

INTERNATIONAL STANDARD



Voltage sourced converter (VSC) valves for static synchronous compensator (STATCOM) – Electrical testing

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Voltage sourced converter (VSC) valves for static synchronous compensator (STATCOM) – Electrical testing

INTERNATIONAL
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INTERNATIONAL ELECTROTECHNICAL COMMISSION

**VOLTAGE SOURCED CONVERTER (VSC) VALVES FOR STATIC
SYNCHRONOUS COMPENSATOR (STATCOM) –
ELECTRICAL TESTING**

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

CDV	Report on voting
22F/412/CDV	22F/431A/RVC

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

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

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

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- withdrawn,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

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

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VOLTAGE SOURCED CONVERTER (VSC) VALVES FOR STATIC SYNCHRONOUS COMPENSATOR (STATCOM) – ELECTRICAL TESTING

1 Scope

This document applies to self-commutated valves, for use in voltage sourced converter (VSC) for static synchronous compensator (STATCOM). It is restricted to electrical type and production tests.

The tests specified in this document are based on air insulated valves. For other types of valves, the test requirements and acceptance criteria are agreed between the purchaser and the supplier.

2 Normative references

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

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

IEC 60060-1, *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 60700-1:2015, *Thyristor valves for high voltage direct current (HVDC) power transmission – Part 1: Electrical testing*

IEC 62501, *Voltage sourced converter (VSC) valves for high-voltage direct current (HVDC) power transmission – Electrical testing*

3 Terms and definitions

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

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

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

3.1 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 1 to entry: There are several types of turn-off semiconductor devices, for example IGBT, IGCT and GTO, which can be used in voltage sourced converters for STATCOM. For convenience, the term IGBT is used throughout this document to refer to the main, controllable turn-off, semiconductor device. However, this document is equally applicable to other types of controllable semiconductor switch device.

3.2.2

gate turn-off thyristor

GTO thyristor

turn-off semiconductor device which can be turned on and off by its gate lead

Note 1 to entry: A GTO thyristor is a special type of thyristor, which is a high-power semiconductor device.

Note 2 to entry: Gate commutated thyristor (GCT) and integrated gate commutated thyristor (IGCT) are special types of GTO thyristor.

3.2.3

insulated gate bipolar transistor

IGBT

transistor provided for power switching having a conduction channel and a PN junction and in which the current flowing through the channel and the junction is controlled by an electric field resulting from a voltage applied between the gate and emitter terminals

3.2.4

free-wheeling diode

FWD

power semiconductor device with diode characteristic connected to an insulated gate bipolar transistor (IGBT) in inverse parallel

Note 1 to entry: An FWD has two terminals: an anode (A) and a cathode (K).

Note 2 to entry: The current through FWDs is in the opposite direction to the IGBT current.

Note 3 to entry: Concepts of "inverse parallel" and "anti-parallel" are identical.

3.2.5

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

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 1 to entry: For a voltage source type valve, one half bridge cell corresponds to one voltage step level and a full bridge cell has two voltage step levels.

3.4 STATCOM construction terms

3.4.1

STATCOM

shunt connected reactive compensation equipment which is capable of generating and/or absorbing reactive power, whose capacitive or inductive output current can be controlled independently of the AC system voltage

Note 1 to entry: Previous alternative terms for the STATCOM have included static var generator (SVG), advanced static var compensator (ASVC) and static synchronous condenser (STATCON).

3.4.2

STATCOM valve

electrically and mechanically combined assembly of IGBT levels, complete with all connections, auxiliary components and mechanical structures, which can be connected in series with each phase of reactor of a STATCOM

Note 1 to entry: Depending 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. For controllable voltage source type converter, the STATCOM controllable voltage source type valve is a complete controllable voltage source assembly, which is generally connected between two AC phases. For switch type converter, the STATCOM switch type valve is an arrangement of IGBTs connected in series and arranged to be switched simultaneously as a single function unit between one AC phase and one DC terminal of the DC capacitor energy storage.

Note 2 to entry: For convenience, the term "STATCOM valve" is shortened as "valve" in this document.

3.4.3

diode valve

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

3.4.4

submodule

part of a valve comprising controllable switches and diodes connected in a half bridge or full bridge arrangement, together with their immediate auxiliaries, storage capacitor, if any, where each controllable switch consists of one or more switched valve device(s) connected in series

Note 1 to entry: This definition is only applicable for converters of controllable voltage source type.

3.4.5

switch type valve

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

3.4.6**controllable voltage source type valve**

complete controllable voltage source assembly, which is generally connected between AC phases or between one AC terminal and one DC terminal

3.4.7**modular multi-level converter****MMC**

multi-level converter in which each VSC valve (see 3.4.5, 3.4.6) consists of a number of MMC building blocks (see 3.4.9) connected in series

3.4.8**cascaded two-level converter****CTL**

modular multi-level converter in which each switch position consists of more than one IGBT-diode pair connected in series

3.4.9**MMC building block**

self-contained, two-terminal controllable voltage source together with DC capacitor(s) and immediate auxiliaries, forming part of a MMC

3.4.10**STATCOM valve level**

the smallest indivisible functional unit of valve

Note 1 to entry: For any valve in which switch devices are connected in series and operated simultaneously, one valve level is one IGBT including its auxiliaries. For modular multilevel converter (MMC) type without IGBT connected in series, one valve level is one submodule (cell) together with its auxiliaries.

