that it is less than the design value. If the valve design allows for continuous operation of VBO protective firing of individual thyristor levels, this feature shall be tested under steady-state conditions by disabling the normal firing signal to one thyristor for a period long enough to reach thermal equilibrium for the stressed components.

NOTE The temporary overload cycle for a TSR valve will be a current overload without voltage. In order for the objectives of the test to be fulfilled, the steady-state operation immediately following the overload should be a blocked condition. This will demonstrate the ability of overheated thyristors to withstand the blocking voltage.

5.4.2 Minimum a.c. voltage test

5.4.2.1 Objectives

The purpose of this test is to verify proper operation of the firing system in the TCR valve at the specified minimum a.c. voltage and specified operating conditions.

5.4.2.2 Test procedures, values and waveshapes

The test procedure shall be as follows:

a) apply the minimum temporary undervoltage for which the TCR shall remain controlled and maintain it for a time which is at least equal to twice the specified duration of the temporary undervoltage;

b) vary the control angle α between α_{min} and α_{max};

c) Repeat item b) by reducing (continuously or in steps) the voltage to zero (or to the intervention level of the protection), in order to demonstrate that this condition is not harmful to the valve.

A test safety factor of 0,95 shall be applied.

NOTE Depending on the valve design, it may be necessary to return to the minimum steady-state value of the a.c. voltage after each undervoltage step in order to replenish the gate power supplies.

5.4.3 Temperature rise test

5.4.3.1 Objectives

The main purpose of this test is to demonstrate that the temperature rise of the most critical heat producing components is within specified limits, to verify that no components or materials are subjected to excessive temperatures under different steady-state operating conditions and to demonstrate that the cooling provided is adequate.

5.4.3.2 Test procedures

The valve shall be subjected to voltages and currents that result in losses that are 5 % greater than those occurring in service under specified operating conditions, for the most stringent cooling conditions. The test shall be continued for 30 min after thermal equilibrium has been reached.

More than one test may be required in order to determine the temperature rise of some components whose maximum thermal loadings can occur under different operating conditions.

In the event when the current conduction capacity of the interconnection links (busbars) between the antiparallel thyristors is a concern, the test shall be repeated with one thyristor level short circuited, for example by substituting a thyristor by a metal dummy.

NOTE Where the temperature of the critical part of the heat-producing components cannot practically be determined by measurement, for example the junction temperature of the thyristors or the element temperature of the dividing/damping resistors, a measurement at an appropriate point from which this temperature can be estimated may be used.

6 Type tests on TSC valves

6.1 Dielectric tests between valve terminals and earth

6.1.1 General

For these tests, each thyristor valve shall be short-circuited across valve terminals or individual thyristor levels.

For valves belonging to a multiple valve unit (MVU), all valves in the same structure shall be short-circuited and connected together. The test voltage shall be applied between all the valves and earth.

See 4.4.1.1 for other detailed requirements of the test object

6.1.2 AC-DC test

6.1.2.1 Objectives

See 4.2.2.1.

6.1.2.2 Test values and waveshapes

a) Test voltage U_{ts1}, 1 min

U_{ts1} has a sinusoidal waveshape superimposed on a d.c. level. U_{ts1} shall be calculated from the following:

$$U_{ts1} = U_{tac1} + U_{tdc1} \qquad (13)$$

$$U_{tac1} = k_{s1} \times k_d \times U_{ac1} \times \sin(2\pi ft) \qquad (14)$$

$$U_{tdc1} = k_{s1} \times k_d \times U_{dcm1} \qquad (15)$$

where

U_{dcm1} is the maximum d.c. voltage remaining across the capacitor bank after any fast-acting discharge devices, e.g. arresters (decay time constant less than 100 ms) have ceased conducting after blocking of the valve following a system disturbance;

U_{ac1} is the peak value of the maximum predicted long duration overvoltage (excluding the d.c. component) that can appear between any valve terminal and earth;

k_{s1} is a test safety factor;

k_{s1} = 1,3;

k_d is the site air density correction factor (see 4.4.1.2);

f is the test frequency (50 Hz or 60 Hz depending on test facilities).

b) Test voltage U_{ts2}, 10 min

U_{ts2} has a sinusoidal waveshape (see 4.2.2). U_{ts2} shall be calculated from the following:

$$U_{ts2} = k_{s2} \times U_{ac2} \times \sin(2\pi ft) \qquad (16)$$

where

U_{ac2} is the peak value of the maximum steady-state operating voltage that can appear between any valve terminal and earth;

k_{s2} is a test safety factor;

k_{s2} = 1,15;

f is the test frequency (50 Hz or 60 Hz depending on test facilities).

6.1.2.3 Test procedures

The test consists of applying the specified test voltages U_{ts1} and U_{ts2} for the specified durations between the two interconnected valve terminals and earth.

a) Raise the voltage from 50 % to 100 % of U_{ts1} in approximately 10 s.

b) Maintain U_{ts1} for 1 min.

c) Reduce the voltage to U_{ts2}.

d) Maintain U_{ts2} for 10 min, record the partial discharge level and then reduce the voltage to zero.

e) The peak value of the periodic partial discharge recorded during the last minute of step d) shall be less than 200 pC, provided that the components which are sensitive to partial discharge in the valve have been separately tested, or alternatively 50 pC if they have not.

f) The measurement of inception and extinction voltage shall be performed according to IEC 60270 for a.c. tests

6.1.2.4 Alternative tests

The composite a.c.-d.c. test may be replaced by an a.c. test and a d.c. test performed separately.

a) AC test

The test consists of applying the specified test voltages $U_{t1(ac)}$ and $U_{t2(ac)}$ for the specified duration between the two interconnected valve terminals and earth. $U_{t1(ac)}$ and $U_{t2(ac)}$ have sinusoidal waveshapes with a frequency of 50 Hz or 60 Hz, depending on the test facilities.

$$U_{t1(ac)} = k_{s1} \times k_d \times (U_{ac1} + U_{dcm1})/\sqrt{2} \quad (17)$$

$$U_{t2(ac)} = k_{s2} \times U_{ac2} / \sqrt{2} \quad (18)$$

See 6.1.2.2 for definitions.

