IEC TS 63336

Edition 1.0 2024-07

TECHNICAL SPECIFICATION

Commissioning of VSC HVDC systems

IEC TS 63336:2024-07(en)

IEC Secretariat
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

About the IEC
The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications
The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigendum or an amendment might have been published.

IEC publications search - webstore.iec.ch/advsearchform
The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee, …). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished
Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and once a month by email.

IEC Customer Service Centre - webstore.iec.ch/csc
If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: sales@iec.ch.

IEC Products & Services Portal - products.iec.ch
Discover our powerful search engine and read freely all the publications previews, graphical symbols and the glossary. With a subscription you will always have access to up to date content tailored to your needs.

Electropedia - www.electropedia.org
The world's leading online dictionary on electrotechnology, containing more than 22 500 terminological entries in English and French, with equivalent terms in 25 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC TS 63336

Edition 1.0 2024-07

TECHNICAL SPECIFICATION

Commissioning of VSC HVDC systems

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 29.200; 29.240.01

ISBN 978-2-8322-8923-5

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

____

COMMISSIONING OF VSC HVDC SYSTEMS

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) IEC draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). IEC takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, IEC had not received notice of (a) patent(s), which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at https://patents.iec.ch. IEC shall not be held responsible for identifying any or all such patent rights.

IEC TS 63336 has been prepared by WG 13: Commissioning of VSC HVDC systems, of IEC technical committee 115: High voltage direct current (HVDC) transmission for DC voltages above 100 kV. It is a Technical Specification.

The text of this Technical Specification is based on the following documents:

Draft	Report on voting
115/360/DTS	115/367/RVDTS

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 Specification 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.

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

- reconfirmed,
- withdrawn, or
- revised.

COMMISSIONING OF VSC HVDC SYSTEMS

1 Scope

This document, which is a technical specification, applies to the commissioning of voltage-sourced converter (VSC) high voltage direct current (HVDC) systems which consist of two converter stations and the connecting HVDC transmission line.

The tests are generally applied to all HVDC configurations and could require addition or deletion to match the given solution.

This document provides guidance on the planning of commissioning activities. The commissioning described in this document is implemented through on-site testing on the whole system functionality, including testing on the subsystem and system. This document provides the scope, procedures and acceptance criteria of the tests.

Factory system tests, on-site equipment tests, electrode tests, and trial operation are not included in this document.

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 60633:2019, *High-voltage direct current (HVDC) transmission – Vocabulary*

IEC 62747:2014, *Terminology for voltage-sourced converters (VSC) for high-voltage direct current (HVDC) systems*
IEC 62747:2014/AMD1:2019

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 62747 and IEC 60633 as well as the following apply.

3.1 Test classification terms

3.1.1
factory system tests
FST
tests which are performed in a factory of HVDC control and protection equipment to verify the main functions and performances as well as the interface with VSC valve, optical measuring devices, etc.

Note 1 to entry: It is also referred to as a functional/dynamic performance test (FPT/DPT).

3.1.2
on-site equipment tests
electrical and mechanical tests which are performed on-site on a single equipment to verify that no equipment damage has occurred during transport and site assembly, and that installation has been correctly performed

3.1.3
subsystem tests
tests which are performed on-site to prove the correct interconnection and functioning of all individual items of equipment within a functional group (or subsystem) and that these items operate and interact correctly

3.1.4
system tests
tests verifying functions and performances of HVDC system as a whole as well as the interaction with adjacent AC systems on-site

3.1.5
converter station tests
tests verifying functions and performances of the converter unit disconnected from the HVDC transmission line on-site

Note 1 to entry: These are also referred to as STATCOM mode tests.

3.1.6
transmission tests
tests verifying functions and performances of HVDC system when transmitting power between both converter stations on-site

Note 1 to entry: These are also referred to as end-to-end tests.

3.1.7
point of common coupling
PCC
point of interconnection of the HVDC converter station to the adjacent AC system

[SOURCE: IEC 62747:2014, 9.25]

3.2 Other terms

3.2.1
PQ characteristic
capability of active and reactive power of a VSC HVDC converter unit, which is normally a closed and irregular region with active and reactive power in a two-axis graphical representation

3.2.2
Qac control
reactive power control mode of VSC converter to control the exchange of reactive power to a specified value

3.2.3
Uac control
reactive power control mode of VSC converter to control the AC bus voltage to a specified value

3.2.4
dynamic performance study
DPS
off-line investigation of the dynamic behaviour of various fault scenarios within the specified boundaries of AC system

Note 1 to entry: The result of the DPS should be the optimum set of control and protection parameters to achieve the best overall dynamic behaviour for the specific HVDC.

3.3
human machine interface
HMI
interface for a human operator to operate, monitor and maintain an HVDC locally at site or from the remote

Note 1 to entry: An HMI typically consists of a monitor, a keyboard and a mouse.

4 Stages, sequence and objectives of commissioning of VSC HVDC systems

4.1 Process of commissioning of VSC HVDC systems

During the commissioning and testing of an HVDC project, the HVDC equipment is verified in groups and in conjunction with the control and protection systems. Usually, this process can be divided into four major parts: factory tests, on-site equipment tests, subsystem tests and system tests as shown in Figure 1.

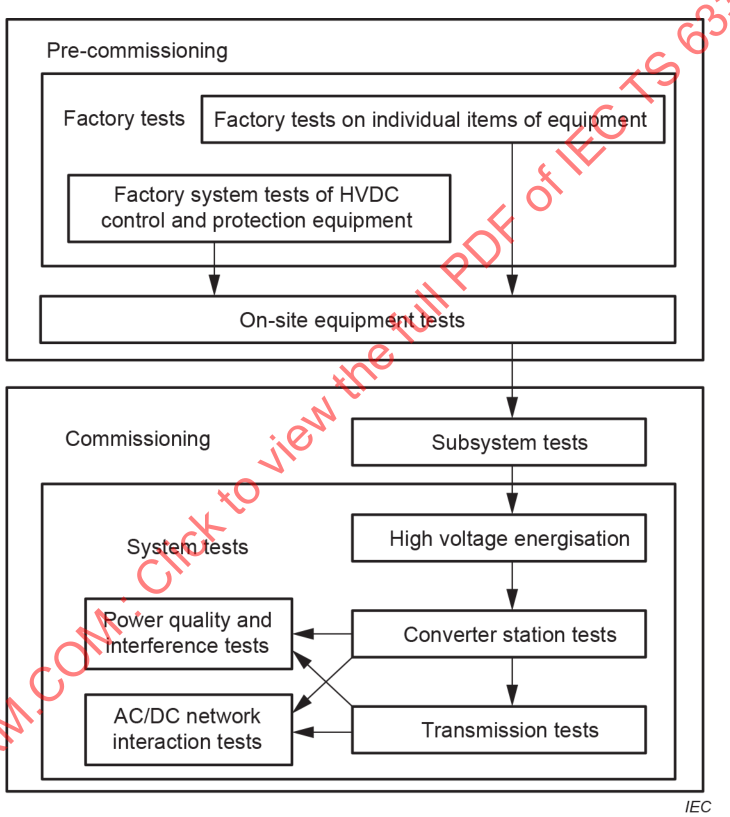


Figure 1 – Overview diagram of commissioning process of VSC HVDC systems

The structure and sequence of the VSC commissioning process require an understanding of the overall VSC HVDC system structure and a definition of various components within this structure. Figure 2 shows an example of two parallel VSC HVDC systems along with graphical designations used in this document.

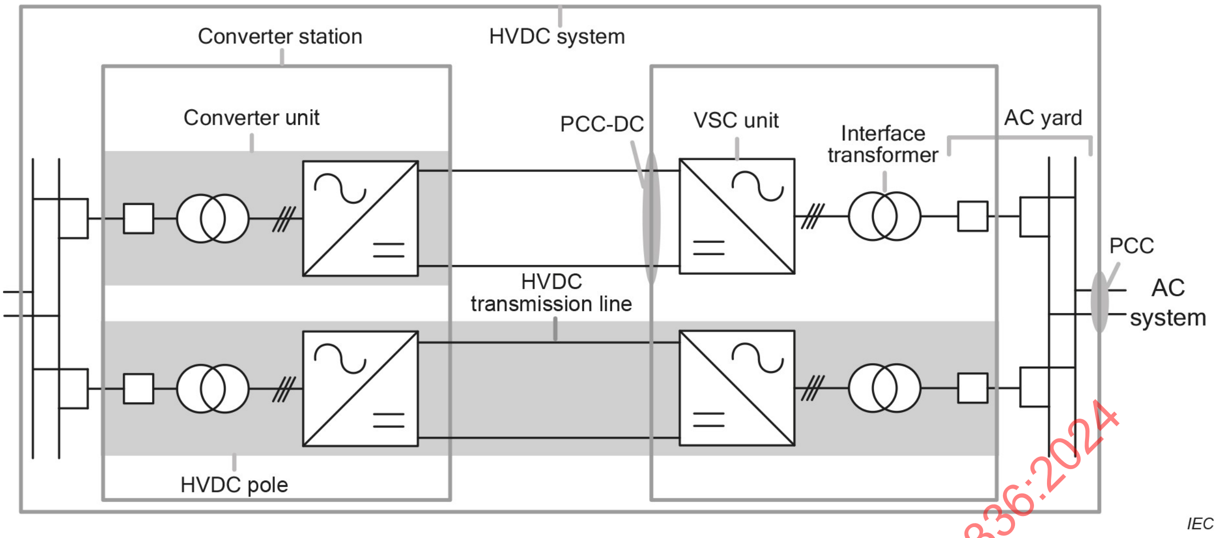


Figure 2 – VSC HVDC systems and designations

4.2 Pre-commissioning

4.2.1 Factory system tests of HVDC control and protection systems

Factory system tests cover the verification of internal connections within and in between the control cabinets and the functional verification of the software and are performed in the factory prior to the control and protection equipment being sent to site.