3.4.11**diode valve level**

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

3.4.12**redundant valve levels**

the maximum number of series connected 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 1 to entry: In valve designs 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.

3.5 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**

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 two or more valves sharing a common valve support, where applicable

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

3.5.5**valve base electronics**

electronic unit, at earth potential, which is the interface between the converter control system and the STATCOM valves

4 General requirements**4.1 Guidelines for the performance of type tests****4.1.1 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 (internal insulation) or connected between the valve structure and earth (external insulation). Other equipment, such as valve control and protection and valve base electronics, can be essential for demonstrating the correct function of the valve during the tests but are not in themselves the subject of the tests.

4.1.2 Dielectric tests

The purpose of these tests is to verify the valve design for voltage stresses under normal and abnormal repetitive conditions as well as under transient conditions.

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

4.1.3 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.

4.1.4 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.

4.1.5 Evidence in lieu

Each design of valve shall be subjected to the type tests specified in this document. 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.

4.1.6 Test object

4.1.6 does not apply to tests on the valve support and multiple valve units. The test object for those tests may be a representative separate object including representation of the adjacent parts of the valve, or may form part of the assembly used for single valve or multiple valve unit tests.

- 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 to 10	Number of valve levels in one valve
11 to 50	10 levels
≥ 51	20% of valve levels in one valve

- 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.

4.1.7 Test procedure

The tests shall be performed in accordance with IEC 60060 (all parts), where applicable.

4.1.8 Ambient temperature for testing

The tests shall be performed in accordance with IEC 60060 (all parts), where applicable.

4.1.9 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.

4.1.10 Conditions to be considered in determination of type test parameters

Type test parameters should be determined based on the worst operating and fault conditions to which the valve can be subjected, according to system studies.

4.1.11 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 for site conditions 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 $\leq 1\,000$ m, then the standard atmospheric air pressure ($b_0 = 101,3$ kPa) shall be used with no correction for altitude. If $a_s > 1\,000$ m, then the standard procedure according to IEC 60060-1 is used except that the reference atmospheric pressure b_0 is replaced by the atmospheric pressure corresponding to an altitude of 1 000 m ($b_{1\,000\text{ m}}$).
 - 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 correction factor for site conditions follows the standard procedure according to IEC 60060-1 with the reference atmospheric pressure b_0 ($b_0 = 101,3$ kPa).
- Temperature: design maximum valve hall air temperature ($^{\circ}\text{C}$).
- 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 .

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

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 can be imposed upon the distribution of short-circuited valve levels. For example, there can 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 :

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

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 Permissible component failures during type testing

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

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 insulated gate bipolar transistors (IGBTs) or auxiliary components have failed during the test. Failed IGBTs or auxiliary components found at the end of a type test shall be remedied before further testing of a valve.

If, following a type test, one valve level (or more according to Table 2) has become short or open circuited, then the failed level(s) shall be restored and this type test repeated.

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

Table 2 – Valve level faults permitted during type tests

Number of valve levels tested	Number of valve levels permitted to become short or open circuited in any one type test	Total number of valve levels permitted to become short or open circuited in all type tests	Additional number of valve levels, in all type tests, which have experienced a fault but have not become short or open circuited
Up to 33	1	1	1
34 to 67	1	2	2
68 to 100	1	3	3
> 100	2	4	4

5 List of tests

List of tests is given in the middle column of Table 3.

Table 3 – List of type tests

Test	Clause or subclause	Test object
Operational type tests		
Maximum continuous operating duty test	6.4	Valve or valve section
Maximum temporary overload operating duty test	6.5	Valve or valve section
Minimum start voltage test	6.6	Valve or valve section
Overcurrent turn-off test	10	Valve or valve section
Short-circuit current test (optional)	12	Valve or valve section
Dielectric type tests		
Valve support DC voltage test	7.3.1	Valve support
Valve support AC voltage test	7.3.2	Valve support
Valve support lightning impulse test	7.3.3	Valve support
MVU AC voltage test	8.4.1	MVU
MVU DC voltage test	8.4.2	MVU
MVU lightning impulse test	8.4.3	MVU
Valve AC voltage test	9.4.1.2	Valve or valve section
Valve AC-DC voltage test	9.4.1.3	
Valve switching impulse test	9.4.2	
Test for valve insensitivity to electromagnetic disturbance		
Test for valve insensitivity to electromagnetic disturbance	11	Valve or valve section
Production tests		
Visual inspection	13.5.1	
Connection check	13.5.2	
Voltage-grading circuit check	13.5.3	
Control, protection and monitoring circuit checks	13.5.4	
Voltage withstand check	13.5.5	
Turn-on/turn-off check	13.5.6	
Pressure test	13.5.7	

6 Operational tests

6.1 Purpose of tests

The principal objectives of the operational tests are

- a) to check the adequacy of the IGBT/diode level and associated electrical circuits in a valve with regard to current, voltage and temperature stresses in the conducting state, blocking state, de-blocked state, at turn-on and turn-off under the worst repetitive stress conditions, and
- b) to demonstrate correct interaction between valve electronics and power circuits of the valves.

6.2 Test object

The tests may be performed on either the complete valve or on valve sections. The choice depends mainly upon the valve design and the test facilities available. For switch type converter valves, the tests specified in 6.2 are valid for valve sections containing five or more

series-connected valve levels. If tests with fewer than five levels are proposed, additional test safety factors shall be agreed. Under no circumstances shall the number of series-connected levels for tests be less than three. For controllable voltage source type converter valves, the valve section shall consist of three or more series-connected valve levels.