1) Raise the voltage from 50 % to 100 % of $U_{t1(ac)}$ in approximately 10 s.
2) Maintain $U_{t1(ac)}$ for 1 min.
3) Reduce the voltage to $U_{t2(ac)}$.
4) Maintain $U_{t2(ac)}$ for 10 min, record the partial discharge level and then reduce the voltage to zero.
5) The peak value of the periodic partial discharge recorded during the last minute of step d) shall be less than 200 pC, provided that the components which are sensitive to partial discharge in the valve have been separately tested, or alternatively, 50 pC if they have not.
6) The measurement of inception and extinction voltage shall be performed in accordance with IEC 60270.

b) DC test

The test consists of applying the specified d.c. test voltage $U_{t1(dc)}$ for the specified duration between the two interconnected valve terminals and earth.

$$U_{t1(dc)} = k_{s1} \times k_d \sqrt{\left(\frac{U_{ac1}}{\sqrt{2}}\right)^2 + U_{dcm1}^2} \quad (19)$$

See 6.1.2.2 for definitions.

The test shall be repeated for both polarities of the d.c. component.

1) Raise the voltage from 50 % to 100 % of $U_{t1(dc)}$ in approximately 10 s.
2) Maintain $U_{t1(dc)}$ for 1 min.
3) Reduce the voltage to zero.

6.1.3 Lightning impulse test

6.1.3.1 Objectives

See 4.2.2.1.

6.1.3.2 Test values and waveshapes

A standard 1,2/50 µs waveshape in accordance with IEC 60060 shall be used.

The peak value of the test voltage is the standard lightning impulse withstand voltage according to IEC 60071-1, Table 2 or 3.

6.1.3.3 Test procedures

The test shall comprise three applications of positive-polarity and three applications of negative-polarity lightning impulse voltages between earth and the two valve terminals connected together.

6.2 Dielectric tests between valves (for MVU only)

6.2.1 General

For these tests, each thyristor valve shall be short-circuited across valve terminals or individual thyristor levels.

The tests shall be repeated to verify the insulation between any two valves located in the same structure, unless the physical arrangement of the MVU makes it unnecessary.

See 4.4.1.1 for other detailed requirements of the test object.

6.2.2 AC-DC test

6.2.2.1 Objectives

See 4.2.2.1.

6.2.2.2 Test values and waveshapes

a) Test voltage U_{tvv1}, 1 min

U_{tvv1} has a sinusoidal waveshape superimposed on a d.c. level. U_{tvv1} shall be calculated from the following:

$$U_{tvv1} = U_{tac1} + U_{tdc1} \tag{20}$$

$$U_{tac1} = k_{s1} \times k_d \times U_{ac1} \times \sin(2\pi f t) \tag{21}$$

$$U_{tdc1} = k_{s1} \times k_d \times U_{dcm1} \times k_{dc} \tag{22}$$

where

U_{dcm1} is the maximum d.c. voltage remaining across the capacitor bank after any fast-acting discharge devices e.g. arresters (decay time constant less than 100 ms) have ceased conducting after blocking of the valve following a system disturbance;

U_{ac1} is the peak value of the maximum predicted long duration overvoltage (excluding the d.c. component) that can appear between adjacent valve terminals;

k_{s1} is a test safety factor;

k_{s1} = 1,3;

k_d is the site air density correction factor (see 4.4.1.2);

k_{dc} = 2. An alternative value, e.g. 1, may be used if the supplier can demonstrate to the satisfaction of the purchaser that this figure is applicable to the MVU design;

f is the test frequency (50 Hz or 60 Hz depending on test facilities).

b) Test voltage U_{tvv2}, 10 min

U_{tvv2} has a sinusoidal whaveshape (see 4.2.2). U_{tvv2} shall be calculated from the following:

$$U_{tvv2} = k_{s2} \times U_{ac2} \times \sin(2\pi ft) \tag{23}$$

where

U_{ac2} is the peak value of the maximum steady-state operating voltage that can appear between adjacent valve terminal and earth;

k_{s2} is a test safety factor;

k_{s2} = 1,15;

f is the test frequency (50 Hz or 60 Hz depending on test facilities).

6.2.2.3 Test procedures

The test consists of applying the specified test voltages U_{tvv1} and U_{tvv2} for the specified duration between the valves. The test voltage U_{tac1} or U_{tac2} may be applied between the terminals (short-circuited together) and earth of one valve and the d.c. voltage U_{tdc1} or U_{tdc2} between the terminals (all short-circuited together) of all remaining valves and earth. Other arrangements for combining the a.c. and d.c. voltages are also possible.

a) Raise the voltage from 50 % to 100 % of U_{ts1} in approximately 10 s.

b) Maintain U_{tvv1} for 1 min.

c) Reduce the voltage to U_{tvv2}.

d) Maintain U_{tvv2} for 10 min, record the partial discharge level and then reduce the voltage to zero.

e) The peak value of the periodic partial discharge recorded during the last minute of step d) shall be less than 200 pC, provided that the components which are sensitive to partial discharge in the MVU have been separately tested, or alternatively 50 pC if they have not.

f) The measurement of inception and extinction voltage shall be performed according to IEC 60270 for a.c. tests.

6.2.2.4 Alternative tests

The composite a.c.-d.c. test may be replaced by an a.c. test and a d.c. test performed separately.

a) AC test

The test consists of applying the specified test voltages $U_{t1(ac)}$ and $U_{t2(ac)}$ for the specified duration between the two valves. $U_{t1(ac)}$ and $U_{t2(ac)}$ have sinusoidal waveshapes with a frequency of 50 Hz or 60 Hz, depending on the test facilities.

$$U_{t1(ac)} = k_{s1} \times k_d \times (U_{ac1} + k_{dc} \times U_{dcm1})/\sqrt{2} \tag{24}$$

$$U_{t2(ac)} = k_{s2} \times U_{ac2} / \sqrt{2} \tag{25}$$

See 6.2.2.2 for definitions.

1) Raise the voltage from 50 % to 100 % of $U_{t1(ac)}$ in approximately 10 s.
2) Maintain $U_{t1(ac)}$ for 1 min.
3) Reduce the voltage to $U_{t2(ac)}$.
4) Maintain $U_{t2(ac)}$ for 10 min, record the partial discharge level and then reduce the voltage to zero.
5) The peak value of the periodic partial discharge recorded during the last minute of step d) shall be less than 200 pC, provided that the components which are sensitive to partial discharge in the MVU have been separately tested, or alternatively 50 pC if they have not.
6) The measurement of inception and extinction voltage shall be performed in accordance with IEC 60270.

b) DC test

The test consists of applying the specified d.c. test voltage $U_{t1(dc)}$ for the specified duration between the two interconnected valve terminals and earth.

$$U_{t1(dc)} = k_{s1} \times k_{d} \sqrt{\left(\frac{U_{ac1}}{\sqrt{2}}\right)^2 + (k_{dc} \times U_{dcm1})^2} \tag{26}$$

See 6.2.2.2 for definitions.

The test shall be repeated for both polarities of the d.c. component.