During the factory system tests, the complete control and protection systems are tested. External stand-alone equipment, such as external protection relays, are typically excluded. Where other external interfaces are present, the tests should be performed as completely as possible, to determine with as much confidence as is practical that the control and protection systems will operate correctly in terms of the expected input and output signals. Such external interfaces include auxiliary power systems, converter cooling systems, fire protection systems, etc.

Finding and correcting hardware and software errors in the control and protection systems is an important function of factory system tests. Such faults are easier to find and rectify in the factory than during on-site commissioning. Correcting such faults reduces the probability of disturbing the power system during the commissioning tests.

4.2.2 On-site equipment tests

On-site equipment tests are electrical and mechanical tests on a single installed item of equipment or plant. The primary purpose of these tests is to ensure, to the extent possible, that no equipment damage has occurred during transport and site assembly, and that the installation has been correctly performed.

The equipment supplier may in some cases specify particular checks and inspections that can help verify the equipment integrity.

4.3 Commissioning

4.3.1 Subsystem tests

A subsystem includes groups of main circuit equipment, associated measurement systems, control and protection systems, and/or auxiliary systems.

The objective of this stage is to validate the correct integration of subsystem components. This is done by verifying the signals and readings, control functions such as switching sequences and interlocking functions. Those parts which are completely tested in FST do not need to be verified again.

Subsystem tests are generally performed per functional group and consequently all equipment and elements within that functional group must be ready for test before that particular subsystem test can commence. All subsystem tests shall be completed before the system tests commence for any individual pole within a converter station.

Subsystems to be tested for a VSC converter station comprise the following key elements:

a) Power, control and communication cabling systems.
b) Main circuit equipment.
c) AC protections and interlocking.
d) Remote SCADA interface.
e) Auxiliary systems.
f) Final trip tests.

4.3.2 System tests

System tests cover the start-up and test of the complete HVDC System in operation. System tests are required to prove that the functions and performances of the HVDC system meet technical requirements when connected to the AC network. The structure of the system tests will follow the structure of the HVDC system, starting from the smallest, least complex, operational unit, and end with the total system in operation.

System tests are comprised of the following commissioning and testing activities:

a) High voltage energisation.
b) Converter station tests.
c) Transmission tests.
d) Power quality and interference tests.
e) AC/DC network interaction tests.

The first three elements are undertaken sequentially. The last two elements are scheduled during appropriate times during the performance of the converter station tests and transmission tests.

The scope and flow of system tests are shown in Figure 3.

Before system tests commence with the energisation tests at the converter unit level, the following preconditions shall be satisfied:

f) All equipment tests are completed and passed.
g) All subsystem tests are completed and passed.
h) The results and outcomes of the factory tests are reviewed and accepted.
i) All necessary control and protection systems and auxiliary systems are verified, operational and confirmed to be in-service, including both active and standby systems.
j) All required high voltage measurement and safety tools and equipment are available, tested and calibrated.
k) All monitoring and test equipment that is required to be connected is confirmed to be connected and ready for service.
l) Final trip tests are completed and passed.

m) All high voltage, and to be energized, areas within the converter unit are fully inspected to ensure all tools, equipment and debris is removed.

n) All high voltage equipment, VSC valves and high voltage areas are thoroughly cleaned.

o) All surge arrester counter readings are recorded.

p) All conditions for a "ready for energisation" state within the control and protection systems, i.e. circuit-breakers and disconnectors are in the correct positions to permit energisation and no alarms with main equipment and control and protections, are satisfied.

q) The triggering of any transient fault recorder is set to settings to capture the conditions under test.

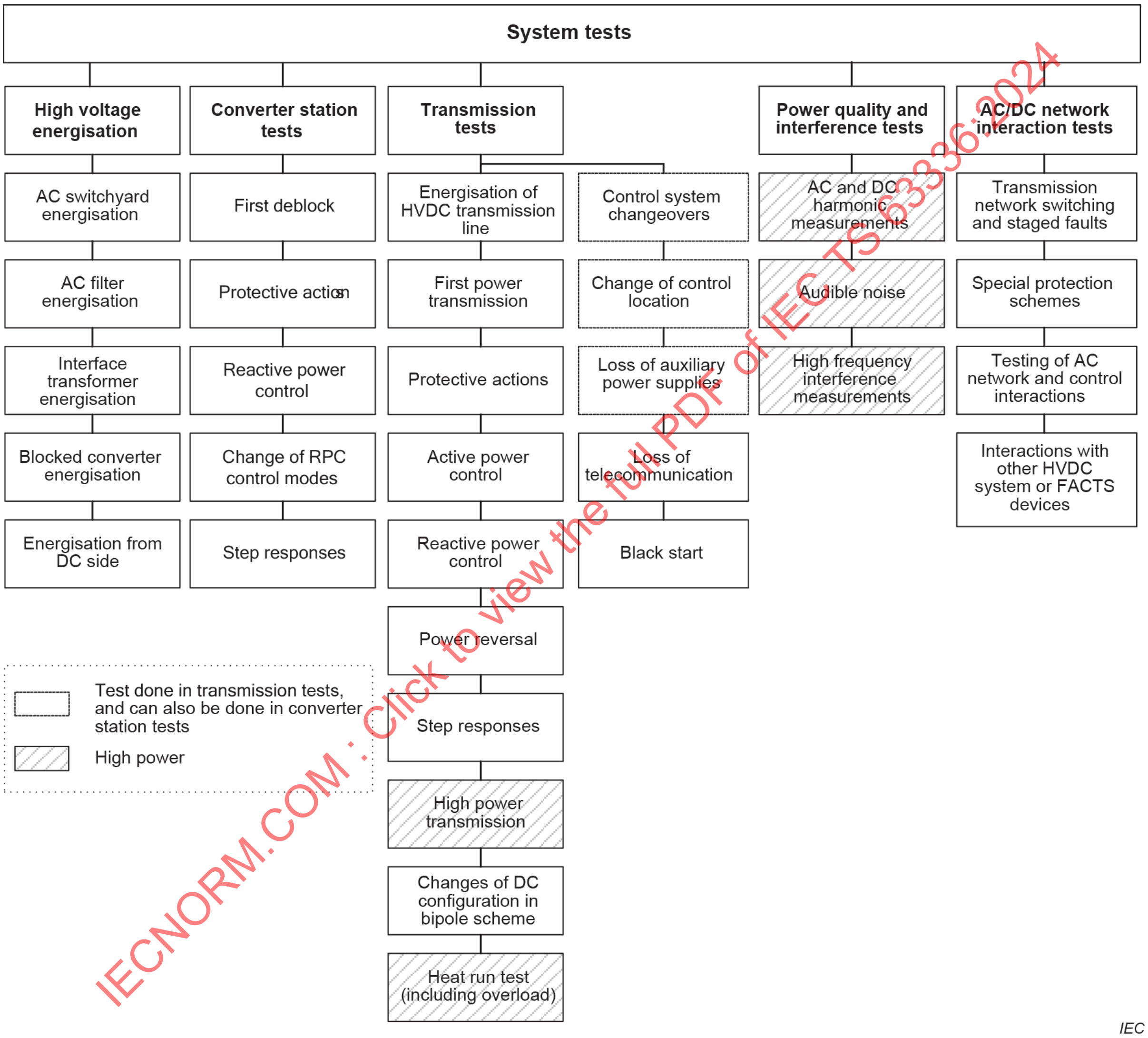


Figure 3 – Scope of system tests

Table 1 provides an overview of the components of system tests for an HVDC system, including the test groups which make up the system tests. These test groups will be typically performed in the order as shown in Table 1. The sequence would start at the local level with tests within each converter unit performed and completed before moving on to the remote converter station, the complete HVDC transmission system and any interfaces such as SCADA and remote control systems.

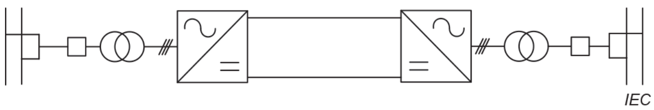
Converter station tests start with the energisation of the converter unit. Converter station tests are performed at each converter unit, with the converter unit being connected to the adjacent AC network but disconnected from the HVDC transmission line. The converter station tests will verify the majority of control and protection modes and functions for the HVDC converter and successful operation of the converter unit in STATCOM mode.

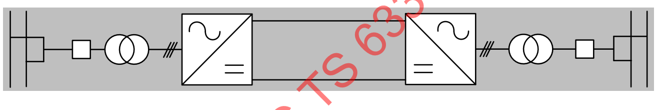
The transmission tests start when both converter units of the HVDC pole have completed their converter station tests. These start with the energisation of the HVDC transmission line and move on to the first active power transmission and operation in various combinations of control modes at various power levels. If the HVDC system is a bipolar system, the transmission tests should be performed on a monopolar basis first and then move on to bipolar operation. The transmission tests conclude with full power transmission at various operating positions on the PQ Characteristic and a final heat run test if supported by the grid.