NOTE For controllable voltage source type converter valves, each submodule is independent voltage controlled. So the number of test levels during one test run can be smaller in comparison with switch type converter valve.

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

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, such that the relevant component temperature(s) are equal to the values applicable in service.

6.3 Test circuit

For valve designs which act as a controllable voltage source and contain in-built DC capacitance, the DC capacitance and its connections to the semiconductor devices are an integral part of the test object.

However, for switch type converter valves, where the DC capacitor is separate from the valve, the DC capacitor needs to be correctly represented in the test circuit. In particular, the series stray inductance in the connections between the DC capacitor and the valve, and the stray capacitance across the valve section, shall be correctly reproduced and scaled to the size of valve section under test. Test circuit interconnections shall be of a type that is representative of the type used in the converter, in order not to introduce unrealistic levels of damping due to skin effects.

6.4 Maximum continuous operating duty test

The test needs to reproduce the following parameters based on the worst in service operating conditions of the converter. More than one test may be necessary to reproduce all parameters at their maximum values.

For STATCOM valves:

- maximum continuous insulated gate bipolar transistors (IGBT) junction temperatures;
- maximum continuous free-wheeling diodes (FWDs) junction temperatures;
- maximum continuous snubber component temperatures;
- maximum continuous turn-on and turn-off voltage and current.

For diode valves:

- maximum continuous diode junction temperature;
- maximum continuous snubber component temperatures;
- maximum continuous diode turn-off voltage and current.

All of these parameters need to be reproduced during the maximum continuous operating duty test. They may be reproduced either in separate tests or as a combined test.

The test voltage shall be based on the maximum continuous AC voltage, the test switching frequency shall be based on the maximum continuous switching frequency, and the modulation pattern shall be representative of that used in service.

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

The test voltage U_{tpv1} corresponding to the maximum continuous operating AC voltage shall be determined as follows:

$$U_{\text{tpv1}} = U_{\text{max}} \times k_n \times k_1$$

where

U_{max} is the maximum continuous operating AC voltage;

k_n is a test scaling factor according to 4.3.1;

k_1 is a test safety factor;

$k_1 = 1,05$.

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

6.5 Maximum temporary overload operating duty test

If the valve is specified for temporary overload operation, a maximum temporary operating duty test shall be performed.

The test conditions, where required, shall be determined using the same methodology as in 6.4 above.

Prior to the test, the valve or valve section shall be brought to thermal equilibrium under the conditions of 6.4. The temporary operating duty test is then started from this initial condition and continued for a duration equal to the duration of the temporary overload multiplied by 1,2.

After the temporary overload operation duty test, 10 min maximum continuous operating duty test shall be performed.

6.6 Minimum start voltage test

This test is to verify the correct performance of those valve designs in which energy for the valve electronic circuits is extracted from the voltage appearing between the valve terminals or valve energy storage capacitor.

The test voltage U_{min} is defined as:

$$U_{\text{min}} = \frac{N_{\text{tut}}}{N_{\text{t}}} \times U_{\text{acmin}} \times k_2$$

where

U_{acmin} is the minimum AC voltage appearing between valve terminals which can start de-blocking operation of the valve;

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

N_{t} is the total number of series-connected valve levels in a single valve, including redundancy;

k_2 is a test safety factor;

$k_2 = 0,95$.

For minimum start voltage test, only the voltage, neither the current nor the test duration, is important. The test shall show that the valve electronics can start up and work properly.

7 Dielectric tests on valve support

7.1 Purpose of tests

The principal objectives of these tests are the following.

- a) To verify the voltage withstand capability of the insulation of the valve support, cooling ducts, light guides and other insulating components associated with the valve support. If there is insulation to earth other than the valve support, then additional tests may be necessary.
- b) To verify that the partial discharge inception and extinction voltages are above the maximum operating voltage appearing on the valve support.

7.2 Test object

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

If a single valve consists of more than one structure such that there is more than one valve support structure per valve, then it shall be demonstrated that the tests proposed cover the worst stresses experienced by any of the valve support structures.

7.3 Test requirements

7.3.1 Valve support DC voltage test

This test is applicable only to those designs in which the valve support is exposed to DC voltage in service.

The two main terminals of the valve shall be connected together and the DC voltage then applied between the two main terminals thus connected and earth.

Starting from a voltage not higher than 50 % of the maximum test voltage, the voltage shall be raised to the specified 1 min test voltage as fast as possible, kept constant for 1 min, reduced to the specified 3 h test voltage, kept constant for 3 h and then reduced to zero. During the last hour of the specified 3 h test, the number of partial discharges exceeding 300 pC shall be recorded as described in Annex B of IEC 60700-1:2015.

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

Where possible, the test voltage shall be increased from 50 % to the maximum voltage level within approximately 10 s; longer time may be used. However, this can overstress the test object.

If an increasing trend in the magnitude or rate of partial discharge is observed, the test duration may be extended until equilibrium partial discharge is achieved.

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

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

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

1 min test:

$$U_{tds} = \pm U_{dmS1} \times k_3 \times k_t$$

3 h test:

$$U_{tds} = \pm U_{dmS2} \times k_3$$

where

U_{dmS1} is the maximum of 1 s average value of voltage appearing across the valve support as determined by the insulation coordination study;

U_{dmS2} is the maximum value of the DC component of the steady-state operating voltage appearing across the valve support;

k_3 is a test safety factor;

$k_3 = 1,1$;

k_t is the atmospheric correction factor according to 4.2.