1) Raise the voltage from 50 % to 100 % of $U_{t1(dc)}$ in approximately 10 s.
2) Maintain $U_{t1(dc)}$ for 1 min.
3) Reduce the voltage to zero.

6.2.3 Lightning impulse test

6.2.3.1 Objectives

See 4.2.2.1.

6.2.3.2 Test values and waveshapes

A standard 1,2/50 µs waveshape in accordance with IEC 60060 shall be used.

The peak value of the test voltage is the standard lightning impulse withstand voltage according to IEC 60071-1, Table 2 or 3.

6.2.3.3 Test procedures

The test shall comprise three applications of positive polarity and three applications of negative polarity lightning impulse voltages between the valves.

6.3 Dielectric tests between valve terminals

6.3.1 General

For valves belonging to a multiple valve unit, these tests need only be performed on one valve. Each other valve in the same structure shall be short-circuited across valve terminals or individual thyristor levels and connected to earth.

See 4.4.1.1 for other detailed requirements of the test object.

6.3.2 AC-DC test

6.3.2.1 Objectives

See 4.2.2.2.

6.3.2.2 Test values and waveshapes

a) Test voltage U_{tv1}, 1 min

U_{tv1} has a sinusoidal waveshape superimposed on a d.c. level. U_{tv1} shall be calculated from the following:

$$U_{tv1} = U_{tac1} + U_{tdc1} \tag{27}$$

$$U_{tac1} = k_{s1} \times U_{ac1} \times \sin(2\pi ft) \tag{28}$$

$$U_{tdc1} = k_{s1} \times U_{dcm1} \tag{29}$$

where

U_{dcm1} is the maximum d.c. voltage remaining across the capacitor bank after any fast acting discharge devices e.g. arresters (decay time constant less than 100 ms) have ceased conducting after blocking of the valve following a system disturbance;

U_{ac1} is the peak value of the long duration overvoltage (excluding the d.c. component) that can appear across the valve;

k_{s1} is a test safety factor;

k_{s1} = 1,1 if the voltage is limited by a surge arrester;

k_{s1} = 1,30 if no arrester is fitted;

f is the test frequency (50 Hz or 60 Hz depending on test facilities).

b) Test voltage U_{tv2}, 10 min

U_{tv2} has a sinusoidal waveshape (see 4.2.1). U_{tv2} shall be calculated from the following:

$$U_{tv2} = k_{s2} \times U_{ac2} \times \sin(2\pi ft) \tag{30}$$

where

U_{ac2} is the peak value of the maximum steady-state operating voltage that can appear between valve terminals;

k_{s2} is a test safety factor;

k_{s2} = 1,15;

f is the test frequency (50 Hz or 60 Hz depending on test facilities).

6.3.2.3 Test procedures

The test consists of applying the specified test voltages U_{tv1} and U_{tv2} for the specified duration between the two valve terminals. One terminal of the valve may be earthed.

a) Raise the voltage from 50 % to 100 % U_{tv1} in approximately 10 s.

b) Maintain U_{tv1} for 1 min.

c) Reduce the voltage to U_{tv2}.

d) Maintain U_{tv2} for 10 min, record the partial discharge level and then reduce the voltage to zero.

e) The peak value of the periodic partial discharge recorded during the last minute of step d) shall be less than 200 pC, provided that the components which are sensitive to partial discharge in the valve have been separately tested, or alternatively 50 pC if they have not.

f) The measurement of inception and extinction voltage shall be performed according to IEC 60270 for a.c. tests.

6.3.2.4 Alternative tests

The composite a.c.-d.c. test may be replaced by an a.c. test and a d.c. test performed separately.

a) AC test

The test consists of applying the specified test voltages $U_{t1(ac)}$ and $U_{t2(ac)}$ for the specified duration between the two valve terminals. $U_{t1(ac)}$ and $U_{t2(ac)}$ have sinusoidal waveshapes with a frequency of 50 Hz or 60 Hz, depending on the test facilities.

$$U_{t1(ac)} = k_{s1} \times (U_{ac1} + U_{dcm1})/\sqrt{2} \qquad (31)$$

$$U_{t2(ac)} = k_{s2} \times U_{ac2} / \sqrt{2} \qquad (32)$$

See 6.3.2.2 for definitions.

1) Raise the voltage from 50 % to 100 % of $U_{t1(ac)}$ in approximately 10 s.

2) Maintain $U_{t1(ac)}$ for 1 min.

3) Reduce the voltage to $U_{t2(ac)}$.

4) Maintain $U_{t2(ac)}$ for 10 min, record the partial discharge level and then reduce the voltage to zero.

5) The peak value of the periodic partial discharge recorded during the last minute of step d) shall be less than 200 pC, provided that the components which are sensitive to partial discharge in the valve have been separately tested, or alternatively 50 pC if they have not.

6) The measurement of inception and extinction voltage shall be performed in accordance with IEC 60270.

NOTE The prescribed test may thermally overstress some valve components unrealistically. Where this is the case, subject to agreement between the purchaser and the supplier, the 1 min a.c. voltage withstand test may be replaced by several shorter tests whose minimum duration is determined from the maximum possible duration of the specified overvoltage condition multiplied by 2, but with a total duration of not less than 1 min.

b) DC test

The test consists of applying the specified d.c. test voltage $U_{t1(dc)}$ for the specified duration between the two interconnected valve terminals and earth.

$$U_{t1(dc)} = k_{s1}\sqrt{\left(\frac{U_{ac1}}{\sqrt{2}}\right)^2 + U_{dcm1}^2} \quad (33)$$

See 6.3.2.2 for definitions.

The test shall be repeated for both polarities of the d.c. component.

1) Raise the voltage from 50 % to 100 % of $U_{t1(dc)}$ in approximately 10 s.
2) Maintain $U_{t1(dc)}$ for 1 min.
3) Reduce the voltage to zero.

6.3.3 Switching impulse test

6.3.3.1 Objectives

See 4.2.2.2.

The main objective of this test is to verify the withstand of the valve including the non-operation of VBO protective firing circuits, if fitted. This test checks for correct coordination between the arrester protective level and the valve protective firing threshold. An additional objective is to verify the electromagnetic interference insensitivity of the valve (see Clause 7).

6.3.3.2 Test values and waveshapes

– Waveshape 1

  Use a 20/200 µs waveshape, which approximates a typical extinction waveshape, or an alternative approximation if supported by system studies.

