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INTERNATIONAL STANDARD

NORME INTERNATIONALE

Voltage sourced converter (VSC) valves for high-voltage direct current (HVDC) power transmission – Electrical testing

Valves à convertisseur de source de tension (VSC) pour le transport d'énergie en courant continu à haute tension (CCHT) – Essais électriques

IEC 62501:2009

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VOLTAGE SOURCED CONVERTER (VSC) VALVES FOR HIGH-VOLTAGE DIRECT CURRENT (HVDC) POWER TRANSMISSION – ELECTRICAL TESTING

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IEC 62501 has been prepared by subcommittee 22F: Power electronics for electrical transmission and distribution systems, of IEC technical committee 22: Power electronic systems and equipment.

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

FDIS	Report on voting
22F/185/FDIS	22F/193/RVD

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 maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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- withdrawn,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

VOLTAGE SOURCED CONVERTER (VSC) VALVES FOR HIGH-VOLTAGE DIRECT CURRENT (HVDC) POWER TRANSMISSION – ELECTRICAL TESTING

1 Scope

This International Standard applies to self-commutated converter valves, for use in a three-phase bridge voltage sourced converter (VSC) 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 must be agreed.

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

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

IEC 60700-1:1998, *Thyristor valves for high voltage direct current (HVDC) power transmission – Part 1: Electrical testing* [1)]

Amendment 1(2003)
Amendment (2008)

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

3 Terms and definitions

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

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

[1)] There exists a consolidated edition 1.2 (2008) that comprises IEC 60700-1, Amendment 1 and Amendment 2.

3.1.2
internal insulation
air external to the components and insulating materials of the valve, but contained within the profile of the valve or multiple valve unit

3.1.3
external insulation
air between the external surface of the valve or multiple valve unit and its surroundings.

3.2 Power semiconductor terms

There are several types of controllable semiconductor switch device which can be used in VSC converters for HVDC. For convenience, the term IGBT is used throughout this standard to refer to the main, controllable, semiconductor switch device. However, the standard is equally applicable to other types of controllable semiconductor switch device.

3.2.1
insulated gate bipolar transistor
IGBT
a controllable switch with the capability to turn-on and turn-off a load current

An IGBT has three terminals: a gate terminal (G) and two load terminals emitter (E) and collector (C).

By applying appropriate gate to emitter voltages, the load current can be controlled, i.e. turned on and turned off.

3.2.2
free-wheeling diode
FWD
power semiconductor device with diode characteristic

A FWD has two terminals: an anode (A) and a cathode (K). The current through FWDs is in the opposite direction to the IGBT current.

FWDs are characterized by the capability to cope with high rates of decrease of current caused by the switching behaviour of the IGBT.

3.2.3
IGBT-diode pair
arrangement of IGBT and FWD connected in inverse parallel

3.3 Operating states

3.3.1 Operating state of an IGBT-diode pair

3.3.1.1
blocking state
the condition in which an IGBT-diode pair is turned off

In that state, the load current does not flow through the IGBT. However, a load current can flow through the diode as the diode is not controllable.

3.3.1.2
de-blocked state
the condition when the load current flows either through the IGBT or diode of an IGBT-diode pair depending on the load current direction

3.3.2 Operating state of converter

3.3.2.1
blocking state
a condition of the converter, in which a turn-off signal is applied to all IGBTs of the converter

Typically, the converter is in the blocking state condition after energization.

3.3.2.2
de-blocked state
a condition of the converter, in which turn-on signals are applied to IGBTs of the converter

3.3.2.3
valve protective blocking
means of protecting the valve or converter from excessive electrical stress by the emergency turn-off of all IGBTs in one or more valves

3.4 VSC construction terms

3.4.1
VSC phase unit
the equipment used to connect the two d.c. busbars to one a.c. terminal

3.4.2
VSC valve
complete controllable device assembly, which represents a functional unit as part of a VSC phase unit and characterized by switching actions of the power electronic devices upon control signals of the converter base electronics

NOTE Dependent on the converter topology, a valve can either have the function to act like a controllable switch or to act like a controllable voltage source.

3.4.3
diode valve
a semiconductor valve containing only diodes as the main semiconductor devices, which might be used in some VSC topologies

3.4.4
valve
VSC valve or diode valve according to the context

3.4.5
VSC valve level
part of a VSC valve comprising a controllable switch and an associated diode, or controllable switches and diodes connected in parallel, or controllable switches and diodes connected to a half bridge arrangement, together with their immediate auxiliaries, storage capacitor, if any

3.4.6
diode valve level
part of a diode valve composed of a diode and associated circuits and components, if any

3.4.7
redundant levels
the maximum number of VSC valve levels or diode valve levels in a valve that may be short-circuited externally or internally during service without affecting the safe operation of the valve as demonstrated by type tests, and which if and when exceeded, would require shutdown of the valve to replace the failed levels or acceptance of increased risk of failures

3.5 Valve structure terms

3.5.1
valve structure
physical structure holding the levels of a valve which is insulated to the appropriate voltage above earth potential

3.5.2
valve support
that part of the valve which mechanically supports and electrically insulates the active part of the valve from earth

NOTE 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.