7.3.2 Valve support AC voltage test

To perform the test, the two main terminals of the valve shall be connected together, and the AC test voltage then applied between the two main terminals thus connected and earth.

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

Before the end of the 10 min test, the level of partial discharge shall be monitored and recorded over a 1 min period. If the value of partial discharge is below 200 pC, the design may be accepted unconditionally. If the value of partial discharge exceeds 200 pC, the test results shall be evaluated.

The RMS value of the valve support AC test voltage U_{tas} shall be determined in accordance with the following:

1 min test:

$$U_{tas} = \frac{U_{mS1}}{\sqrt{2}} \times k_4 \times k_t$$

10 min test:

$$U_{tas} = \frac{U_{mS2}}{\sqrt{2}} \times k_4$$

where

U_{mS1} is the peak value of maximum voltage appearing on the valve support in service, particularly in system fault condition and valve fault operation condition. The overvoltage limiting effect of phase arrester or other overvoltage protection means, if any, shall be taken into account to derive this overvoltage;

U_{mS2} is the peak value of voltage across the valve support in maximum steady-state continuous operations;

- k_4 is a test safety factor of 1,3 for the 1 min test and 1,15 for the 10 min test;
- k_t is the atmospheric correction factor of the value according to 4.2 for the 1 min test.

7.3.3 Valve support lightning impulse test

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

A standard lightning impulse voltage wave shape in accordance with IEC 60060-1 shall be used.

The peak value of the test voltage is the standard lightning impulse withstand voltage according to IEC 60071-1:2006, Table 2 or 3.

8 Dielectric tests on multiple valve unit (MVU)

8.1 General

Clause 8 is only applicable if more than one valve is installed in a common valve structure (multiple valve units). In the case where each individual valve is mounted in one or several dedicated valve structures, Clause 8 is not applicable.

8.2 Purpose of tests

The principal objectives of these tests are

- a) to verify the voltage withstand capability between single valves in a MVU structure, and
- b) to verify that the partial discharge levels are within specified limits.

8.3 Test object

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

It can be necessary to have to short-circuit individual valves depending on the configuration of the MVU and the objectives of the test.

8.4 Test requirements

8.4.1 MVU AC voltage test

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

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

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

Before the end of the 10 min test, the level of partial discharge shall be monitored and recorded over a 1 min period. If the value of partial discharge is below 200 pC, the design may be accepted unconditionally. If the value of partial discharge exceeds 200 pC, the test results shall be evaluated.

The RMS value of MVU AC test voltage U_{tam} shall be determined in accordance with the following:

1 min test:

$$U_{\text{tam}} = \frac{U_{\text{mmp}}}{\sqrt{2}} \times k_5 \times k_t$$

10 min test:

$$U_{\text{tam}} = \frac{U_{\text{mms}}}{\sqrt{2}} \times k_5$$

where

U_{mmp} is the peak value of the maximum voltage, after taking into account the surge arrester, if any, protection effect, between adjacent valves at system fault;

U_{mms} is the peak value of the maximum voltage between adjacent valves of the MVU at steady state operation;

k_5 is a test safety factor of 1,3 for the 1 min test and 1,15 for the 10 min test;

k_t is the atmospheric correction factor of the value according to 4.2 for the 1 min test.

8.4.2 MVU DC voltage test

MVU DC voltage is generally not needed. For design of valves where DC voltage can exist on MVU, test shall be performed according to IEC 62501.

8.4.3 MVU lightning impulse test

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

A standard lightning impulse voltage wave shape in accordance with IEC 60060-1 shall be used.

The peak value of the test voltage is the standard lightning impulse withstand voltage according to IEC 60071-1:2006, Table 2 or 3.

9 Dielectric tests between valve terminals

9.1 Purpose of the test

These tests are intended to verify the design of the valve regarding its voltage-related characteristics for various types of overvoltages (DC, AC and switching impulse overvoltages). The tests shall demonstrate that

- a) the valve will withstand the specified overvoltages,
- b) partial discharges will be within specified limits under specified test conditions,
- c) the internal voltage grading circuits, where applicable, have sufficient power rating, and

d) the valve electronic circuits behave as expected.

It should be noted that the tests described in Clause 9 are based on standard waveshapes and standard test procedures as developed for the testing of high-voltage AC systems and components. This approach offers great advantages to the industry because it allows much of the existing technology of high-voltage testing to be carried over to the qualification of valves. On the other hand, it must be recognized that a particular STATCOM application may result in wave shapes different from the standards and, in this case, the test may be modified so as to realistically reflect expected conditions.

9.2 Test object

The test object should generally be a complete valve. Tests on individual valve sections are acceptable if the supplier can demonstrate that the voltage distribution between valve sections, under test conditions, is representative of the voltage distribution within a complete valve in service. The test valve or valve section shall be assembled with all auxiliary components except for the valve surge arrester, if provided.

If valve section is used as test object, the minimum number of valve levels should be representative of a complete valve in terms of dielectric stresses.

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

The test object used for the valve dielectric tests will normally not permit the application of atmospheric correction to the specified test voltages without overstressing the internal components. For this reason, no atmospheric correction factor is applied to any of the dielectric tests between valve terminals. The supplier shall demonstrate that the effects of atmospheric conditions on the valve internal withstand have been allowed for adequately.