– Waveshape 2

  A standard 250/2 500 µs waveshape shall be used.

a) Valves protected by surge arresters

The test voltage shall be calculated from the following equation:

$$U_{tsv} = k_s \times U_{cms} \text{ (waveshapes 1 and 2)} \quad (34)$$

where

U_{cms} is the arrester protective level for switching impulses;

k_s is a safety factor;

k_s = 1,1.

b) Valves not protected by surge arresters

The test voltage shall be calculated from the following equation:

$$U_{tsv} = k_s \times U_{cms} \text{ (waveshapes 1 and 2)} \quad (35)$$

where

U_{cms} is the switching impulse prospective voltage according to IEC 60071, or as determined by insulation coordination studies;

k_s is a safety factor;

k_s = 1,3.

The valve shall withstand the test without switching or insulation breakdown.

6.3.3.3 Test procedures

Three applications of each polarity of a switching impulse voltage of the specified amplitude and waveshape shall be applied between the valve terminals, one of which may be earthed.

Instead of reversing the polarity of the surge generator, the test may be performed with one polarity of the surge generator and reversing the valve terminals.

NOTE Protective firing, if fitted, should not operate during the test.

6.4 Operational tests

6.4.1 Overcurrent tests

6.4.1.1 General

The main objective of these tests is to demonstrate the proper design of the valve during overcurrent conditions, caused by valve firing at instants with non-zero voltage between its terminals.

The overcurrent tests may be carried out using an oscillatory circuit, which consists of a reactor and capacitor fed from a fundamental frequency power source, or by an appropriate synthetic test circuit.

6.4.1.2 Overcurrent with subsequent blocking

6.4.1.2.1 Objectives

The objective of the test is to demonstrate the correct design of the valve with regard to voltage stress at elevated thyristor junction temperatures produced by the overcurrent. Both forward and reverse reapplied voltage need to be demonstrated.

6.4.1.2.2 Test values and waveshapes

The most important parameters to be reproduced are the magnitude and timing of the reapplied voltage (forward and reverse), and the corresponding thyristor temperature. Adequate representation of di/dt and step recovery voltage is also important.

The circuit diagramme of one TSC branch is shown in Figure 1.

The test current waveshape shall comprise one or two pulses having a current of peak value at least equal to the highest value of overcurrent after which blocking is permitted. The worst case of overcurrent and corresponding reapplied voltage (step and peak value), considering firing instant and number of pulses, shall be determined from system studies using the following sequence of events:

a) the valve shall be blocked at the highest system voltage permitted by the SVC control and protective systems;
b) the valve shall be fired with the system voltage as indicated above, with the capacitors charged. It shall be fired shortly before the voltage between its terminals is at its maximum. Where a protective system is installed to prevent firing at high-voltage levels, the firing shall occur at the limit set by the protection. This valve firing shall determine the current peak;

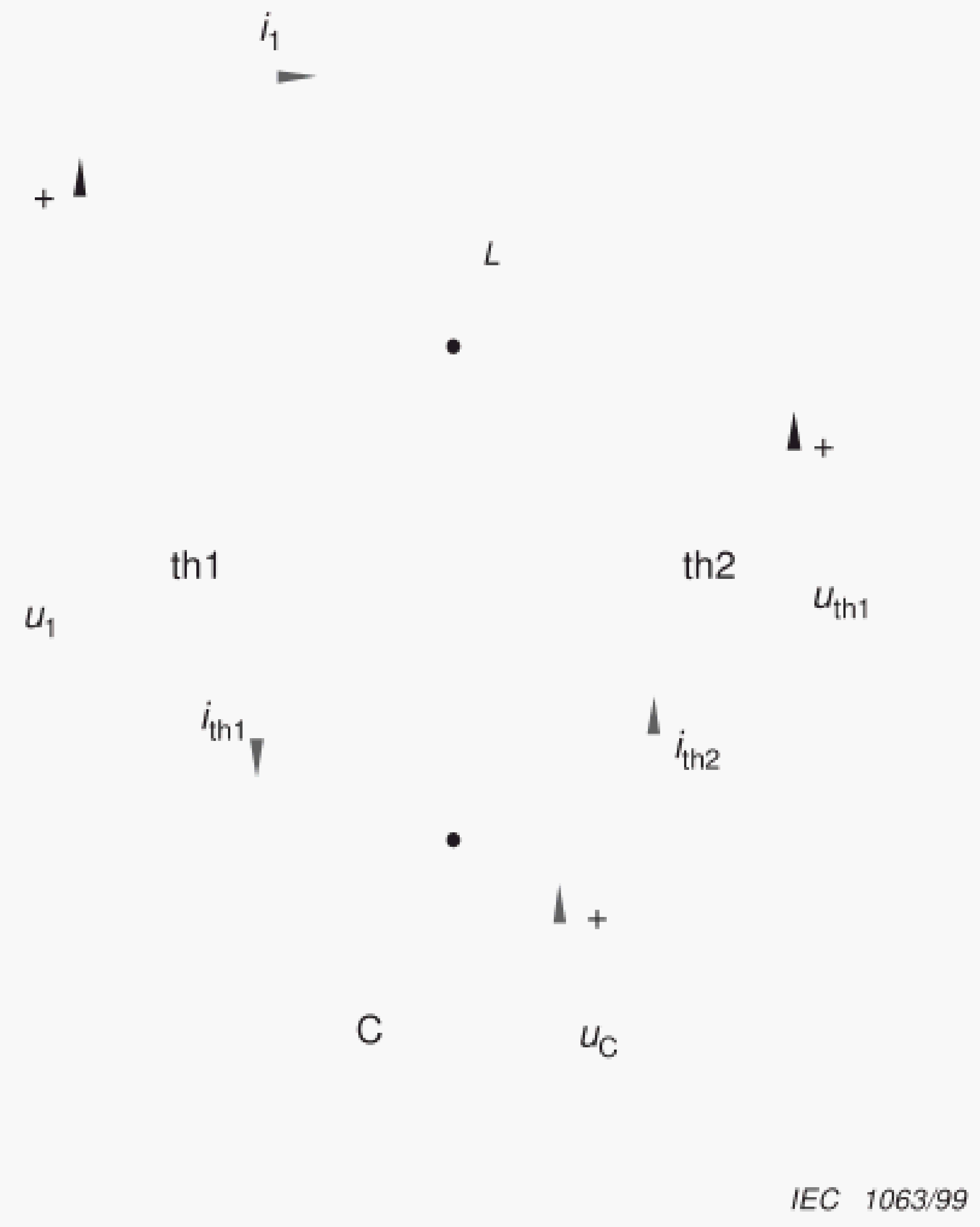


Figure 1 – TSC branch

c) the valve shall be blocked at its first current zero crossing in order to define the valve maximum reverse voltage stress (Figure 2). The step voltage shall be defined directly after the valve blocking, and it shall not include the valve current extinction overshoot. The peak voltage shall be defined at the largest subsequent voltage peak within a fundamental frequency cycle;

d) the valve shall be blocked at its second current zero crossing in order to define the valve maximum forward voltage stress (Figure 3). The step voltage shall be defined directly after the valve blocking, and it shall not include the valve current extinction overshoot. The peak voltage shall be defined at the largest subsequent voltage peak within a fundamental frequency cycle.

