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Electrical Test of STATCOM Valves

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SUMMARY

Electrical test for STATCOM valves is reviewed and the test duties and associated test safety factors are agreed. The electrical test is preferably made on a complete valve if the test facility allows this. Valve sections electrical test is acceptable under the condition that the worst stress on a valve can be well represented during the test.

Valve operations in maximum continuous operating duty, maximum temporary over-load operating and fault cases shall be tested in the valve operational tests. As a general rule, a test safety factor 1,05 shall be applied to both test current and voltage.

Valve internal and external insulations shall be verified by the dielectric tests between valve terminals and dielectric tests on valve support. Different test safety factors are defined in different test duties depending on different fault tolerance requirements. Special attentions shall be paid to the influence of the large built-in valve capacitance when performing the dielectric test between valve terminals. Two test methods are therefore proposed to make this test feasible.

Valve insensitivity to electromagnetic disturbance can be compositely done in the operational test and dielectric test.

KEYWORDS

Flexible Alternating Current Transmission Systems (FACTS), Static Synchronous Compensators (STATCOM), STATCOM valves, Electrical type test

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1 INTRODUCTION

Static Synchronous Compensators (STATCOM) was developed in 1980's. With the fast development of power electronic devices in recent years, especially turn-off semiconductor device IGBT, STATCOM becomes one general product in flexible alternating current transmission system (FACTS).

Several types of "switch" type converters or "controllable voltage source" type converters (VSC) are used for STATCOM. All of them utilize voltage sourced converters which enables full four quadrant control of real and reactive power in service. Although there are many STATCOM installations in power systems worldwide a test guide or standard for STATCOM valves is still not available. Agreement is needed for each STATCOM project. IEC publication, IEC 62501 Voltage sourced converter (VSC) valves for high-voltage direct current (HVDC) power transmission – Electrical testing, can been used to support the specification of STATCOM valve electrical test. However, the difference in application leads to different requirements for VSC valves, although HVDC VSC converters are capable of acting as a full featured STATCOM both under DC power transmission and zero DC power transmission.

To meet the FACTS industry need a working group was established in IEC to develop a test standard on STATCOM valves in 2014. This paper reports the outputs of this working group and highlights those tests, and test safety factors associated with those tests, which are deemed as a minimum in STATCOM valve design verification.

2 STATCOM VALVE ELECTRICAL TEST ESSENTIALS

STATCOM converters are based on force commutated converters in parallel with a high energy capacitive storage, regardless whether the "switch" type valve or "controllable voltage source" type valve is chosen. Some basic properties such as very low input impedance makes test methods for electrical test of Static Var Compensator (SVC) valves and Line Commutated Converter (LCC) HVDC valves infeasible to be adopted directly on STATCOM valves. New test principles and methods for STATCOM valve electrical test need to be investigated and agreed upon.

On the other side since STATCOM converter is power electronic based equipment as SVC valves and HVDC converter there are some common rules applicable in the design and test. The test acceptance criteria, for example, shall be same as those defined in IEC standards, IEC 61954, IEC 60700-1 and IEC 62501, for electrical test of power electronic equipment for power transmission and distribution applications.

The appearance of high capacitance and large phase / valve inductance in STATCOM are an essential and unseparated part of the STATCOM valve design, regardless of the valve types, in STATCOM solution. Those high capacitance and phase / valve inductance will efficiently block and bypass any high frequency voltage transients, resulting in an insignificant impulse voltage across the valve. Fast transient / lightning impulse test across valve is therefore not possible to accomplish in valve electrical test. Those high valve capacitance and inductance may also lead the valve switching impulse or even power frequency voltage dielectric test infeasible in a direct way. Alternative methods shall be specified for a unified test.

STATCOM valve electrical test shall be done on a certain number of valve levels. Considering industry experience of semiconductor application indicates that occasional random failures of valve level components can occur during service operation permissible component failures during valve electrical test shall therefore be specified.

3 OPERATIONAL TESTS

Operational tests are aimed for the design verification on the adequacy of the turn-off semiconductor device level and associated electrical circuits in a valve with regard to current, voltage and temperature stresses in the conducting state, at turn-on and turn-off under the worst repetitive stress conditions.

Correct interaction between valve electronics and power circuits of the STATCOM valves shall be demonstrated in this test too.

The operational tests shall consist of following test duties:

a) Maximum continuous operating duty test;

b) Maximum temporary over-load operating duty test;

c) Minimum start voltage test;

d) Overcurrent turn-off test.

The tests may be performed on either the complete valve or on valve sections mainly depending upon the valve design and the test facility available. The valve or valve sections under test shall be assembled with all auxiliary components and the coolant shall be in a condition representative of service conditions.

3.1 Maximum continuous operating duty test

The maximum turn-off semiconductor devices junction temperature, maximum snubber component temperature, turn-on and turn-off voltage and current corresponding to the worst service operating conditions shall be reproduced in this test.

A test safety factor 1,05 shall be incorporated in the test current and as well as the test voltage. Industry experience indicates that 30 min test duration, after the exit coolant temperature has stabilized, is judicious for this test.

3.2 Maximum temporary over-load operating duty test

In case that maximum temporary over-load operation is specified the valve is subjected to the maximum temporary over-load operating duty test. Same as the maximum continuous operating duty test a test safety factor 1,05 shall be incorporated in the test current and test voltage.