9.3 Test methods

9.3.1 General

Performing the valve dielectric test presents considerable practical difficulties on valves of the controllable voltage source type because of the high current drawn by the in-built capacitance. For this reason, the following valve dielectric test methods are acceptable.

9.3.2 Method 1

Temporary substitution of a reduced capacitance but the same physical size test capacitor is permissible. This test capacitor shall allow a test voltage build-up across the test object during test.

It may be necessary too to disable gate electronics or other auxiliary circuits in this test, or provide independent means for powering them, in order to prevent interference with partial discharge measurement, for example, from gate unit power supply circuits. In this case, the active voltage control function, if any, provided by gate electronics on each IGBT level is allowed to be represented by other means, for example, high resistance shunt resistors across test IGBT levels.

In event that it is not possible to disable gate electronics or other auxiliary circuits in this test and interference can be proven to be caused by electronics circuit, then this interference may be deducted from measurement.

9.3.3 Method 2

Valve dielectric test is done by two steps.

Step one focuses on the component level and step two on the valve or valve section. In step one, module levels are tested independently. In step two, the test is done with submodule levels short-circuited, interconnections between adjacent submodules removed and valve or valve section voltage distribution controlled by an external grading circuit, for example a resistor array, capacitor array or RC array.

NOTE Atmospheric correction to the specific test voltages can be added in step two.

9.4 Test requirements

9.4.1 Valve AC voltage or AC-DC voltage test

9.4.1.1 General

This test consists of a short-duration test followed by a long-duration test. The short-duration test reproduces the AC voltage or composite AC-DC voltage resulting from certain converter or system faults.

This test consists of 10 s short-duration and 30 min long-duration voltage test.

This test can be done either by one combined test or by separated short-duration test and long-duration test.

Starting from a voltage not higher than 50 % of the maximum test voltage, the voltage shall be ramped up to the specified 10 s test voltage as fast as possible, reduced to the specified 30 min test voltage if combined test is performed, or zero if separate test is performed, kept constant for 30 min and then reduced to zero.

Where a separate test is performed, the long-duration test shall be performed after the short-duration test. In long-duration test, starting from a voltage not higher than 50 % of the 30 min test voltage, the voltage shall be ramped up to 30 min test voltage, kept constant for 30 min and then reduced to zero.

For partial discharge measurement, the peak value of the periodic partial discharge recorded during the last minute of the 30 min test shall be less than 200 pC, provided that the components which are sensitive to partial discharge in the valve have been separately tested.

Where possible, the test voltage shall be increased from 50 % to the maximum voltage level within approximately 10 s. A longer time may be used; however, this overstresses the test object.

If an increasing trend in the rate or magnitude of partial discharge is observed, the test duration may be extended until equilibrium partial discharge is achieved.

9.4.1.2 Valve AC voltage test

This test is applicable only to valves which are terminated directly to two AC phases or between one AC phase and neutral.

The RMS value of valve AC test voltage U_{tv} shall be determined in accordance with the following:

10 s test:

$$U_{tv} = \frac{U_{tac1}}{\sqrt{2}} \times k_o \times k_6$$

30 min test:

$$U_{tv} = \frac{U_{tac2}}{\sqrt{2}} \times k_o \times k_6$$

U_{tac1} is the peak value of maximum voltage across valve during operation, including valve de-blocking and blocking operation in system temporary overvoltage condition. The limiting effect of valve voltage control function and valve arrester, if any, shall be taken into account to derive the overvoltage in service condition;

U_{tac2} is the maximum value of the peak steady-state operating voltage appearing across the valve, including switching overshoot;

k_o is a test scaling factor according to 4.3.2;

k_6 is a test safety factor of 1,10.

9.4.1.3 Valve AC-DC voltage test

This test applies to the valve that is terminated between one DC terminal and one AC phase.

The valve test voltages have a sinusoidal waveshape superimposed on a DC level.

In this test, a capacitor can be used in conjunction with an AC test voltage source to produce a composite AC-DC voltage waveform. Depending on the converter topology, the capacitor can be an integral part of the valve, or it can be a separate item (part of the test circuit, not part of the test object).

Alternatively, a separate DC voltage source can be used to substitute the capacitor.

The RMS value of valve AC-DC test voltage U_{tv} shall be determined in accordance with the following:

10 s test:

$$U_{tv} = (k_{c1} \times U_{tac1} \times \sin(2\pi ft) + U_{tdc1}) \times k_o \times k_7$$

30 min test:

$$U_{tv} = U_{tac2} + U_{tdc2}$$

$$U_{tac2} = \frac{\sqrt{2} \times U_{\max\text{-cont}} \times \sin(2\pi ft)}{\sqrt{3}} \times k_{c2} \times k_o \times k_7$$

$$U_{tdc2} = U_{d\max} \times k_o \times k_7$$

where

U_{tac1} is the peak value of maximum voltage across valve during operations, including valve de-blocking and blocking operation in system temporary overvoltage condition. The limiting effect of valve voltage control function and valve arrester, if any, shall be taken into account to derive the overvoltage in service condition;

U_{tdc1}	is the maximum transient DC component overvoltage across valve. The limiting effect of valve arrester or pole arrester can be taken into account to derive the overvoltage in service condition;
$U_{\text{max-cont}}$	is the maximum steady-state phase-to-phase voltage on the AC system or the valve side of the transformer, if a converter transformer is used in between AC system and converters;
U_{dmax}	is the maximum value of the DC component of the steady-state operating voltage of the DC side;
k_{c1}	is the voltage step overshoot factor related to one output voltage step of the converter, under the condition consistent with that used to define U_{tac1} . For a MMC or cascaded two-level (CTL) type converter, the voltage step overshoot factor relates to the overshoot factor of one cell or submodule;
k_{c2}	is the voltage step overshoot factor related to one output voltage step of the converter, under the condition consistent with that used to define U_{tac2} ;
k_0	is a test scaling factor according to 4.3.2;
k_7	is a test safety factor of 1,10;
f	is the test frequency (50 Hz or 60 Hz depending on test facilities).