The frequency of the test current should approximate to the resonant frequency of the real TSC circuit.

If a surge arrester is used to limit the valve voltage, then a special arrester, pro-rated according to the number of thyristor levels under test, may be included in the test circuit.

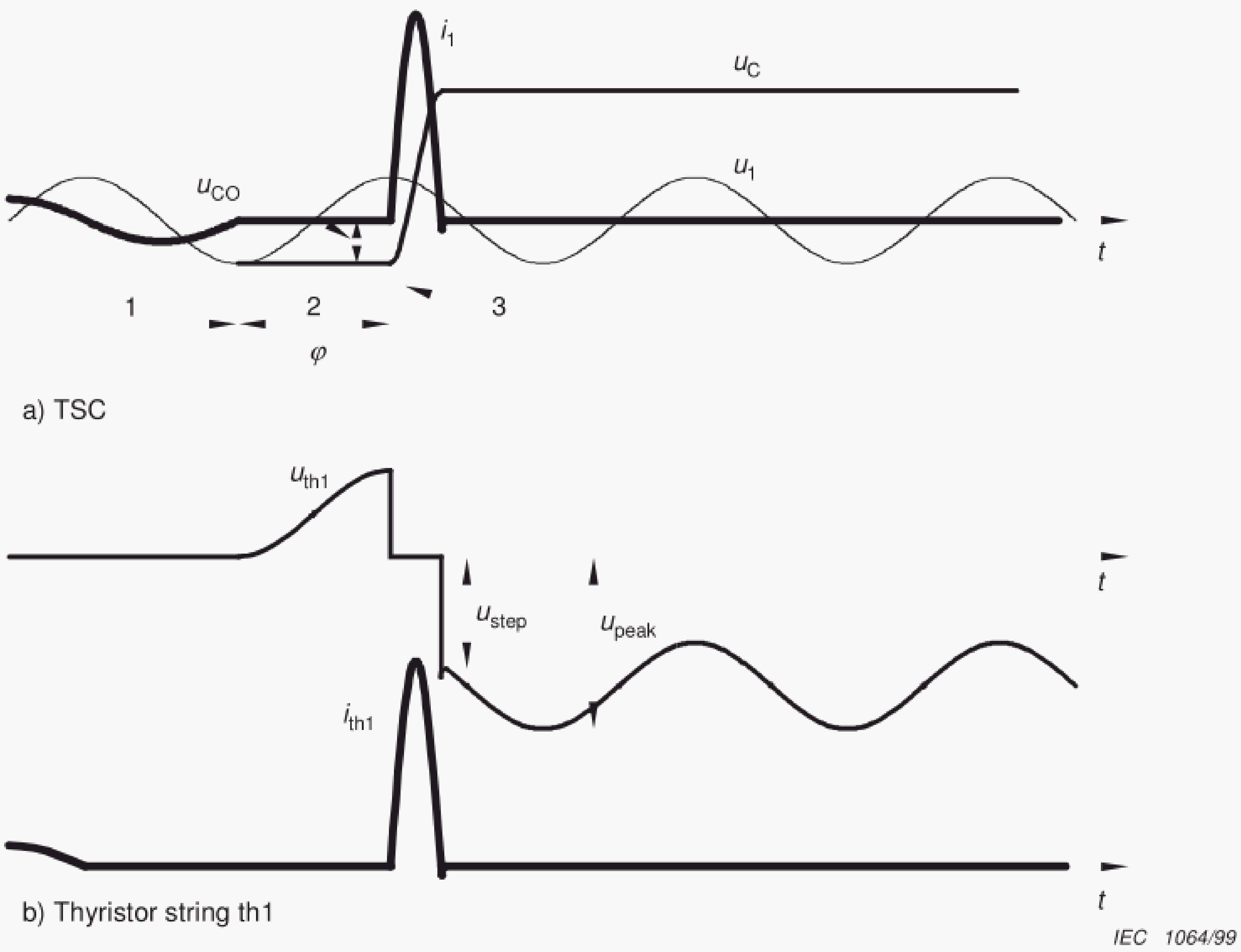
6.4.1.2.3 Test procedure

The test should be performed such that both directions of conduction of thyristor strings are tested.

a) Preheat the valve (or valve section) to a condition which represents the maximum steady-state temperature.

b) Subject the valve (or valve section) to the worst overcurrent and associated reapplied voltage determined by 6.4.1.2.2.

NOTE The test may comprise one or two loops or both, provided the test objectives are met.



Key

1 Normal operation

2 Blocked

3 Valve fired

u_{co} Voltage of charged capacitor C

φ Conduction angle of thyristor string th2

Figure 2 – One-loop overcurrent

6.4.1.3 Overcurrent without blocking

6.4.1.3.1 Objectives

The objective of this test is to demonstrate the correct design of the valve with regard to the heating effect and electromagnetic forces imposed by the most onerous overcurrent to which the valve can be subjected in service.