With the complete system verified as running correctly, the performance of the HVDC system in steady state operation is verified. With normal operating ramp settings and automatic switching sequences in place, the operation, network interaction, power quality, interference and disturbance tests can be performed. In some cases, the transient performance and behaviour during faults should be verified. Some disturbance tests, such as staged faults, are dependent on approval from regulatory bodies, other impacted utilities and the suitability of the AC network to accommodate such tests as it is not always practical to perform on-site demonstration of real fault performance.

If maximum active power or reactive power levels cannot be achieved, perform the test at the highest power levels possible, according to the AC system and agreed by all parties.

Table 1 – Structure of system tests

Test	Equipment under test
High voltage energisation tests	
1) AC switchyard energisation	
2) AC filter energisation	
3) Interface transformer energisation	
4) Blocked converter energisation	
5) Energisation from DC side*	
Converter station tests	
1) First deblock	
2) Protective actions	
3) Reactive power control	
4) Change of RPC control modes	
5) Step responses	

Test	Equipment under test
Transmission tests 1) Energisation of HVDC transmission line 2) First power transmission 3) Protective actions 4) Active power control 5) Reactive power control 6) Power reversal 7) Step responses 8) High power transmission 9) Changes of DC configuration in bipole scheme 10) Heat run test 11) Control system changeovers 12) Change of control location 13) Loss of auxiliary power supplies 14) Loss of telecommunication 15) Black start	
Power quality and interference tests 1) AC and DC harmonic measurements 2) Audible noise 3) High frequency interference measurements	
AC/DC network interaction tests 1) Transmission network switching and staged faults 2) Special protection schemes 3) Tests of AC network and control interactions 4) Interactions with other HVDC systems or FACTS devices	
* For this test the test range is extended up to HVDC transmission line and the other converter station	

4.3.3 Operating states of VSC HVDC transmission

The VSC HVDC transmission system may be capable of operating in any or all the following distinct and mutually exclusive states:

a) Earthed: Pole/converter is isolated and earthed on the AC and DC sides, normally used for safe maintenance work. The converter is not operational.

b) Stopped/Isolated: Converter is isolated on both AC and DC sides, with all earthing switches open.

c) Standby/De-energised: Converter is not transmitting power. Sufficient auxiliary power circuits and secondary systems are operational to allow energisation. The converter is not yet receiving control commands, and there is no high voltage feed from either the AC or DC side.

d) Blocked/energised: Pole/converter is fully energised from either the AC or the DC side, and the converter is not yet receiving control commands.

e) Deblocked: Converter is energised from either the AC side or the DC side and receives control commands to enable the VSC valves to be switched to allow where appropriate control of the AC and DC voltages of the converter.

f) STATCOM mode: The converter is deblocked and fully energised from the AC side, but the DC side is either isolated or configured such that no active power is transmitted. The reactive power can be controlled at the converter's AC side and the DC bus voltage can be controlled.

g) Islanded/DC connected mode: The converter at one end is connected via the DC system to another converter which is connected to an AC network. The converter connected to the islanded network is able to control its AC voltage and frequency.

h) Transmission mode: The converters at both ends are deblocked and fully energised from the AC side and is joined to one or more other converters via DC interconnections. The active and reactive power and AC and DC voltages can be controlled.

4.4 Trial operation

For VSC HVDC systems, it is typical for a period of trial operation following the completion of the commissioning. The duration, purpose and requirements of the trial operation period are as agreed between the owner and the supplier and are usually defined in the contract documents or the technical specifications.

The trial operation period provides the opportunity for:

a) Verification of operation of the complete HVDC system by operating for an extended period of time.

b) Demonstration of key availability and reliability requirements defined in the technical specifications.

c) Completion of converter station tests or transmission tests which are not possible during the structured commissioning program due to the inability to achieve high active and reactive power levels.

5 Subsystem tests

5.1 General

Subsystem tests prove the correct interconnection and functioning of all individual items of equipment within a functional group (or subsystem) and that these items operate and interact correctly.

Before subsystem tests commence, besides the preconditions listed in each subclause the following preconditions shall be satisfied:

a) Installation or assembly of all equipment within the subsystem is completed.

b) Equipment tests of all individual equipment within the subsystem are completed.

c) All necessary test and measurement equipment are in service.

Subsystem tests conclude with final trip tests which guarantee the reliable trip of the AC circuit-breaker.

5.2 Power, control and communication cabling systems

5.2.1 Test purpose

The purpose of this test is to verify the correctness of each power, control and communication cable installed at site within the converter station. The subsystem test of cabling systems involves the point-to-point test.

5.2.2 Test preconditions

Before this subsystem test, the following minimum preconditions should be fulfilled:

All cabling installation, termination and insulation tests are completed.

5.2.3 Test procedures

The test procedures should include the following steps:

Identify each cable in either a plant circuit schematic diagram or cable schedule, and then mark each cable on these documents after the cable is confirmed to originate and terminate at the correct position.

5.2.4 Test acceptance criteria

The test acceptance criteria should include the following:

All cables shall originate and terminate as per the plant circuit schematic diagram or cable schedule.

5.3 Main circuit equipment

5.3.1 Test purpose

The purpose of this test is to verify the measurements and the signals between the main circuit equipment and the control and protections are correct, and to verify the switchgear can act as per the design. The areas covered by these subsystem tests include the interface transformers, VSC valves, AC and DC yards. Subsystem tests for these areas are provided in Table 2.

Table 2 – Subsystem tests of main circuit equipment

Area	Subsystem tests
Interface transformers	a) Verification of alarms and trips from transformer protections. b) Polarity and loop resistance measurements for transformer CTs. c) Secondary injection testing from transformer CTs. d) Verification of control signals to and from the transformer cooling system and tap changer. e) Checking of signals and indications up to the HMI display.
AC and DC yards	a) Circuit-breakers, disconnectors and earth switches: 1) Check local and remote operation[a]. 2) Trip circuit checks. 3) Interlocking checks. b) Primary and secondary injection testing of measurement devices where required. c) Tuning of filters. d) Pressure measurement and alarms for gas filled equipment such as wall bushings and voltage dividers. e) Checking of signals and indications up to the HMI display.
VSC valves	a) Fiber optic system checks. b) Control and communication tests. c) Supplier and project specific tests.

[a] Remote operation: to operate from the HVDC control room at the station.

5.3.2 Test preconditions

Before this subsystem test, the following minimum preconditions should be fulfilled:

The subsystem test of cabling systems (5.2) is completed.

5.3.3 Test procedures

The test procedures should include the following steps:

For each subsystem of interface transformers, VSC valves, AC and DC yards, perform the corresponding test items in Table 2.

5.3.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) Switchgears shall be closed and opened by local and remote control, and verification that the interlocking functions shall be correct.

b) For each measuring point, the values in relevant control and protections shall be correct in injection tests.

c) Signals between the main circuit equipment and the control and protections shall be correct,

d) Correct alarms and events shall be received in the sequence of events recorder.

5.4 AC protections and interlocking

5.4.1 Test purpose

The purpose of this test is to test any AC protection relays at the interfaces to the AC network (connection points), any interlocking at the connection points as well as any other discrete relays used throughout the HVDC system, such as interface transformer protection. The subsystem test of these AC protections and interlocking involves the point-to-point tests and the functional tests for AC protection relays.

For interlocking, test arrangements and plans should be agreed by related parties. Hardwired interlocks shall be tested in full, whereas computerized interlock schemes are fully tested in the factory. However, all individual inputs to the control system need to be verified then the interlocks that are inside the control and protection system should not be necessary to repeat unless under specific circumstances.

5.4.2 Test preconditions

Before this subsystem test, the following minimum preconditions should be fulfilled:

a) The subsystem tests of cabling systems (5.2) and the associated measuring circuits (5.3) are completed.

b) All required communication systems between relays are in service.

5.4.3 Test procedures

The test procedures should include the following steps:

a) Perform tests of AC protection relays and their interconnection to the HVDC system in accordance with the supplier’s recommendations.

b) Test the functionality of the hardwired electrical interlocking system including all input and output signals.

5.4.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) The AC protection relays shall act as per the protection design, settings and the supplier's recommendations.

b) All switchgear or functions that are a part of the interlocking system shall be either allowed to operate or to be prevented from doing so in accordance with the interlocking design.

5.5 Remote SCADA interface

5.5.1 Test purpose

The purpose of this test is to verify the correct connection and functioning of the remote operator workstation, including the remote control and operation of the converter unit and the receipt of alarms and status indications.

In some cases, signals are transmitted via a SCADA system from the converter station to either another control room or an external party, such as a system or market operator. These systems shall be tested to ensure the integrity of the signals being transmitted to these SCADA systems, from the converter control and protection system to the final destination. If signals have been checked with the aid of a SCADA emulator in the factory tests, a reduced sample test of signals may be carried out at site.

It may not be possible to verify some SCADA functionality during subsystem tests, particularly functions that are only available while the converter is energised and in operation, such as power level and direction. Planning for complementary SCADA test during the system tests is therefore recommended if it is not possible to provide the signals by other means during subsystem tests.

5.5.2 Test preconditions

Before this subsystem test, the following minimum preconditions should be fulfilled:

a) The subsystem test of cabling systems (5.2) is completed.

b) The telecommunication between converter station and the remote location is in service.