3.5.3
multiple valve unit
MVU
mechanical arrangement of 2 or more valves or 1 or more VSC phase units sharing a common valve support

NOTE A MVU might not exist in all topologies and physical arrangement of converters.

3.5.4
valve section
electrical assembly defined for test purposes, comprising a number of VSC or diode valve levels and other components, which exhibits pro-rated electrical properties of a complete valve

The minimum number of VSC or diode valve levels allowed in a valve section is defined along with the requirements of each test.

3.5.5
valve base electronics
electronic unit, at earth potential, which is the interface between the converter control system and the VSC valves

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

This subclause does not apply to tests on the valve supporting structure and multiple valve unit. The test object for those tests is defined in 7.2 and 8.2.

a) Type tests may be performed either on a complete valve or, in certain circumstances, on valve sections, as indicated in Table 3.

b) The minimum number of valve levels to be tested, depending on the valve levels in a single valve, is as shown in Table 1.

Table 1 – Minimum number of valve levels to be tested as a function of the number of valve levels per valve

Number of valve levels per valve	Total number of valve levels to be tested
1 – 50	Number of valve levels in one valve
51 – 250	50
≥ 251	20 %

c) Generally, the same valve sections are recommended to be used for all type tests. However, with the agreement of the purchaser and supplier, different tests may be performed on different valve sections in parallel, in order to speed up the programme for executing the tests.

d) 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 test

In order to confirm that the valve terminal-terminal insulation has not been degraded by the fast repetitive switching stresses experienced by the converter in operation, the valve a.c. – d.c. voltage test between terminals with partial discharge measurement should be performed after the operational tests. Other type tests specified can be carried out in any order.

NOTE For valves of the “controllable voltage source” type (Clause A.5), the test sequence, where the a.c. – d.c. voltage test is performed before the operational test, may be acceptable by mutual agreement between the purchaser and supplier.

4.1.4 Test procedure

The tests shall be performed in accordance with IEC 60060, where applicable.

4.1.5 Ambient temperature for testing

The tests shall be performed in accordance with IEC 60060, where applicable.

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 14.

4.2 Atmospheric correction factor

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 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_{1000m}).

- If the insulation coordination of the tested part of the 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 Operational tests

For operational tests, redundant valve 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 valve levels in the test object;

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

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

4.3.2 Dielectric tests

For all dielectric tests between valve terminals, the redundant valve levels shall be short-circuited. The location of valve levels to be short-circuited shall be agreed by the purchaser and supplier.

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

For all dielectric tests on valve section, the test voltages used shall be adjusted by means of a scaling factor k_o:

$$k_o = \frac{N_{tu}}{N_t - N_r}$$

where

N_{tu} is the number of series valve levels not short circuit connected in the test object;

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

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

4.4 Criteria for successful type testing

4.4.1 General

Experience in semiconductor application shows that, even with the most careful design of valves, it is not possible to avoid occasional random failures of valve 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 valve 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 valve levels

Criteria applicable to valve levels are as follows.

a) If, following a type test as listed in Clause 5, more than one valve level (alternatively more than 1 % of the tested valve levels, 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 valve 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 valve levels during all type tests is more than 3 % of the tested valve levels, then the valve shall be deemed to have failed the type test.

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

e) 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 valve levels;
   – check of the gating circuits;
   – check of the monitoring circuits;
   – check of any protection circuits forming an integral part of the valve;
   – check of the voltage grading circuits.

f) Valve levels 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 valve levels exhibiting faults which do not result in valve level short circuit, which are discovered during the type test programme and the subsequent check test, shall not exceed 3 % of the number of tested valve levels in dielectric and operational type tests, whichever is lower. 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.

g) When applying the percentage criteria to determine the permitted maximum number of short-circuited valve levels and the permitted maximum number of levels with faults which have not resulted in a valve level becoming short-circuited, it is usual practice to round off all fractions to the next highest integer, as illustrated in Table 2.

Table 2 – Valve level faults permitted during type tests

Number of valve levels tested	Number of valve levels permitted to become short-circuited in any one type test	Total number of valve levels permitted to become short-circuited in all type tests	Additional number of valve 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
etc.			