The use of a capacitor instead of a DC source in the test circuit shall be agreed by manufacturer as the test voltage is higher than actual value.

9.4.2 Valve switching impulse test

The following should be taken into account during valve switching impulse test.

- Influence of valve phase reactor and valve energy storage capacitor to impulses.
- The impulse test will be applied only in one polarity for the valve with a half-bridge design. This is the valve voltage withstand polarity. For the valve with a full-bridge design, the test shall be done on both positive and negative polarities.
- If the valve impulse withstand levels are equal to or less than the valve AC or AC-DC voltage test level, it is deemed that the valve AC or AC-DC voltage test can cover the impulse tests and consequently the impulse tests can be omitted.

A standard switching impulse voltage waveshape in accordance with IEC 60060-1 shall be used.

The test shall comprise three applications of switching impulse voltages of specified amplitude on the valve.

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

- Valve with valve arrester protection:

$$U_{\text{tsv}} = SIPL_v \times k_0 \times k_8$$

where

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

k_0 is a test scaling factor according to 4.3.2;

k_8 is a test safety factor of 1,10.

- Valve without valve arrester protection:

This test is intended to verify the valve insulation when the valve is not directly protected by surge arresters.

$$U_{tsv} = U_{cms} \times k_o \times k_g$$

where

U_{cms} is the switching impulse prospective voltage across valve terminals according to system insulation coordination studies;

k_o is a test scaling factor according to 4.3.2;

k_g is a test safety factor of 1,15.

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

NOTE Same as AC voltage test or AC- DC voltage test performing, the valve switching impulse test presents considerable practical difficulties on valves of the controllable voltage source type because of the large in-built capacitance. The test facility has difficulty in generating the switching impulse voltage. For this reason, the test methods described in 9.3 are applicable here as well.

10 IGBT overcurrent turn-off test

10.1 Purpose of test

The principal objective is to check the adequacy of the STATCOM valve design, especially the IGBT, and the associated electrical circuits with regard to current and voltage stresses at turn-off in the event of certain short circuit faults or misfiring events.

The test shall replicate the worst combination of voltage stress and instantaneous junction temperature, based on conditions that represent the most unfavourable tolerance settings of the monitoring/protection circuits. Depending on the control and protection strategy, more than one test may be required in order to reproduce all relevant stresses.

General requirements related to the test circuit and the representation of DC capacitor, loop stray inductance, etc. are as stated in 6.3.

10.2 Test object

As described in 6.2. However, certain protection or monitoring circuits shall be represented if they are essential for the detection of an overcurrent event.

10.3 Test requirements

The test consists of operating the test object to thermal equilibrium under the conditions which lead to the highest steady-state junction temperature of the relevant IGBTs (see 6.4) and then initiating an overcurrent event. The control and protection system then detects the overcurrent and suppresses the overcurrent by the valve protective blocking, i.e. by turning off the IGBTs at a current below the maximum safe turn-off limit.

The DC voltage, U_{tpv2} , during the test shall be determined as follows:

$$U_{tpv2} = U_{dtemp} \times k_n \times k_{10}$$

where

U_{dtemp} is the maximum temporary DC overvoltage;

k_n is a test scaling factor according to 4.3.1;

k_{10} is a test safety factor;

$k_{10} = 1,05$.

The test current waveform in the time interval between detection of the overcurrent and the instant of turn-off of the IGBTs should be representative of the service condition, particularly in terms of current rate-of-rise di/dt .

11 Tests for valve insensitivity to electromagnetic disturbance

11.1 Purpose of tests

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

Generally, the valve insensitivity to electromagnetic disturbance can be checked by monitoring the valve during other type tests. Of these, the valve and the valve maximum continuous operating duty test and maximum temporary overload operating duty test (see 6.4 and 6.5), the valve impulse test (see 9.4.2) and the IGBT overcurrent turn-off test (see Clause 10) are the most important.

The tests shall demonstrate that

- a) out-of-sequence or spurious switching of IGBT does not occur,
- b) the electronic protection circuits installed in the valve operate as intended, and
- c) false indication of valve level faults or erroneous signals sent to the converter control and protection systems by the valve base electronics, arising from receipt of false data from the valve monitoring circuits, does not occur.

NOTE For this document, tests to demonstrate valve insensitivity to electromagnetic disturbance apply only to the VSC 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 document.

11.2 Test object

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

When insensitivity to electromagnetic disturbance arising from coupling between adjacent valves in a MVU is to be demonstrated, two approaches are acceptable as defined in 11.3. In this case, the test object will be a separate valve or valve section according to the approach adopted.

11.3 Test requirements

11.3.1 General

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

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

11.3.2 Approach 1

Approach 1 is to simulate the source of electromagnetic disturbance directly as part of a test set-up. Such a test set-up will require more than one valve or valve section in order to check for interaction between them. The geometric arrangements of the source of the electromagnetic disturbance with respect to the valve under test shall be as close as possible to the service arrangement (or worse from an electromagnetic disturbance point of view). The

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

11.3.3 Approach 2

Approach 2 is to determine the intensity of electromagnetic fields under worst operational conditions, either from theoretical considerations or by measurements. In a second step, these fields are simulated by a test circuit which generates correct (or worse) electromagnetic radiation at the respective frequencies. A valve section is then exposed to the fields generated by the test source.

