SLOVENSKI STANDARD
oSIST prEN IEC 62501:2023

01-september-2023

Elektronke za pretvornike napetostnih virov (VSC) za enosmerni visokonapetostni prenos električne energije (HVDC) - Električno preskušanje

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

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TITLE:

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

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NOTE FROM TC/SC OFFICERS:

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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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.

This second edition cancels and replaces the first edition published in 2009, Amendment 1:2014 and Amendment 2:2017. This edition constitutes a technical revision.

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

a) Conditions for use of evidence in lieu are inserted as a new added table, Table 1;
b) Test parameters for valve support DC voltage test, 7.3.1, and MVU DC voltage test, 8.3.1, updated;
c) AC – DC voltage test between valve terminals, Clause 9, is restructured and alternative tests, by individual AC and DC voltage tests, added in subclause 9.4.2;
d) Partial discharge test in routine test program is removed;
e) More information on valve component fault tolerance, Annex B, is added;
f) Valve losses determination is added as Annex C.

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

Draft	Report on voting

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

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

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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 DC power transmission or as part of a back-to-back link, and to dynamic braking valves. It is restricted to electrical type and production tests.

This standard can be used as a guide for testing of high-voltage VSC valves used in energy storage systems (ESS)

The tests specified in this standard are based on air insulated valves. The test requirements and acceptance criteria can be used for guidance to specify the electrical type and production tests of other types of valves.

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

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

IEC 60700-1:2021, *Thyristor valves for high voltage direct current (HVDC) power transmission – Part 1: Electrical testing*

IEC 62747, *Terminology for* voltage-*sourced converters (VSC) for high-voltage direct current (HVDC) systems*

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 62747 and the following 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

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

3.2.1
turn-off semiconductor device
controllable semiconductor device which may be turned on and off by a control signal, for example an IGBT

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

3.2.2
insulated gate bipolar transistor
IGBT
turn-off semiconductor device with three terminals: a gate terminal (G) and two load terminals emitter (E) and collector (C).

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

3.2.3
free-wheeling diode
FWD
power semiconductor device with diode characteristic

NOTE 1 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.

NOTE 2 FWDs are characterized by the capability to cope with high rates of decrease of current caused by the switching behaviour of the IGBT.

3.2.4
IGBT-diode pair
arrangement of IGBT and FWD connected in inverse parallel

3.3 Operating states of converter

3.3.1
blocking state
condition of the converter, in which a turn-off signal is applied continuously to all IGBTs of the converter

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

3.3.2
de-blocked state
condition of the converter, in which turn-on and turn-off signals are applied repetitively to IGBTs of the converter

3.3.3
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

3.3.4
voltage step level
voltage step caused by switching of a valve or part of a valve during the de-blocked state of the converter

NOTE For valves of the controllable voltage source type, the voltage step level corresponds to the change of voltage caused by switching one submodule or cell. For valves of the switch type, the voltage step level corresponds to the change of voltage caused by switching the complete valve.

3.4 VSC construction terms

3.4.1
VSC phase unit
equipment used to connect the two DC busbars to one AC terminal

3.4.2
switch type VSC valve
arrangement of IGBT-diode pairs connected in series and arranged to be switched simultaneously as a single function unit

3.4.3
controllable voltage source type VSC valve
complete controllable voltage source assembly, which is generally connected between one AC terminal and one DC terminal

3.4.4
diode valve
semiconductor valve containing only diodes as the main semiconductor devices, which might be used in some VSC topologies

3.4.5
dynamic braking valve
complete controllable device assembly, which is used to control energy absorption in braking resistor or other components

3.4.6
valve
VSC valve, dynamic braking valve or diode valve according to the context

3.4.7
submodule
part of a VSC valve comprising controllable switches and diodes connected to a half bridge or full bridge arrangement, together with their immediate auxiliaries, storage capacitor, if any, where each controllable switch consists of only one switched valve device connected in series

3.4.8
cell
MMC building block where each switch position consists of more than one IGBT-diode pair connected in series

NOTE See Figure A.13

3.4.9
VSC valve level
smallest indivisible functional unit of VSC valve

NOTE For any VSC valve in which IGBTs are connected in series and operated simultaneously, one VSC valve level is one IGBT-diode pair including its auxiliaries (see Figure A.13). For MMC type without IGBT-diode pairs connected in series one valve level is one submodule together with its auxiliaries (see Figure A.12).