6.4.1.3.2 Test values and waveshapes

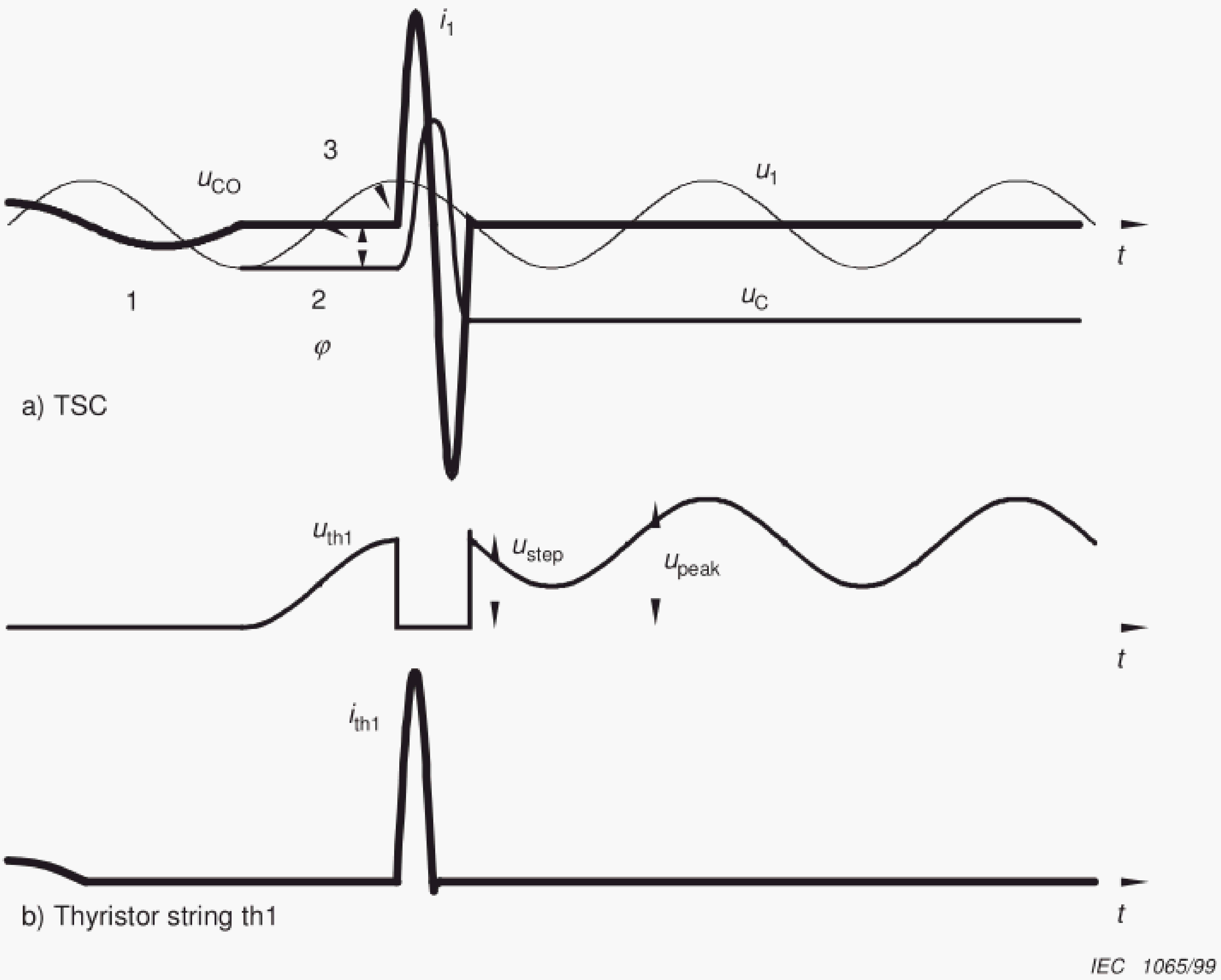
The test current waveshape shall be a damped sinusoidal current oscillation, or a suitable alternative representation which gives a peak current, total I^2t and peak thyristor junction temperature not less than in service.

The frequency of the test current should approximate to the resonant frequency of the real TSC circuit.

6.4.1.3.3 Test procedure

a) Preheat the valve (or valve section) to a condition which represents the maximum steady state temperature.

b) Subject the valve (or valve section) to the overcurrent.



Key

1 Normal operation

2 Blocked

3 Valve fired

u_{co} Voltage of charged capacitor C

φ Conduction angle of thyristor string th2

Figure 3 – Two-loop overcurrent

6.4.2 Minimum a.c. voltage test

6.4.2.1 Objectives

The purpose of this test is to verify proper operation of the firing system in the TSC valve at specified minimum a.c. voltage and specified operating conditions.

6.4.2.2 Test procedures, values and waveshapes

The test procedure shall be as follows:

a) apply the minimum temporary undervoltage for which the TSC shall remain controlled and maintain the valve in the conducting state for a time which is at least equal to twice the specified duration of the temporary undervoltage;

b) repeat item a) by reducing (continuously or in steps) the voltage to zero (or to the intervention level of the protection), in order to demonstrate that this condition is not harmful to the valve.

NOTE Depending on the valve design, it may be necessary after each undervoltage step to return to the minimum steady-state value of the a.c. voltage in order to replenish the gate power supplies.

A test safety factor of 0,95 shall be applied.

6.4.3 Temperature rise test

6.4.3.1 Objectives

The main purpose of this test is to demonstrate that the temperature rise of the most critical heat producing components is within specified limits, to verify that no components or materials are subjected to excessive temperatures under different steady-state operating conditions and to verify that the cooling is adequate.

6.4.3.2 Test procedures

The valve shall be subjected to voltages and currents that result in losses that are 5 % greater than those occurring in service under specified operating conditions, for the most stringent cooling conditions. The test shall be continued for 30 min after thermal equilibrium has been reached.

More than one test may be required in order to determine the temperature rise of components whose maximum thermal loading can occur under different operating conditions.

In the event that the current conduction capacity of the interconnection links (busbars) between the antiparallel thyristors is a concern, the test shall be repeated with one thyristor level short circuited, for example by substituting a thyristor by a metal dummy.

NOTE Where the temperature of the critical part of the heat-producing components cannot practically be determined by measurement, for example the junction temperature of the thyristors or the element temperature of the damping resistors, a measurement at an appropriate point from which this temperature can be estimated may be used.

7 Electromagnetic interference tests

7.1 Objectives

The objective of these tests is to demonstrate the insensitivity of the valve to electromagnetic emission imposed by external events or by the switching of other closely located valves.

The tests shall demonstrate that, as a result of electromagnetic emission,

– spurious triggering of thyristors does not occur;
– false indication of thyristor level faults or erroneous signals sent to the SVC control and protection system do not occur.

NOTE 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.

7.2 Test procedures

7.2.1 General

Insensitivity to electromagnetic interference is verified by monitoring the valve during the switching impulse and non-periodic firing tests. In the first case, the valve which is subjected to the switching impulse is also monitored for electromagnetic interference insensitivity. In the second case, an additional test valve shall be positioned adjacent to the valve being subjected to the non-periodic firing test. This additional test object shall be monitored for electromagnetic interference.

The geometric arrangements of the test valves shall be as in service.

7.2.2 Switching impulse test

The test is performed as a part of the TCR/TSR and TSC type tests (5.3.3.1 and 6.3.2.1, respectively).

The electronics of the valve under test shall be energized.

Those parts of the valve base electronics that are necessary for the proper exchange of information with the test valve shall be included.

The criteria for test acceptance are that no spurious valve firing or false indication from the valve to control or protection system occur. The criteria apply to both the valve under test and the adjacent valve where fitted.

7.2.3 Non-periodic firing test

The test is performed as a part of the TCR/TSR and TSC optional tests (9.3 and 10.2, respectively).

The electronics of the valve under test shall be energized.

Those parts of the valve base electronics that are necessary for the proper exchange of information with the test valve shall be included.

The test object shall have operational fundamental frequency voltage (nominal service voltage) across its terminals. The tests shall be performed close to the peak of the voltage and run at both polarities of the voltage.