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

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

- the valve section shall have operational voltage (proportionally scaled) between its terminals and be forward biased at the time of energization of the field coil;
- the electronics of the valve section under test shall be energized;
- those parts of the valve base electronics that are necessary for the proper exchange of information with the valve section shall be included.

11.3.4 Acceptance criteria

The criteria for acceptance for both approaches 1 and 2 shall be as defined in 11.1.

12 Short-circuit current test (optional)

12.1 Purpose of tests

This test is for the valve without fault current switching function and applicable only for the valves with a common DC-link.

The principal objective is to check the adequacy of the devices, especially the diodes, any additional components used to protect the diodes (such as bypass thyristors) and the associated electrical circuits with regard to current stresses under specified short circuit conditions, for example DC energy storage capacitor terminal to terminal short-circuit fault, until the control and protection circuit breaks the fault current. The STATCOM valves should be designed to withstand the short-circuit overcurrent for the number of cycles needed to open the main AC circuit breaker, without any failure or damage in the equipment, considering also that a possible recovery voltage could appear. The test should normally be performed with the valve electronics initially energized, unless the short-circuit current can occur under conditions where the valve is de-energized (for example due to the inrush current when the converter breaker is closed at start-up).

12.2 Test object

As described in 6.2.

NOTE Subject to agreement between purchaser and supplier, this test can be done on component level instead of valve or valve section.

12.3 Test requirements

The test consists of operating the test object to thermal equilibrium under the conditions which lead to the highest steady-state junction temperature of the relevant semiconductor component (see 6.4) and then initiating a fault current event. In order to define the maximum junction temperature rise of the IGBTs and the diodes, all the possible overload conditions (in terms of amplitude and duration) shall be taken into consideration.

The fault current amplitude, duration and the number of cycles should be the maximum values expected in the actual field operation. No test safety factor is applied to the current.

Where the test object experiences a recovery voltage between cycles of fault current, then this recovery voltage, including commutation overshoot where applicable, shall also be reproduced during the test. A test safety factor of 1,05 is applied to the recovery voltage.

13 Production tests

13.1 General

Clause 13 covers tests on assemblies of components that are parts of valves, valve sections, or auxiliary circuits for their protection, control and monitoring. It does not cover tests on individual components that are used within the valve, the valve support, or valve structure.

13.2 Purpose of tests

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

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

13.3 Test object

All valve sections or parts thereof manufactured for the project shall be subjected to the routine production tests. The tests may be performed on valve sections or individual levels as appropriate to the design and available test facilities.

13.4 Test requirements

Uniformity in the specified production tests of different suppliers is unnecessary. The production tests shall take into account the special design characteristics of the valve and its components, the extent to which the components are tested prior to assembly, and the particular manufacturing procedures and techniques are involved. In Clause 13, only production test objectives are given.

In all cases, the supplier shall submit, for approval by the purchaser, a detailed description of the test procedures proposed to meet the production test objectives.

The minimum requirements for routine production tests are listed in 13.5. The order in which the tests are listed implies neither ranking of importance nor the order in which the tests should be performed.

In some cases, it may be necessary to perform production sample tests on complete assemblies in addition to the routine tests, for example when modifications are introduced in

the course of production. The nature and extent of such additional tests shall be agreed on a case-by-case basis.

13.5 Production test objectives

13.5.1 Visual inspection

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

13.5.2 Connection check

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

13.5.3 Voltage-grading circuit check

Check the grading circuit parameters and thereby ensure that voltage division between series-connected levels will be correct for applied voltages from DC to impulse waveshapes, if applicable.

13.5.4 Control, protection and monitoring circuit checks

Check the function of any control, protection or monitoring circuits that form an integral part of the valve, such as IGBT gate drive circuits and any local protection or monitoring circuits.

If type tests and tests of the effectiveness of fuse protection are considered to be necessary, they shall be specified separately with conditions for tests.

13.5.5 Voltage withstand check

Check that the valve components can withstand the voltage corresponding to the maximum value specified for the valve. The checks shall include AC test voltage or DC voltage or AC-DC combination. Annex B includes information on valve component fault tolerance.

13.5.6 Turn-on/turn-off check

Check that the IGBT(s) in each valve level turns on and turn off correctly in response to switching commands.

13.5.7 Pressure test

Check that there are no coolant leaks.

14 Presentation of type test results

The test report shall include the following information:

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

- description of equipment or component failure.

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Annex A (informative)

Overview of STATCOM valves

A.1 General

A rapid development of modern semiconductor switches has enabled also the development of power electronics technology in general. In addition to diodes and thyristors, also turn-off semiconductor devices such as metal-oxide-semiconductor field effect transistors (MOSFETs), gate turn-off thyristors (GTOs) gate commutated thyristors (GCTs), integrated gate commutated thyristors (IGCTs) and insulated gate bipolar transistors (IGBTs) are now utilised in various converter types of DC-DC, DC-AC, AC-DC and AC-AC power conversion.

Along with this power electronics evolution, the amount of applications where these converters are used has been increased: they are used in wide range of applications such as switched mode power supplies, motor drives, HVDC-systems. One of the applications is the power conditioning, where static synchronous compensators (STATCOM) are one of the most modern devices.