5.5.3 Test procedures

The test procedures should include the following steps:

a) Check the measurements, status of switchgears and HVDC operation modes in the remote location.

b) Send orders from the remote location to operate the equipment in the converter station as per the design.

5.5.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) The measurements, status of switchgears and HVDC operation modes displayed in the remote location shall be correct.

b) Orders from the remote location to operate the equipment in the converter station shall be received and where possible demonstrated to be correctly enacted.

5.6 Auxiliary systems

5.6.1 Valve cooling system

5.6.1.1 Test purpose

The purpose of this test is to verify the completeness and correctness of the overall system installation with the aid of checklists, diagrams, drawings and instructions.

5.6.1.2 Test preconditions

Before this subsystem test, the following minimum preconditions should be fulfilled:

The subsystem test of cabling systems (5.2) is completed.

5.6.1.3 Test procedures

The test procedures should include the following steps:

a) Check all measurement signals, status signals and alarm signals from flow meters, conductivity meters, pressure transducers and temperature transducers back to the control and protection system.
b) Start and stop valve cooling system from the control and protection system.
c) Changeover from active to standby pumps from the control and protection system.
d) Start and stop each cooling fan from the control and protection system.
e) Operate all controlled coolant flow valves.
f) Where practical simulate AC power supply interruption.

5.6.1.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) All measurement signals, status signals and alarm signals displayed in the control and protection system shall be correct.
b) Valve cooling system shall be started and stopped from the control and protection system.
c) Active pump shall be switched to standby state from the control and protection system, and meanwhile, the standby pump shall be switched to active state automatically.
d) Each cooling fan shall be started and stopped from the control and protection system.
e) All controlled coolant flow valves shall operate as intended.
f) Correct alarms and events shall be received in the sequence of events recorder.

5.6.2 Auxiliary power

5.6.2.1 Test purpose

The purpose of this test is to verify the function and behaviour of auxiliary power system. Depending on the power sources, parts of this test may only be carried out when the converter is energised.

5.6.2.2 Test preconditions

Before this subsystem test, the following minimum preconditions should be fulfilled:

The subsystem test of cabling systems (5.2) is completed.

5.6.2.3 Test procedures

The test procedures should include the following steps:

a) Verify correct start-up procedures for applicable auxiliary power sources.
b) Switch between multiple auxiliary power sources, without, where specified, any interruption to converter operation.
c) Check the voltage at power distribution boards and sub-boards throughout the converter units and in the AC and DC yards.
d) Check the voltage of all AC and DC power supplies within the control and protection system.
e) Verification of correct operation of all battery systems and uninterruptible power supplies (UPS).

5.6.2.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) Transition from the primary auxiliary power supply to and from any standby supplies shall be successful and the switchover time shall be within design range.
b) Voltage at power distribution boards and sub-boards shall be within design range.
c) Voltage of all AC and DC power supplies within the control and protection system shall be within design range.
d) Correct operation of all battery systems and uninterruptible power supplies.
e) Correct start-up of generators and changeover between backup power sources without any interruption to converter operation.

5.6.3 Fire protection systems

5.6.3.1 Test purpose

The purpose of this test is to verify the correct operation of the individual subsystems of fire detection systems and fire suppression systems, and the interaction between them, as well as verification of alarming and control actions within the converter control and protection system.

5.6.3.2 Test preconditions

Before this subsystem test, the following minimum preconditions should be fulfilled:

The subsystem test of cabling systems (5.2) is completed.

5.6.3.3 Test procedures

The test procedures should include the following steps:

Generate controlled fire or smoke near the fire detection probes, or simulate the fire signals, and check the alarms in operator’s workstation and the actions of the fire suppression systems..

5.6.3.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) Alarm events shall be received in the sequence of events recorder.
b) The fire system shall generate the appropriate alarm and trip signals as per the design.
c) The fire suppression system shall be appropriately triggered.

5.6.4 Air handling and conditioning systems

5.6.4.1 Test purpose

The purpose of this test is to verify the correct operation of air handling and conditioning, and the interaction and interface to the HVDC control and protection system of any of the following systems:

a) Converter reactor cooling systems (if applicable).
b) Valve hall air conditioning and handling systems.
c) Air conditioners in control rooms.
d) Dehumidifiers.
e) Air filtration systems.
f) Air evacuation systems.

5.6.4.2 Test preconditions

Before this subsystem test, the following minimum preconditions should be fulfilled:

The subsystem test of cabling systems (5.2) is completed.

5.6.4.3 Test procedures

The test procedures should include the following steps:

a) Check the temperature at all air-in and air-out points and humidity in the control panel or workstation of air handling and conditioning systems.
b) Trigger or simulate alarm signals and check in the control panel or workstation of air handling and conditioning systems.
c) Set settings of temperature or humidity from control panel or workstation of air handling and conditioning systems, if not already done.

5.6.4.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) The displayed temperature and humidity in the control panel or workstation of air handling and conditioning systems shall be correct.
b) The alarm signals shall be displayed in the control panel or workstation of air handling and conditioning systems.
c) The air handling and conditioning systems shall operate at the settings of temperature or humidity.

5.6.5 HVDC transmission line monitoring systems

5.6.5.1 Test purpose

Some VSC HVDC systems may have fault location systems or cable temperature measurement systems installed. In some cases, these systems trigger operations within the converter station’s control and protection systems, including run backs, blocking or tripping of the HVDC system. Note that the accuracy of fault location can in most cases only be demonstrated during operation of the HVDC scheme. The purpose of this test is to verify the interfaces and functionality as far as practical.

5.6.5.2 Test preconditions

Before this subsystem test, the following minimum preconditions should be fulfilled:

The subsystem test of cabling systems (5.2) is completed.

5.6.5.3 Test procedures

The test procedures should include the following steps:

a) Check the measurement signals as per the supplier's recommendations.
b) Check the signals sent to the HVDC control and protection system.

5.6.5.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) Measurement signals shall be correct.
b) Signals sent to the HVDC control and protection system shall be received.
c) Alarm events shall be received in the sequence of events recorder.

5.6.6 Earth electrode and earth electrode line monitoring system

5.6.6.1 Test purpose

An earth electrode and earth electrode line monitoring system may be installed for an asymmetrical monopolar HVDC system or a bipolar HVDC system which is capable of operating in monopolar mode. The purpose of this test is to verify the correct measurement and operation.

The subsystem test should be completed in accordance with the supplier's recommendations.

5.6.6.2 Test preconditions

Before this subsystem test, the following minimum preconditions should be fulfilled:

The subsystem test of cabling systems (5.2) is completed.

5.6.6.3 Test procedures

The test procedures should include the following steps:

a) Check the measurement signals as per the supplier's recommendations.
b) Check the signals sent to the HVDC control and protection system.

5.6.6.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) Measurement signals shall be correct.
b) Signals sent to the HVDC control and protection system shall be received.
c) Alarm events shall be received in the sequence of events recorder.

5.7 Final trip tests

5.7.1 Test purpose

The purpose of this test is to verify the AC circuit-breakers can be tripped successfully by operators or HVDC control and protections before energisation. Final trip tests shall be carried out after all other subsystem tests are completed.

5.7.2 Test preconditions

Before this subsystem test, the following minimum preconditions should be fulfilled:

a) All other subsystem tests (5.2, 5.3, 5.4, 5.5 and 5.6) are completed.

5.7.3 Test procedures

The test procedures should include the following steps:

a) Push the emergency stop button in the control room to trip the AC circuit-breaker.
b) Trigger a trip order from the HVDC control and protection system.
c) Trigger a trip from an AC protection relay if applicable.

5.7.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) The AC circuit-breaker shall be tripped successfully
b) Events shall be received in the sequence of events recorder.

6 High voltage energisation

6.1 General

Energisation of the AC and DC equipment prior to deblocking of the converters includes:

a) AC switchyard energisation.
b) AC filter energisation.
c) Interface transformer energisation.
d) Converter energisation in the blocked state.
e) Converter energisation from DC side.

In reality, the total number of stages during initial energisation will depend on the location of high voltage disconnectors and circuit-breakers within the HVDC converter circuit. For example, if there is no disconnector or circuit-breaker between the AC switchyard and the interface transformer, both areas will normally be energised at the same time. In these instances, the respective test purpose, preconditions, procedures and acceptance criteria should be combined.

The presence of any pre-insertion resistors should be taken into account in the development of test procedures to ensure that their correct operation is verified. This would include the monitoring and verification of the correct switching and controls to manage the resistor’s temperature constraints, as well as noting any limitations this system may have on re-energisation throughout the test.

Besides the special test preconditions under each sub-clause, all preconditions as outlined in 4.3.2 should be fulfilled.

6.2 AC switchyard energisation

6.2.1 Test purpose

The purpose of this test is to verify that the AC switchyard up to the interface transformer disconnector can withstand the AC supply voltage and that all voltage measurements are correct. If the AC switchyard is isolated in sections, the test should be carried out in stages to individually check each section of the yard.

6.2.2 Test preconditions

Before energising the AC switchyard, the following minimum preconditions should be fulfilled:

a) Final visual inspection of the high voltage equipment is completed.

b) Any AC switchyard disconnectors or AC circuit-breakers required to segregate the section under test from other sections of the AC switchyard, filters or the interface transformers, are open.