3.4.10
diode valve level
part of a diode valve composed of a diode and associated circuits and components, if any

3.4.11
redundant levels
maximum number of series connected VSC valve levels or diode valve levels in a valve that may be short-circuited externally or internally 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

NOTE In valve designs such as the cascaded two level converter, which contain two or more conduction paths within each cell and have series-connected VSC valve levels in each path, redundant levels shall be counted only in one conduction path in each cell.

3.4.12
dynamic braking valve level
part of a dynamic braking 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 bridge arrangement, together with their immediate auxiliaries, storage capacitor and energy dissipation resistors, if any

3.5 Valve structure terms

3.5.1
valve structure
structural components of a valve, required in order to physically support the valve modules

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

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 valve levels and other components, which exhibits pro-rated electrical properties of a complete valve

NOTE 1 For valves of controllable voltage source type the valve section shall include cell or submodule DC capacitor in addition to VSC valve levels.

NOTE 2 The minimum number of VSC or diode valve levels allowed in a valve section is defined along with the requirements of each test.

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 or individual parts of it, 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. Conditions for use of evidence in lieu are listed in Table 1.

Table 1 – Conditions for use of evidence in lieu from another HVDC project

Type test	Clause	Conditions
Operational tests	6	• Equal or smaller number of valve levels to be tested • Same valve level design • Same valve electronics design • Identical or lower voltage stress and thermal stress[1] on each valve level

Dielectric tests on valve support structure	7	• Identical valve structure, including cooling pipes, cable paths, earthing system, if any • Same valve material and geometrical dimension • Equal or higher air clearance to valve hall and other related equipment inside the valve hall • Equal or lower voltage stress, including DC voltage stress, AC voltage stress and impulse voltage stresses
Dielectric tests on multiple valve unit	8	• Same MVU geometry between valves
Dielectric tests between valve terminals	9	• Identical valve structure, including cooling pipes, cable paths and earthing system, if any • Same valve material and geometrical dimension • Equal or lower voltage stress
IGBT overcurrent turn-off test	10	• Same valve level design • Same valve electronics design • Identical or lower prospective current stress
Short-circuit current test	11	• Same valve level design • Same short-circuit bypass components, if any, and function • Same valve electronics design • Identical or lower short-circuit current stress
Tests for valve insensitivity to electromagnetic disturbance	12	• Same as those indicated for clauses 6 & 9
[1] Semiconductor devices thermal stress is a combined effect of current and cooling. Device thermal stress is characterised by the device junction temperature.		

4.1.2 Selection of 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 MVU, or parts thereof, as indicated in Table 4.

b) The minimum number of valve levels to be operational type tested, depending on the valve levels in a single valve, is as shown in Table 2. This number applies to the type tests in clauses 6, 10, 11 and 12. Those valve levels shall be tested in one test setup or multiple setups on several valve sections as defined in those clauses.

Table 2 – Minimum number of valve levels to be operational type **tested as a function of the number of valve levels per valve**

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

The minimum number of valve levels to be dielectric type tested can be equal to or lower than the number specified for the operational type test.

The minimum number of valve levels, however, shall be representative to the valve dielectric design.

c) Generally, the same valve sections are recommended to be used for all type tests. However, 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 shall be demonstrated to have withstood the production tests to ensure proper manufacture.

4.1.3 Test procedure

The tests shall be performed in accordance with IEC 60060, where applicable with due account for IEC 60071 (all parts). Partial discharge measurements shall be performed in accordance with IEC 60270.

4.1.4 Ambient temperature for testing

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

4.1.5 Frequency for testing

AC dielectric tests can be performed at either 50 Hz or 60 Hz. Operational tests shall be performed at the service frequency.

4.1.6 Test reports

At the completion of the type tests, the supplier shall provide type test reports in accordance with Clause 15.

4.1.7 Conditions to be considered in determination of type test parameters

Type test parameters shall be determined based on the worst operating and fault conditions to which the valve can be subjected, according to system studies. Guidance on the conditions can be found in CIGRE Technical Brochure No. 447.

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 1000 m. Hence if the altitude of the site a_s at which the equipment will be installed is ≤1000 m, then the standard atmospheric air pressure (b_0= 101,3 kPa) shall be used with no correction for altitude. If a_s >1000 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 1000 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).

Realistic worst case combinations of temperature and humidity which can occur in practice shall be used for atmospheric correction.

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_0:

$$k_0 = \frac{N_{tu}}{N_t - N_r}$$

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 and providing that the failed valve level permits the rest of the valve or valve section to continue operating without degraded performance.

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 or open circuited, then the valve shall be deemed to have failed the type tests.