NOTE In many cases the non-periodic firing test objectives can be fulfilled by other tests e.g. for the TCR by the switching impulse test with VBO firing and for the TSC by the overcurrent tests.

The criteria for test acceptance are that no spurious valve firing or false indication from the valve to control or protection system occur. These criteria apply to both the test object and the adjacent valve.

8 Production tests

8.1 General

The specified tests define the minimum testing required. The supplier shall provide a detailed description of the test procedures to meet the test objectives.

8.2 Visual inspection

Test objective:

a) to check that all materials and components are undamaged and correctly installed;
b) to check data of components installed;
c) to check air clearances and creepage distances within the valve.

8.3 Connection check

Test objective:

a) to check that all the main current-carrying connections have been made correctly;
b) to check the clamping force of thyristors;
c) to check the point to point wiring.

8.4 Voltage-dividing/damping circuit check

Test objective: check the dividing/damping circuit parameters (resistance and capacitance) and thereby ensure that voltage sharing between series-connected thyristors will be correct.

8.5 Voltage withstand check

Test objective: check that the thyristor levels can withstand the voltage corresponding to the maximum value specified for the valve.

8.6 Check of auxiliaries

Test objective: 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.

8.7 Firing check

Test objective: check that the thyristors in each thyristor level turn on correctly in response to firing signals.

8.8 Cooling system pressure test

Test objective:

a) check that there are no leaks;

b) check for adequate flow, both in the valve as a whole and in all subcircuits;

c) check the differential pressure.

8.9 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.

9 Optional tests on TCR and TSR valves

9.1 Overcurrent test

9.1.1 Overcurrent with subsequent blocking

9.1.1.1 Objectives

This test verifies the capability of the valve to withstand overcurrent with subsequent blocking at thyristor temperatures equal to the maximum value allowed by valve control or protection. The test considers the condition of d.c. trapped current where the overcurrent is terminated by blocking at high d*i*/d*t*.

NOTE In many cases the objectives of this test can be satisfied by the periodic firing and extinction test (5.4.1), in which case this test may be omitted.

9.1.1.2 Test values and waveshapes

The valve shall be subjected to a reapplied voltage which approximates to the extinction waveshape experienced in service. The reapplied voltage may be produced either by a separate impulse generator or by the test circuit itself.

Waveshape 1: use a 20/200 µs waveshape, which approximates a typical extinction waveshape, or an alternative approximation if supported by system studies.

$$U_{tsv} = k_s \times U_{cms} \text{ (waveshape 1)} \quad (36)$$

where

U_{cms} is the minimum valve protective level defined by the surge arrester or VBO, or the guaranteed withstand level of the valve where no overvoltage protection is provided;

k_s is a test factor;

k_s = 0,9.

9.1.1.3 Test procedures

a) Establish a maximum steady-state condition for current and maintain it until thermal equilibrium at steady-state junction temperature is reached.
b) Subject the valve to an appropriate test current to raise the junction temperature to the maximum allowed by valve control and protection.
c) Block the valve at a representative d*i*/d*t*.
d) Subject the valve to the reverse extinction overshoot voltage.

9.1.2 Overcurrent without blocking

9.1.2.1 Objectives

Fault conditions are assumed where the valve current exceeds the design limit. This test verifies the capability of the valve to withstand overcurrent without blocking until the SVC is tripped.

9.1.2.2 Test values and waveshapes

The test current shall have a peak value and a heating effect corresponding to the specified worst case time-dependent overvoltage, such that both directions of conduction are tested. The test duration shall be based on the SVC protection system.

9.1.2.3 Test procedures

The test circuit may be a power frequency current source with the test object and a reactor in series, or a suitable alternative circuit. No voltage need be applied to the valve at the end of the test.

a) Preheat the valve or valve section so that the thyristor junctions reach the maximum steady-state operating temperature.
b) Subject the valve to the current waveshape specified.

9.2 Positive voltage transient during recovery test

9.2.1 Objectives

It shall be demonstrated that the valve will not be damaged if a positive switching voltage impulse occurs at any instant after current extinction.

NOTE Where protection external to the valve is provided in order to permit the valve to withstand such an event, this protection should be included in the test.

9.2.2 Test values and waveshapes

Waveshape 1: use a 20/200 µs waveshape, which approximates a typical extinction waveshape, or an alternative approximation if supported by system studies.

$$U_{tsv} = k_s \times U_{cms} \text{ (waveshape 1)} \quad (37)$$

where

U_{cms} is the minimum valve protective level defined by the surge arrester or VBO, or the guaranteed withstand level of the valve where no overvoltage protection is provided;

k_s is a test factor;

k_s = 0,9.

This impulse voltage will change the polarity of the valve voltage after current extinction into a polarity which forward biases the thyristors which have just ceased conduction.

For test performed on a valve section, the amplitude U_{tsv} shall be scaled proportionally in accordance with 4.4.3.2.

9.2.3 Test procedures

a) Carry an appropriate current through the valve such that the thyristor junction is fully spread and d*i*/d*t* at turn off is correct.

b) Block the valve at maximum steady-state junction temperature.

c) Submit the valve or the valve section to the prospective voltage impulses specified above.

The impulse voltages shall be applied in not less than five time steps between the extinction of the current and a full recovery of the valve.

The test shall be performed for both directions of conduction of the valve.

9.3 Non-periodic firing test

9.3.1 Objectives

The objective of the non-periodic firing test is to check the adequacy of the thyristors and the associated electrical circuits with regard to current and voltage stresses at turn-on under non-periodic conditions. An additional objective is to verify the electromagnetic interference insensitivity of the valve (see Clause 7).

NOTE In many cases the objectives of this test can be satisfied by the valve terminal to terminal switching impulse test (5.3.3), in which case this test may be omitted.

9.3.2 Test values and waveshapes

The test shall be performed on a complete valve at room temperature.

The test circuit shall apply a switching impulse voltage to the valve and the valve shall be triggered into conduction at the peak of the impulse. The main task of the test circuit, after firing of the valve, is to reproduce the correct valve current at turn-on. The important time frame is the first 10 µs to 20 µs of conduction.

The surge generator shall be selected for its representative source impedance, in order to reproduce a turn-on current pulse at least as severe as the discharge of circuit stray capacitances as in service.

The turn-on stresses and the test circuit required depend on the method chosen for protecting the valves against transient overvoltages.

Waveshape 2: a standard 250/2 500 µs waveshape shall be used.

a) Valve protected by surge arrester

The prospective test voltage U_{tsv2} is determined as follows:

$$U_{tsv2} = k_s \times U_{cms} \text{ (waveshape 2)} \quad (38)$$

where

U_{cms} is the arrester protective level;

k_s is a test safety factor;

k_s = 1,0.