6.2.3 Test procedures

The test procedures should include the following steps:

a) Energise each section of the yard in turn by closing the relevant AC circuit-breaker.

b) Keep each section energised until all measurements and inspections of the energised section are completed before proceeding to the next section.

c) On completion of the test, arrange safe access to the high voltage equipment and inspect all AC equipment within the AC switchyard.

6.2.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) No atypical noise shall be emitted by high voltage components. Partial discharge and corona noise shall be within the expected limits.

b) No protection operation.

c) Parameters such as the AC voltage on any switchyard voltage transformer shall be in the designed range.

d) No damage, anomaly or evidence of arcing shall be observed after inspection of the AC switchyard equipment.

6.3 AC filter energisation (if applicable)

6.3.1 Test purpose

The purpose of this test is to verify that the AC filter can withstand the AC supply voltage and that all voltage and current measurements are correct, no inappropriate protection action and the behaviour of any point on wave switching. This test is only required where AC filters are included as a part of the design of the HVDC scheme.

6.3.2 Test preconditions

Before energising any available AC filters, the following minimum preconditions should be fulfilled:

a) Final visual inspections of the high voltage equipment are completed.

b) All disconnectors are in correct position.

c) If the adjacent AC network is weak, it may be necessary to reduce the voltage prior to AC filter energisation.

6.3.3 Test procedures

The test procedures should include the following steps:

a) Energise the AC filter.

b) Measure the bus voltage and verify voltage level.

c) Measure the branch current and verify current level.

d) Keep the AC filter energised for an agreed period of time.

e) Measure and verify the protective values related to the AC filter, such as unbalance protections.

f) On completion of the test, arrange safe access to the high voltage equipment for visual inspection.

It is important to be aware that in most cases it may not be permitted to have an AC filter for a higher harmonic connected and one for a lower harmonic disconnected due to resonance. Therefore, if the HVDC scheme has more than one AC filter, it is advisable to begin with the lowest harmonic, and keep the lower harmonic AC filter connected when performing the energisation sequence of the higher harmonic. In general, it is recommended to operate two filters in parallel for a certain duration if more than one filter is available.

6.3.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) No atypical noise shall be emitted by high voltage components. Partial discharge and corona noise shall be within the expected limits.

b) No triggering of unbalance protection or other protective settings.

c) Parameters such as voltage transformer as well as current transformer/transducer signals to the converter control system shall be in the designed range before and after energisation.

d) Inrush current shall be within designed limits.

e) No damage, anomaly or evidence of arcing shall be observed after inspection of the AC filter equipment.

6.4 Interface transformer energisation

6.4.1 Test purpose

The purpose of this test is to verify that the interface transformer can withstand the AC supply voltage at no load and that all voltage and current measurements are correct.

6.4.2 Test preconditions

Before energising the interface transformer, the following minimum preconditions should be fulfilled:

a) The AC switchyard energisation test (6.2) is completed to the extent necessary for controlled energization.

b) Final visual inspection of the transformer and associated high voltage equipment is completed.

6.4.3 Test procedures

The test procedures should include the following steps:

a) Ensure that the interface transformer tap changer is set to provide the lowest converter side voltage.

b) Energise the interface transformer from the AC circuit-breaker. Multiple energisations are necessary to verify the protection settings, inrush current and inrush current limiting devices. The temperature rise of pre-insertion resistor (PIR) should be taken into consideration.

c) Monitor the interface transformer for abnormal sounds and discharge.

d) Record AC voltage and currents by transient fault recorder.

e) On completion of the test, arrange safe access to the high voltage equipment and inspect all AC equipment and the interface transformers.

6.4.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) No atypical noise shall be emitted by high voltage components. Partial discharge and corona noise shall be within the expected limits.
b) No protection operation.
c) Parameters such as voltage transformer as well as current transformer signals to the converter control system shall be of the expected magnitudes and correct polarity.
d) Inrush current shall be within designed limits.
e) No damage, anomaly or evidence of arcing shall be observed after inspection of the transformer.

6.5 Blocked converter energisation

6.5.1 Test purpose

The purpose of this test is to verify that at the first energisation, the converter can withstand the AC supply voltage and that all voltage and current measurements are correct.

6.5.2 Test preconditions

Before energising the blocked converter, the following minimum preconditions should be fulfilled:

a) The AC switchyard energisation (6.2) and interface transformer energisation tests (6.4) if appropriate are completed.
b) The required DC side disconnect switches are open.
c) Final visual inspection of the high voltage equipment is completed.

6.5.3 Test procedures

The test procedures should include the following steps:

a) Ensure that the interface transformer tap changer is set to provide the lowest converter side voltage.
b) Energise converter for a time coordinated with the converter design.
c) Record AC voltages and currents and inspect the equipment for abnormal sounds and discharge.
d) Verify the correct DC side voltage is measured.
e) On completion of the test, arrange safe access to the high voltage equipment and inspect all equipment inside the buildings and valve halls, interface transformers, reactors and wall bushings.

6.5.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) No atypical noise shall be emitted by high voltage components. Partial discharge and corona noise shall be within the expected limits.
b) No protection operation.
c) Voltage and current measurements to the HVDC control and protection system shall be of the expected magnitudes and correct polarity.
d) Correct operation of energisation sequence.
e) Correct reporting back from the VSC valves to the HVDC control and protection system.
   1) Voltages within the valves shall be in the designed range and balanced.
   2) The VSC valves shall be healthy and in the blocked state.

f) No damage, anomaly or evidence of arcing shall be observed after inspection of all equipment inside the buildings and valve halls, interface transformers, reactors and wall bushings.

6.6 Energisation from DC side (if applicable)

6.6.1 Test purpose

The purpose of this test is to verify that the converter unit and AC switchyard up to the main AC circuit-breaker can withstand the AC supply voltage when energised from the DC side and that all voltage and current measurements are correct. This test is required in scenarios where high voltage AC supply is available at only one end, such as offshore platforms or wind farms.

6.6.2 Test preconditions

Before energising the converter unit from the DC side, the following minimum preconditions should be fulfilled:

a) The other converter unit connected to the AC grids (AC supply converter unit) completes the AC switchyard, interface transformer and blocked converter energisation tests.

b) The two converter units are connected to each other via the HVDC transmission line. The DC side disconnect switches are closed in both stations.

c) The HVDC transmission line is completed and commissioned according to 8.2.

6.6.3 Test procedures

The test should be carried out in stages to individually check each area of the converter unit progressively.

For converter units that can only be energised from the DC side, the following test procedures or sequence should be followed:

a) Energise the auxiliary power system of the remote converter unit via the medium voltage network or the diesel generator in the case of offshore applications. The appropriate actions should be taken to ensure that the process of energising the converter unit will not result in a changeover of auxiliary power supply.

b) Energise and deblock the AC supply end converter unit and energise the HVDC transmission line and the remote DC yard and converter unit.

c) On completion of the test, arrange safe access to the high voltage equipment and inspect all equipment inside the buildings and valve halls, interface transformers, reactors and wall bushings.

6.6.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) No atypical noise shall be emitted by high voltage components. Partial discharge and corona noise shall be within the expected limits.

b) Correct operation of energisation sequence. The remote converter unit and the interface transformer shall be energised in accordance with the design.

c) No protection operation.

d) Voltage and current measurements to the HVDC control and protection system shall be of the expected magnitudes and correct polarity.

e) Correct reporting back from the VSC valves to the HVDC control and protection system, and Voltages within the valves shall be in the designed range and balanced.

f) No damage, anomaly or evidence of arcing shall be observed after inspection of all equipment inside the buildings and valve halls, interface transformers, reactors and wall bushings.

7 Converter station tests

7.1 General

The converter station tests are comprised of a set of verifications of deblocking and blocking sequences, the protective actions and reactive power control in Uac control and Qac control when the converter unit is connected to the adjacent AC network.

Each test described in this clause is defined as a stand-alone test, however they may be combined as appropriate depending on AC network limitations and project time schedules. The combining of tests is preferable in cases where there is limited time available for test or to reduce the necessity of shutdown in between individual tests.

Converter station tests also allow high reactive power levels to be tested and for the converter to be proved at these high levels. This is particularly useful if it is known beforehand that high active or reactive power levels will not be possible during the transmission tests (e.g., due to constraints on the AC network). In this instance, additional high reactive power tests could be added during the converter station tests to verify the thermal capabilities of the high voltage equipment.

Where high reactive power tests are required, and an adjacent pole is available (for example, for a bipole system or where more than one symmetric monopole is installed in parallel), the adjacent pole reactive power level can be used to compensate for the reactive power dispatch of the converter pole under test, resulting in a zero or very low net reactive power level seen by the AC network, and arrangements should be made with the AC network operator on how to manage the case where either pole trips during the test.

The tests to verify the behaviour of the HVDC system to a change in configuration of the HVDC control and protection systems and auxiliary systems apply to both converter station tests and transmission tests. The tests listed in 8.12, 8.13.1 and 8.14 can also be performed during converter station tests with minor modifications to the preconditions and procedures.

Besides the special test preconditions under each sub-clause, all preconditions as outlined in 4.3.2 should be fulfilled, and the high voltage energisation tests (Clause 6) should also be completed.

7.2 First deblock

7.2.1 Test purpose

First deblock test is also referred to as open converter test or open circuit test, which involves deblocking of the converter valves to actively control the converter busbar voltages.

The purpose of this test is to verify the correct deblocking and blocking sequences, measurements and to verify stable operation of the HVDC system.