The test duration shall be 1,2 times the specified over-load operation duration in service. A subsequent 10 min operation based on maximum continuous operating duty test shall be followed after the maximum temporary over-load operating duty.

3.3 Minimum start voltage test

STATCOM valve can provide compensation function regardless the system voltage level while the energy storage capacitors have been initially energized. However, it may be important to determine the minimum start voltage of STATCOM valve after connected to an a.c. system without initial energization.

3.4 Overcurrent turn-off test

Switching capability of STATCOM valve at fault overcurrent case shall be verified in the operational tests. The principal objective is to check the adequacy of the STATCOM valve design, especially the turn-off semiconductor devices, 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.

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.

Prior to the overcurrent turn-off test the test object shall be operated to thermal equilibrium under the conditions which lead to the highest steady-state junction temperature of turn-off semiconductor devices.

The test current waveform in the time interval between detection of the fault overcurrent and the instant of turn-off of the semiconductor devices should be representative of the service condition, particularly in terms of current rate-of-rise di/dt. None test safety factor is needed for the fault overcurrent but for the subsequent blocking voltage.

A test safety factor 1,05 shall be incorporated in the subsequent blocking voltage after overcurrent turn-off.

4 DIELECTRICAL TESTS

Dielectric tests of STATCOM valve focus on the external insulation verification by valve support test and internal insulation verification by test between valve terminals.

4.1 Valve support dielectric test

There are two principal objectives for valve support dielectric test. One is 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. The second one is to verify that the partial discharge inception and extinction voltages are above the maximum operating voltage appearing on the valve support.

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.

If multiple valve units use one support structure dielectric test shall be done between valves to verify the insulation in between.

Unless the valve support is exposed to d.c. voltage in service the valve support dielectric test shall be done at power frequency a.c. voltage.

4.1.1 Valve support a.c. voltage test and d.c. voltage test

The test consists of one minute short duration a.c. voltage withstand test and ten minutes long duration a.c. voltage test.

The maximum voltage appearing on the valve support in service, particularly in system fault condition and valve fault operation condition shall be the base for the test voltages. Test safety factor 1,30 and 1,15 shall be incorporated in the short duration voltage test and long duration voltage test respectively.

If the valve support exposes to a d.c. voltage in service condition the valve support is subjected to one min short duration d.c. withstand voltage test and 3 h long duration d.c. voltage test.

4.1.2 Valve support lightning impulse voltage test

STATCOM valve doesn’t see a significant impulse voltage in service. The power frequency voltage test is most important. However, to be in harmony with other IEC test standards, a lightning impulse withstand voltage test is requested. A standard lightning impulse voltage wave shape in accordance with IEC 60060 shall be used. The test voltage shall be determined by the insulation coordination study and selected from the nearest upper standard lightning impulse voltage in Table 2 or 3, IEC 60071-2.

4.2 Dielectric tests between valve terminals

Dielectric tests between valve terminals are intended to verify the design of the valve regarding its voltage-related characteristics for various types of over-voltages (d.c., a.c. and switching impulse over-voltages). The tests shall demonstrate that:

- the valve will withstand the specified over-voltages;
- partial discharges will be within specified limits under specified test conditions;
- the internal voltage grading circuits have sufficient power rating;
- the valve electronic circuits behave as expected.

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. Partial discharge identification in "switch" type valve dielectric test is a challenge too due to the use of high impedance IGBT control circuits or cell active voltage control function in some designs.

Two valve dielectric test methods are deemed technically acceptable alternatives.

Method one is a temporary substitution of a reduced capacitance but the same physical size test capacitor. This test capacitor shall allow a test voltage build-up across the test object during test. To disable gate electronics or other auxiliary circuits to prevent interference with partial discharge measurement may be an additional need in this method.

Method two is to do the test in two steps. Step one focuses on the component level and step two on the valve or valve section. In step one active module levels are tested independently. In step two the test is done with active modules short-circuited and valve or valve section voltage distribution is controlled by an external resistor array.

4.2.1 Valve a.c. voltage test or a.c. – d.c. voltage test

An a.c. test voltage is generally applicable. In some designs, for example "switch" type valve, this test may need to be done under a.c. – d.c. voltage.

Valve voltage withstand capability under maximum system temporary overvoltage, including the overvoltage at fault, shall be tested with a short duration, 10 sec., a.c. voltage test or a.c. – d.c. voltage.

A long duration, 30 min., a.c. or a.c. – d.c. voltage test shall be followed to prove the partial discharges are within specified limits.

A test factor of 1,10 shall be applied in both short-duration and long duration tests.

4.2.2 Valve switching impulse voltage test

Valve shall withstand the switching impulse prospective voltage across valve terminals according to system insulation coordination studies, with a test safety factor 1,10 for the valves with surge arrester protection and 1,15 for valves without surge arrester protection.

If the valve impulse withstand levels are equal to or less than the valve a.c. or a.c. – d.c. voltage test level, it is deemed that the valve a.c. or a.c. – d.c. voltage test can cover the impulse tests and consequently the impulse tests can be omitted.

5 TEST FOR VALVE INSENSITIVITY TO ELECTROMAGNETIC DISTURBANCE

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 tests. Of these, the valve maximum continuous operating duty test and maximum temporary overload operating duty test, the valve impulse test and the IGBT overcurrent turn-off test are the most important.

The tests shall demonstrate that:

- out-of-sequence or spurious switching of IGBT does not occur;
- the electronic protection circuits installed in the valve operate as intended;
- 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

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