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

Two methods for achieving this are acceptable:

1) parallel capacitor method: in this method, a capacitor is connected in parallel with the test valve, whose value will result in a current discharge at least as severe as predicted for commutation of arrester current. The valve is triggered into conduction when the voltage reaches U_{tsv2}.
2) surge arrester method: in this method, a surge arrester is connected between the valve terminals and the test voltage is applied from behind an inductance representative of the TCR reactor. When the current in the arrester reaches the prescribed level, the valve is triggered into conduction.

Due to limitations in the practical size of impulse generators, the surge arrester method is suitable only for valves of low-voltage rating.

Where protection against valve firing during instants with current in the arrester is provided, commutation of arrester current does not have to be considered. Therefore the test level U_{cms} may be reduced to the maximum arrester non conduction voltage.

b) Valve protected by VBO

The prospective test voltage U_{tsv2} is determined as follows:

$$U_{tsv2} = k_s \times U_{VBO} \text{ (waveshape 2)} \quad (39)$$

where

U_{VBO} is the minimum VBO protective voltage level;

k_s is a test safety factor;

k_s = 0,95.

If it can be shown that triggering by VBO action is equivalent to normal firing, then the test can be omitted, as the test objective is already demonstrated in the valve terminal to terminal switching impulse test (see 5.3.3).

c) Valve with no protection provided

$$U_{tsv2} = k_s \times U_{cms} \text{ (waveshape 2)} \quad (40)$$

where

U_{cms} is the switching impulse prospective voltage level according to IEC 60071-1, Table 3, or as determined by insulation coordination studies;

k_s is a test safety factor;

k_s = 1,3.

9.3.3 Test procedures

One terminal of the valve may be earthed.

Apply three shots of the switching impulse voltage. The valve shall be triggered into conduction at the peak of the switching impulse voltages. Repeat for the reverse polarity (alternatively, reverse the terminals of the valve).

10 Optional tests on TSC valves

10.1 Positive voltage transient during recovery test

10.1.1 Test objective

It shall be demonstrated that the valve will not be damaged if a positive switching impulse voltage occurs at any instant after current extinction.

NOTE Where protection external to the valve is provided in order to permit the valve to withstand such an event, this protection should be included in the test.

10.1.2 Test values and waveshapes

Waveshape 1: use a 20/200 µs waveshape which approximates a typical extinction waveshape, or an alternative approximation, if supported by system studies.

The prospective test voltage U_{tsv} shall be calculated from the following equation:

$$U_{tsv} = k_s \times U_{cms} \text{ (waveshape 1)} \qquad (41)$$

where

U_{cms} is the minimum valve switching impulse protective level defined by surge arrester, or the guaranteed withstand level of the valve where no overvoltage protection is provided;

k_s is a test factor;

k_s = 0,9.

This impulse voltage will change the polarity of the valve voltage after current extinction into that which forward biases the thyristors which have just ceased conduction. For the test performed on a valve section, the amplitude U_{tsv} shall be scaled proportionally in accordance with 4.4.3.2.

10.1.3 Test procedures

a) Carry an appropriate current through the valve such that the thyristor junction is fully spread and d*i*/d*t* at turn off is correct.
b) Block the valve at maximum steady-state junction temperature.
c) Submit the valve or the valve section to the voltage impulses specified above.

The impulse voltage shall be applied in not less than five time steps between the extinction of the current and a full recovery of the valve.

The test shall be performed for both directions of conduction of the valve.

10.2 Non-periodic firing test

10.2.1 Objectives

The objective of the TSC valve non-periodic firing test is to check the adequacy of the thyristors and the associated electrical circuits with regard to current and voltage stresses at turn-on under non-repetitive conditions. An additional objective is to verify the electromagnetic interference insensitivity of the valve (see Clause 7).

NOTE In many cases the objectives of this test can be satisfied by the overcurrent test (see 6.4.1), in which case this test may be omitted.

10.2.2 Test values and waveshapes

The test shall be performed on a complete valve at room temperature.

The test circuit shall apply a switching impulse voltage to the valve, and the valve shall be triggered into conduction at the peak of the impulse. The main task of the test circuit, after firing the valve, is to reproduce the correct valve current at turn-on. The important time frame is the first 10 µs to 20 µs of conduction.

The surge generator shall be selected to have representative source impedance, so as to reproduce a turn-on current pulse at least as severe as the discharge of circuit stray capacitances in service.

The turn-on stresses and the test circuit depend on the method chosen for protecting the valves against transient overvoltages.

The impedance of the impulse generator shall be selected to reproduce not only the turn-on current arising from the discharge of circuit stray capacitance but also that arising from commutation of the surge arrester current, where this can occur.

Waveshape 2: a standard 250/2 500 µs shall be used.

a) Valve protected by surge arresters

The prospective test voltage U_{tsv2} shall be calculated from the following equation:

$$U_{tsv2} = k_s \times U_{cms} \text{ (waveshape 2)} \tag{42}$$

where

U_{cms} is the arrester protective level for switching impulses;

k_s is a test safety factor;

k_s = 1,0.

Two methods for achieving this are acceptable:

1) parallel capacitor method: in this method, a capacitor is connected in parallel with the test valve, whose value will result in a current discharge at least as severe as predicted for commutation of the arrester current;
2) surge arrester method: in this method, a surge arrester is connected between the valve terminals, and the test voltage is applied from behind an inductance representative of the TSC series reactor. When the current in the arrester reaches the prescribed level, the valve is triggered into conduction.

Owing to limitations in the practical size of impulse generators, the surge arrester method may be possible only for valves of low-voltage rating.

Where protection against valve firing during instants with current in the arrester is provided, the commutation of arrester current does not have to be considered. Therefore, the test level U_{cms} may be reduced to the maximum arrester non-conduction voltage. In the overcurrent test (6.4.1) the objective of this test may already have been demonstrated, in which case this test may be omitted.

b) Valve with no protection provided

The prospective test voltage U_{tsv2} shall be calculated from the following equation:

$$U_{tsv2} = k_s \times U_{cms} \text{ (waveshape 2)} \quad (43)$$

where

U_{cms} is the switching impulse prospective voltage level according to IEC 60071-1, Table 3, or as determined by insulation coordination studies;

k_s is a test safety factor;

k_s = 1,3.

10.2.3 Test procedures

One terminal of the valve may be earthed.

Apply three shots at the switching voltage, the valve is triggered into conduction when the voltage reaches U_{tsv2}. Repeat for the reverse polarity (alternatively, reverse the terminals of the valve).

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