7.2.2 Test preconditions

Before the first deblock of the converter, the following minimum preconditions should be fulfilled:

Permissions and approvals are obtained to commence the test.

7.2.3 Test procedures

The test procedures should include the following steps:

a) Configure the converter station for STATCOM mode.
b) Energise the converter unit.

c) Set the setpoint to 0 Mvar in Qac control or the actual busbar voltage in Uac control.

d) Deblock the converter unit, verify correct deblocking sequence and allow the converter to operate in steady state operation for an agreed period of time.

e) Verify AC and DC measurements are in the design range and that no oscillatory or unstable behaviour occur during steady state idle operation.

f) Block and de-energise the converter unit and verify correct blocking sequence.

g) On completion of the test, arrange safe access to the high voltage equipment and inspect all equipment inside the buildings and valve halls, interface transformers, reactors and wall bushings.

7.2.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) The deblocking and blocking sequences shall occur as per the design.

b) The deblocking and subsequent blocking shall not disturb the connected AC network.

c) No protection operation.

d) Voltage and current measurements to the HVDC control and protection system shall be in the design range.

e) Correct reporting back from the VSC valves to the HVDC control and protection system.

f) No damage, anomaly or evidence of arcing shall be observed after inspection of all equipment inside the buildings and valve halls, interface transformers, reactors and wall bushings.

7.3 Protective actions

7.3.1 Test purpose

The purpose of this test is to verify correct protective actions from a sample of protective functions. These tests are selected in cooperation between the user and the supplier. Those tests should include basic protection actions such as the operation of the emergency stop button and converter protections.

The protective actions should be performed in selected control and protection systems to verify that blocking or protective tripping sequences take place as per the design when clearing a fault or equipment malfunction.

Depending on the type of fault, the protective blocking and tripping sequence shall result in some combination of the following actions:

a) Transferring to redundant control systems (if applicable).

b) Temporary blocking of the converter valves.

c) Permanent blocking of the converter valves.

d) Tripping of the AC circuit-breakers.

e) Operation of DC switches as per the design.

7.3.2 Test preconditions

Before the protective actions test, the following minimum preconditions should be fulfilled:

a) The correct operation of and coordination between the protective systems and the control systems are demonstrated during the factory tests.

b) All monitoring and alarm systems are in service.

c) The first deblock (7.2) test is completed.

7.3.3 Test procedures

The test procedures should include the following steps:

a) Configure the converter station for STATCOM mode.
b) Energise and deblock the converter unit.
c) Set the setpoint to 0 Mvar in Qac control or the actual busbar voltage in Uac control.
d) Push the emergency stop button or simulate the required fault. A single fault in the control and protection systems corresponding to each type of blocking and tripping sequence should be simulated.

7.3.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) For each simulated fault, the expected protective function shall operate as per the design and the corresponding protection actions shall occur.
b) Correct alarms and events shall be received in the sequence of events recorder and the measurements obtained from the transient fault recorder shall be in the design range.
c) The impact of the HVDC system on the connected AC network shall be within specified performance criteria.

7.4 Reactive power control

7.4.1 Test purpose

The reactive power control (RPC) tests serve to verify exchanging reactive power control ability in Qac control and AC voltage regulation ability in Uac control within the predefined PQ characteristic of the HVDC system. This test could also include the verification of the reactive power capability if there are limitations to perform it as part of high power transmission tests.

The purpose of this test is to verify the correct operation including stable operation at the required reactive power and AC voltage levels and stable ramping whenever a new setpoint is entered. The focus during RPC tests is on the following aspects:

a) Reactive power control operates within the PQ characteristic and ramping limits of the HVDC system.
b) Reactive power limitation controls within the defined PQ characteristics of the HVDC system.
c) Stable voltage control within the defined PQ characteristic of the HVDC system.
d) Limitation/disabling of Qac control and Uac control if required according to the design.

7.4.2 Test preconditions

Before reactive power control test, the following minimum preconditions should be fulfilled:

The first deblock (7.2) and protective actions (7.3) tests are completed.

7.4.3 Test procedures

The test procedures should include the following steps:

a) Configure the converter station for STATCOM mode.
b) Energise the converter unit and deblock with 0 Qac setpoint in Qac control.
c) Enter a new Qac setpoint for each level in the reactive power schedule and observe stable ramping of reactive power to the new setpoint and stable operation for several minutes.
d) Where possible, perform the tests at maximum reactive power levels (both generation and absorption) as allowed by the PQ characteristic, to verify stable operation at maximum reactive power levels.

e) Repeat steps b) to c) for other RPC control modes, such as Uac control (if applicable).

f) Set maximum and minimum Uac control reference points allowed by the AC network and in each case, observe stable ramping of reactive power and that the new AC voltage level is achieved or limited by the PQ characteristic. Where possible, set these levels such that the maximum reactive power levels of the converter, according to the PQ characteristic, are achieved (both generation and absorption) (if applicable).

7.4.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) The reactive power and AC voltage ramps at the required ramp rate, and the ramping shall be linear, stable and executed as ordered.

b) All voltage and current measurements shall be correct.

c) Start and stop controls of reactive power and AC voltage ramping shall be functional as specified.

d) Reactive power output shall remain within the PQ characteristic of the HVDC system.

e) Reactive power ramping shall be limited when the capability of the HVDC system is exceeded or reduced, without any transients or adverse effects.

f) The converter shall demonstrate stable operation at maximum reactive power levels (both generation and absorption).

g) The valve cooling system successfully maintains the valve temperature within the specified limits.

7.5 Change of RPC control modes

7.5.1 Test purpose

The purpose of this test is to verify smooth and stable transition between the different RPC control modes, predominantly Qac control and Uac control during the converter operation of STATCOM and to verify proper co-ordination of the basic HVDC control and protection functions.

7.5.2 Test preconditions

Before the change of RPC control modes test, the following minimum preconditions should be fulfilled:

a) The first deblock (7.2) and protective actions (7.3) tests are completed.

b) Stable operation of the converter in Qac control and Uac control is demonstrated in 7.4.

7.5.3 Test procedures

The test procedures should include the following steps:

a) Configure the converter station for STATCOM mode.

b) Energise the converter unit and deblock in Qac control.

c) Order a change in control mode from Qac control to Uac control and verify that the transition is smooth without overshoots in the control parameters and with an appropriate speed of response.

d) Repeat the transition of control modes back to Qac control, and verify that the transition is smooth, without overshoots in the control parameters and with an appropriate speed of response.

7.5.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) The control mode transitions shall be made smoothly and correctly.

b) The functions of the control modes shall be as per the design requirements.

c) The impact of the HVDC system on the connected AC network shall be within the specified performance criteria.

7.6 Step responses

7.6.1 Test purpose

The purpose of this test is to verify the controller response to disturbances. The results of these tests can also serve as a benchmark for future reference of the response of the HVDC system following disturbances during operation.

These tests can be done at low or high reactive power levels. To do these tests at the lower reactive power flows will minimise the risk of any adverse impacts on the AC network. These tests can however also be performed or repeated at high reactive power levels if required, provided the parties understand and accept the risks.

These tests can also be repeated later during the transmission tests (see 8.8).

7.6.2 Test preconditions

Before the step response tests, the following minimum preconditions should be fulfilled:

a) All low reactive power tests, except the step response test, are completed.

b) The converter station is configured to operate in STATCOM mode.

c) All relevant parties are advised of the step response/disturbance and the expected outcomes/converter response.

The following information should be agreed between owner and supplier (and any other affected third parties if applicable) as a part of setting the parameters of the step response tests:

a) The duration of the applied steps.

b) The magnitude of the step changes.

c) The level of reactive power generated or absorbed before the step changes.

7.6.3 Test procedures

The test procedures should include the following steps:

a) Energise and deblock the converter as per normal sequences and procedures.

b) Ensure the agreed control modes are initiated, ramp reactive power to the desired levels and verify stable operation.

c) Verify that the transient fault recorder is set to trigger when the disturbance occurs.

d) Through the control system, simulate the following step changes individually within the parameters agreed between owner and supplier, and observe stable post-disturbance operation of the converter after the disturbance:

   1) Reactive power order step change.

   2) AC voltage order step change.

e) Review the transient fault recorder and sequence of events recorder measurements and results and compare these to those obtained in the DPS or factory system tests if they have similar scenarios.

7.6.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) The measured response to the reactive and AC voltage order step change shall be demonstrated to be within the technical requirements for the HVDC system.

b) The measured response to the reactive and AC voltage order step change shall be in the designed range. The strength of the AC network should be considered.

c) No instability shall occur during the step response tests and stable operation shall be observed before and after the step response is triggered if the network conditions are within the design range as given in the specification.

8 Transmission tests

8.1 General

The transmission tests are performed with the converter units interconnected via a HVDC transmission line or, in the case of back-to-back HVDC projects, the interconnecting DC bus. These tests are also called end-to-end tests and are where the transmission of active power over the HVDC system is verified.

Each test described in this clause is described and defined as a single test, however they may be combined as appropriate depending on AC network limitations and project time schedules. The combining of tests is preferable in cases where there is limited time available for test or to reduce the necessity of shutdown in between individual tests.

After the initial HVDC transmission line energisation and completion of the converter station tests (Clause 7), the transmission of active power can commence. The purpose of the transmission tests is to verify operation of the HVDC system in terms of active and reactive power transmission as per specification and design.