Basically, the main circuit of STATCOM consists of two-, three- or multi-level converter. With two- and three-level converters, the STATCOM includes a converter bridge that enables bi-directional power flow and a capacitor connected on its DC side serving as an energy storage component. With multi-level converters, the STATCOM typically consists of a number of small bridge converters, each with its own DC energy storage, connected in series between AC phases or from an AC phase to neutral.

Annex A presents the basic operation principles of the STATCOM. However, it is emphasised that a detailed treatment of all possible details, such as all variations in STATCOM valve topologies, are beyond the scope of this document. The purpose of Annex A is only to present a brief overview about basic features of the STATCOM and the converters used within.

A.2 STATCOM applications and operating limits

The compensation power of STATCOM is generally from couple of MVAs to couple of hundreds of MVAs and its control principle is chosen based on the target of its operation. On one hand, STATCOMs are used in utility applications, where the purpose is to support the supply grid voltage. In here, STATCOM is typically used for voltage regulation, power factor correction or reactive power compensation. On the other hand, STATCOMs can be used in industrial applications where the aim is to protect the supply grid against the disturbances generated by a large load. Typical control targets in this case are balancing of unsymmetrical phases, flicker control or filtering of harmonics.

The basic operating principle of the STATCOM is essentially different from static var compensator (SVC), which is also used in reactive power compensation. Since STATCOM is based on the utilisation of turn-off semiconductor switches, its response speed is remarkably faster. In addition to this, since a DC storage is always a part of STATCOM converter, its compensation characteristics are not so dependent on the supply grid characteristics as is the case with SVC.

Figure A.1 presents the principal $U-I$ characteristics of the STATCOM. It is noticed that STATCOM is able to generate full compensation current with very low supply grid voltage. In theory, grid voltage can even be close to zero. However, in this case, STATCOM would need external power source on DC side to compensate its losses and to maintain DC side voltage at required level.

Without external power source, it is necessary for STATCOM to draw also active power from the supply grid in order to maintain DC voltage at required level. Since this has to be done without exceeding current rating of the STATCOM converter, the minimum grid voltage for its operation is typically between 0,2 p.u. and 0,4 p.u. When the voltage is higher than this, STATCOM is able to generate full output current independently on the grid voltage level. Therefore, the maximum reactive power generated or drawn by the STATCOM is only linearly dependent on the grid voltage level, whereas in the case of SVC it is dependent on the second power of grid voltage.

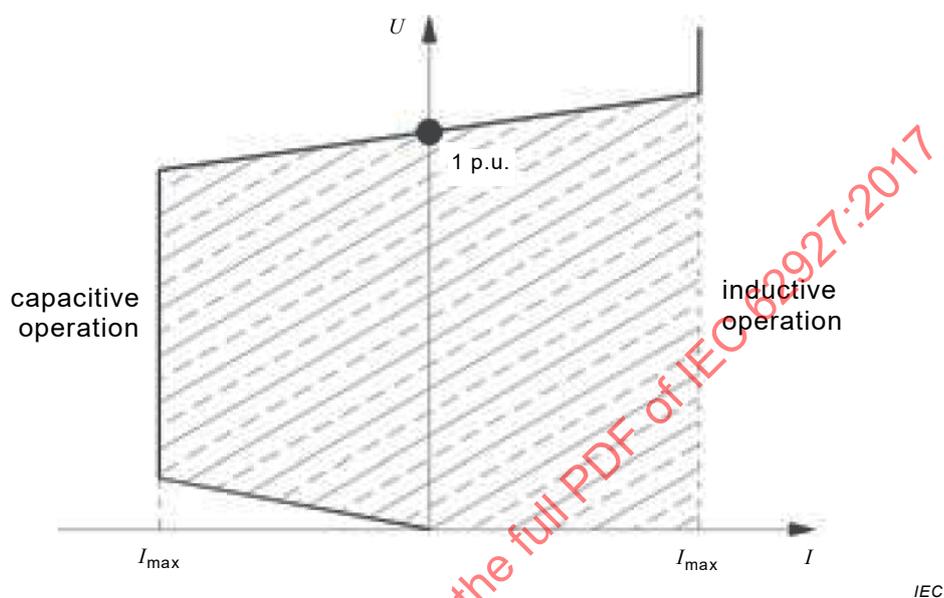


Figure A.1 – STATCOM U - I characteristics

A.3 Overview of STATCOM valve types

There are several three-phase, two-, three-, or multilevel converter types which can be used to make a STATCOM. These are well described in literature and it is far beyond the scope of this document to present them all. However, the basic function block of STATCOM, a STATCOM valve, can be identified in all of these topologies. All STATCOM valves fall into one of the two following categories:

- STATCOM valves of the switch type: these switch type valves function only as a controllable switch with only two permanent states: on and off. In converters based on this topology, the DC capacitors are completely separated from the valves and can be tested in isolation;
- STATCOM valves of the controllable voltage source type: in valves of this type, the DC capacitors form an integral part of the valve and cannot be separated from it for testing purposes.

A.4 STATCOMs based on switch type valve

A.4.1 General

STATCOM valves of this type bear close apparent resemblance to conventional thyristor valves, in that they consist of series-connected IGBT devices which are switched simultaneously. As with conventional thyristor valves, simultaneous switching of the series-connected IGBTs is vital. Valves of this type are normally used with converters with a relatively low number of output levels.