Many of the transmission tests outlined in this clause can be performed entirely at low active power. The philosophy of verifying the transmission functionalities of the HVDC system at low power have benefits for both the owner and the supplier. Low power is normally no more than 0.2 pu of the rated power. The owner can verify a significant amount of the HVDC system, at lower cost of test energy and with a lower risk of causing disturbance on the AC network if the test is not executed as planned. The requirement of low active power for transmission test also allows for shorter time schedules and completion of the project, especially in projects where the supply of active power is limited, i.e. offshore or wind power applications.

Although protective actions test in STATCOM mode in 7.3 has verified most types of converter protections, it is better to verify the behaviour of HVDC system and the coordination between the sending and receiving converter stations in transmission mode. Especially for the sending and receiving converter units which cannot be isolated with each other to perform this test in converter station test such as back-to-back HVDC, protective actions test in this clause is indispensable.

Subclauses 8.12, 8.13 and 8.14 are tests to verify the behaviour of the HVDC system to a change in configuration of the HVDC control and protection systems and auxiliary systems. These tests can also be performed during converter station tests or during both. These tests should be performed first at low power level to reduce the adverse effect from any unexpected trip or power change.

Although the power quality and interference tests (Clause 9) can be performed independently, it can be convenient and economic to perform these tests during transmission tests.

Besides the special test preconditions under each subclause, all preconditions as outlined in 4.3.2 should be fulfilled, and the electrode (if applicable) tests should also be finished.

8.2 Energisation of HVDC transmission line

8.2.1 Test purpose

The purpose of this test is to verify that the condition of the HVDC transmission line is able to withstand the operating voltage. There is no power transmitted during this test, but the HVDC transmission line is connected and energised at its nominal voltage.

The energisation of the HVDC transmission line is not a transmission test in itself, but is the final stage of setting up the HVDC system for transmission tests. This test does not apply to back-to-back HVDC systems. For a bipole configuration, the HVDC transmission line tests would be performed on each pole.

8.2.2 Test preconditions

Before the energisation of HVDC transmission line test, the following minimum preconditions should be fulfilled:

The DC disconnectors that connect each converter unit to the HVDC transmission line are:

a) Closed at the converter unit to be energised and deblocked to energise the HVDC transmission line.
b) Open or the circuit is open at the HVDC transmission line end at the remote converter station.

8.2.3 Test procedures

The test procedures should include the following steps:

a) If adjustable set the DC voltage reference within the control and protection system of the converter station to the minimum value.
b) Energise and deblock the converter unit connected to the HVDC transmission line as per normal sequences and procedures, and verify stable connection and satisfactory AC and DC voltages.
c) Increase the DC voltage reference within the control and protection system in increments and monitor operation in between each adjustment, until the nominal DC voltage is reached.
d) Record and observe stable DC voltage at the nominal level and monitor operation for a period of time.
e) Repeat steps a) to d) to energise the HVDC transmission line from the other converter unit if necessary.
f) On completion of the test, arrange safe access to the high voltage equipment and inspect the DC yard.

8.2.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) The expected DC voltages measured at the converter unit and the DC voltage shall be stable.
b) No abnormal measurements and no protection operations shall occur.
c) No damage shall be observed after inspection of newly energized equipment.

8.3 First power transmission

8.3.1 Test purpose

The purpose of this test is to verify the correct deblocking and blocking sequences and to verify stable operation of the HVDC system for all agreed configurations as per the design. This test is performed at a low active power level.

8.3.2 Test preconditions

Before the first power transmission test, the following minimum preconditions should be fulfilled:

The HVDC transmission line energisation test (8.2) is completed.

8.3.3 Test procedures

The test procedures should include the following steps:

a) Energise and deblock converter units as per normal sequences and procedures, and verify stable connection and satisfactory AC and DC voltages. Either Qac control or Uac control can be selected depending on the needs of the project and requirements of the AC network.
b) At the converter station in active power control mode, set the active power setpoint to the agreed first active power level and the ramp rate to the agreed active power ramp rate (if selectable).
c) Monitor and observe that the HVDC system ramps active power at the required ramp rate and that the system is stable during ramping and on completion of the active power ramp.
d) Verify correct system measurement readings during steady state operation.
e) Ramp active power to zero and block converter units.
f) Reconfigure the HVDC main circuits for each agreed configuration as per the design and repeat steps a) to e).

8.3.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) No abnormal measurements and no protection operations shall occur.
b) The operation shall be linear, stable during active power ramping and on completion of the ramp and the power flow levels achieved shall be aligned with the entered setpoint values.
c) For each converter and pole, the control actions associated with each active power level change as well as start and stop sequences shall be executed correctly.
d) The valve cooling system shall successfully maintain the valve temperature within the specified limits.

8.4 Protective actions

8.4.1 Test purpose

Similar to that in converter station tests in 7.3.1, the purpose of this test is to verify correct protective actions, especially the coordination between the sending and receiving converter station, from a sample of protective functions. These are selected in cooperation between the owner and the supplier but should include actions such as the operation of the emergency stop button, converter protections and HVDC transmission line protections. The protective functions chosen may vary depending on the protection philosophy in the HVDC system design.

Once a protection function is triggered, besides the actions in the local converter station in 7.3.1, actions in the remote converter unit will also be triggered as per the design.

8.4.2 Test preconditions

Before the protective actions test, the following minimum preconditions should be fulfilled:

a) The correct operation of and coordination between the protective systems and the control systems are demonstrated during the factory tests.
b) All monitoring and alarm systems are in service.
c) The first power transmission test (8.3) is completed.

8.4.3 Test procedures

The test procedures should include the following steps:

a) Deblock converter units in both stations and ramp up to a low power point as per normal sequences and procedures.
b) Push the emergency stop button or simulate the required fault. A single fault in the control and protection systems corresponding to each type of blocking and tripping sequence should be simulated.

8.4.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) The expected protective function shall operate as per the design and the corresponding protection actions shall occur.
b) Correct alarms and events shall be received in the sequence of events recorder and the measurements obtained from the transient fault recorder shall be in the design range.
c) The impact of the HVDC system on the connected AC network shall be within specified performance criteria.

8.5 Active power control

8.5.1 Test purpose

The purpose of this test is to confirm that the active power control, and its relationship with the reactive power capability, reacts in the design range in accordance with issued operating instruction. Operator interface functions are tested, including the entering of active power and ramp rate setpoints and the ability to stop/start active power ramping.

This test is usually done at a low active power level. The levels of power to ramp up to should be determined by what is possible and considering the impact of a trip to the connected AC network.

8.5.2 Test preconditions

Before the active power control test, the following minimum preconditions should be fulfilled:

The first power transmission (8.3) and protective actions tests (8.4) are completed.

8.5.3 Test procedures

The test procedures should include the following steps:

a) Energise and deblock HVDC converter units as per normal sequences and procedures. Either Qac control or Uac control can be selected depending on the needs of the project and requirements of the AC network.
b) At the converter station in active power control mode, set the active power setpoint to the agreed active power level and the ramp rate to the agreed active power ramp rate (if selectable). Commence ramping active power to the desired levels.
c) Operate the ramp start/stop function on the HMI while the system is ramping and verify correct and stable operation of the start and stop sequences.
d) Repeat steps a) to c) for each agreed HVDC configuration as per the design.
e) Transfer the DC power control mode subsequently from DC voltage control to pole power control, then to bipole power control and vice versa, if applicable.
f) Test the automatic power control function if applicable.

8.5.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) No abnormal measurements and no protection operations shall occur.
b) The operation shall be linear, stable during active power ramping and on completion of the ramp and the power flow levels shall be aligned with the entered setpoint values.
c) For each converter and pole, the control actions associated with each active power level change as well as start and stop sequences shall be executed correctly.
d) Transfer between power control modes shall have no significant disturbance to DC power.
e) DC power shall be as per the automatic power curve once the automatic power control function is activated.
f) When the PQ characteristic limits of the HVDC system are reached, active or reactive power shall be restricted as per the design without any transients or adverse effects.

8.6 Reactive power control

8.6.1 Test purpose

The purpose of this test is to verify reactive power transfer in both Qac control and Uac control remain within the predefined PQ characteristic of the HVDC system while there is active power flow across the HVDC system and during the ramping of active power. When ramping in reactive power control, the AC system strength has great impact, especially in Uac control.

8.6.2 Test preconditions

Before the reactive power control test, the following minimum preconditions should be fulfilled:

The active power control test (8.5) is completed.

8.6.3 Test procedures

The test procedures should include the following steps:

a) Energise and deblock both HVDC converter units as per normal sequences and procedures.
b) Ramp active power to the desired levels.
c) Execute the following functions at various active power levels, both when active power is stable and while it is ramping, for either or both converters:
   1) Set and execute new reactive power setpoint levels, both with and without intermediate ramp stop and release.
   2) Execute control mode changeovers between Qac control and Uac control.
   3) Set and execute new AC voltage setpoint levels, both with and without intermediate ramp stop and release.
d) Observe reactive and active power levels of both converters when in both Qac control and Uac control and compare to the PQ characteristic of the HVDC system.

8.6.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) No abnormal measurements and no protection operations shall occur.
b) Reactive power and AC voltage ramping shall be stable and the power flow levels and AC voltage level shall be aligned with the entered setpoint values, depending on the strength of the AC network.
c) Start and stop controls of reactive power and AC voltage ramping shall be functional as specified while active power is flowing and ramping across the HVDC system.

d) When the PQ characteristic limits of the HVDC system are reached, active or reactive power shall be restricted or reduced as per the design without any transients or adverse effects.

e) Changeovers between RPC control modes shall be bumpless to the AC grid.

8.7 Power reversal

8.7.1 Test purpose

The purpose of this test is to verify the power reversal function if designed.

8.7.2 Test preconditions

Before the power reversal test, the following minimum preconditions should be fulfilled:

The active power control test (8.5) is completed.

8.7.3 Test procedures

The test procedures should include the following steps:

a) Set the power direction to reverse power direction.

b) Energise and deblock both converter units as per normal sequences and procedures. Either Qac control or Uac control can be selected depending on the needs of the project and requirements of the AC network.

c) At the converter station in active power control mode, set the active power setpoint to the agreed active power level and the ramp rate to the agreed active power ramp rate (if selectable), and observe stable ramping of active power to the setpoint.

d) Ramp down power to zero and then block both converter units.

e) Set normal power direction and repeat steps b) to c).

f) Set a new opposite setpoint to the active power and observe ramping of active power through the zero crossing.

g) Again set a new opposite setpoint to the active power and observe ramping of active power through the zero crossing.

h) Verify correct system measurement readings during steady state operation.

8.7.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) No abnormal measurements and no protection operations shall occur.

b) The operation shall be linear, stable during active power ramping and on completion of the ramp and the power flow levels achieved shall be aligned with the entered setpoint values.

8.8 Step responses

8.8.1 Test purpose

The purpose of this test is to verify the controller response to disturbances. The results of these tests can also serve as a benchmark for future reference of the response of the HVDC system following disturbances during operation.

The main focus during the step response tests will be on the control response and dynamic behaviour in active and reactive power control modes.

The reactive power step responses can be done during STATCOM operation as described in 7.6. However, these tests can also be repeated here during the transmission tests and typically at the same time that the active power step responses are performed.

8.8.2 Test preconditions

Before the step response tests, the following minimum preconditions should be fulfilled:

a) All converter station tests and transmission tests to verify active and reactive power control are completed.

b) All relevant parties are advised of the step response/disturbance and the expected outcomes/converter response.

The following information should be agreed between owner and supplier (and any other affected third parties if applicable) as a part of setting the parameters of the step response tests:

a) The duration of the applied steps.

b) The magnitude of the step changes.

c) The level of power transmitted before the step changes.

8.8.3 Test procedures

The test procedures should include the following steps:

a) Energise and deblock both HVDC converter units as per normal sequences and procedures.

b) Ensure the agreed control modes are initiated, ramp active or reactive power to the desired levels and verify stable operation.

c) Verify that the transient fault recorder is set to trigger when the disturbance occurs or arrangements are made for manual triggering.

d) Through the control system, simulate the following step changes individually within the parameters agreed between owner and supplier, and observe stable post-disturbance operation of the converter after the disturbance:

   1) Active power order step change.

   2) Reactive power order step change.

e) Review the transient fault recorder and sequence of events recorder measurements and results and compare these to those obtained in the DPS or factory system tests if they have similar scenarios.

8.8.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) The measured response to the active and reactive power order step changes shall be demonstrated to be within the technical requirements for the HVDC system.

b) The measured response to the active power, reactive power and AC voltage order step change shall be in the designed range. The strength of the AC network should be considered.

c) No instability shall occur during the step response tests and stable operation shall be observed before and after the step response is triggered if the network conditions are within the design range as given in the specification.

8.9 High power transmission

8.9.1 Test purpose

The high power transmission tests serve to verify thermal capability of the installation and equipment, control stability and accuracy at the specified maximum active and reactive power transfer capability of the HVDC system as defined by the PQ characteristic.

The purpose of this test is to confirm the compliance of the HVDC system with the agreed PQ characteristic and other technical requirements and to verify, as much as the AC network will allow, that the equipment within the HVDC converter stations and the control and protection system allows operation of the HVDC system on the predefined PQ characteristic.

8.9.2 Test preconditions

Before the high power transmission test, the following minimum preconditions should be fulfilled:

All low power transmission tests are completed.

8.9.3 Test procedures

The test procedures should include the following steps:

a) Energise and deblock both HVDC converter units as per normal sequences and procedures.

b) Ramp active power, in steps as agreed between the owner and supplier, above the low power transmission test threshold and up to 1 pu (or continuous overload if applicable) of power transfer capability. At each step, hold for a period of time and observe electrical measurements and verify stable operation.

c) Perform the previous step for the other power direction (if applicable for a bidirectional HVDC system).

d) Ramp reactive power levels to achieve the active power and reactive power levels, at the limits of the PQ characteristic, or as close as the AC network can allow. Verify stable operation at these operating points.

e) On completion of the test, arrange safe access to the high voltage equipment and inspect all equipment inside the buildings and valve halls, interface transformers, reactors and wall bushings.

8.9.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) No abnormal measurements and no protection operations shall occur.

b) Stable operation of the converters and HVDC system at high active and reactive power levels in accordance with the technical specifications.

c) The HVDC system shall be able to achieve the desired active and reactive power combinations at the limits of the PQ characteristic, and shall demonstrate stable operation at these levels.

d) Reactive power and active power levels shall remain within the PQ characteristic of the HVDC system.

e) Reactive power or active power levels shall be limited when the PQ characteristic of the HVDC system is exceeded or reduced, without any transients or adverse effects.

f) Satisfactory operation of the valve cooling system, to keep valve temperatures and valve coolant temperatures within the specified requirements.

g) All equipment inside the buildings and valve halls, interface transformers, reactors and wall bushings shall be inspected and no visible damage shall be observed.

8.10 Changes of DC configuration in bipole scheme

8.10.1 Test purpose

There may be several options of changing the DC configuration for a HVDC scheme. This subclause provides a test procedure specifically for a bipole HVDC consisting of two asymmetric monopoles with two types of configurations assuming either an electrode, dedicated metallic return and/or metallic return options. One is a manual transfer of DC configurations, and the other is an automatic transfer of DC configurations in case of fault.

The purpose of this test is to verify the two types of changes of DC configuration for bipole scheme.

8.10.2 Test preconditions

Before the changes of DC configuration test, the following minimum preconditions should be fulfilled:

The active power control (8.5) and high power transmission (8.9) tests are completed.

8.10.3 Test procedures

If applicable, perform the tests with and without telecommunications.

a) Manual transfer of DC configuration when only one pole is operating if applicable:
   1) Energise and deblock one pole as per normal sequences and procedures.
   2) Ramp active power to the agreed level and verify stable operation.
   3) Transfer from electrode or dedicated metallic return to metallic return which is the transmission line of the other pole and vice versa. Verify no significant disturbance for the DC power during the transfer.
b) Automatic change of DC configuration caused by trip of one of the poles when both poles are operating if applicable:
   1) Energise and deblock both HVDC poles in the bipolar mode as per normal sequences and procedures, and verify stable connection and satisfactory AC and DC voltages.
   2) Ramp active power to the agreed level and verify stable operation.
   3) Trip pole 1 converter unit at one station and observe steady state operation on pole 2.
   4) Verify correct operation of sequences at pole 1 and pole 2.
   5) Restore the operation of pole 1 and repeat steps 3) to 4) in the other converter station.

8.10.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) Correct demonstration of operation and sequences when transferring between an electrode, a dedicated metallic return and metallic return which is the transmission line of the other pole.
b) Correct demonstration of operation and sequences when transferring from bipolar to monopolar operation.
c) No abnormal measurements and no protection operations shall occur.
d) Switching sequences to transfer the current shall operate correctly and all events shall be logged in the correct sequence. If applicable, all tests shall demonstrate the transfers operate correctly with and without telecommunications.
e) Any incomplete transfer sequences shall be terminated in a safe condition.
f) Stable operation in the final configuration following each step/test (bipolar or monopolar).
g) The other pole shall automatically compensate the power loss of the tripped pole if applicable.

8.11 Heat run test (including overload)

8.11.1 Test purpose

The purpose of this test is to demonstrate that all components of the HVDC system are capable of continuously running at the load levels guaranteed in the contract without exceeding its maximum allowable temperature.

There are some applications however where this may not be possible. This could be due to limitations on the AC networks, late AC network augmentation works or the need for the progressive commissioning of remote generators (as in the case for offshore wind projects or similarly for solar projects). In these instances, the scope of the heat run test will likely differ from that presented in this document and require discussion and agreement between the owner and the supplier.

The maximum power levels are required under maximum ambient conditions. The heat run test should run until such time that stable temperature of the equipment with the longest time constant which normally are the interface transformers, is achieved. It is impossible for ambient temperatures to be achieved and held steady for the duration of the test. Therefore, the results and measurements will need to be analysed after the test and compared to thermal calculations and modelling performed beforehand to verify that the equipment will be able to operate at the maximum power levels under the maximum ambient conditions.

During this test, the power load of the HVDC system will be brought to the test value or the maximum available power level and held constant. During this time the required measurement values will be recorded. Additionally, the surface temperatures of the interface transformer, phase reactors, DC reactors and other equipment which operate close to their thermal limits, including all primary equipment connections, will be measured and recorded.

The test is to verify that the cooling systems work correctly under the maximum cooling load, and that all thermal elements of the converter unit are able to be operated at the maximum active power level for the desired period of time.

Note that there is often an opportunity during the heat run test to perform other tests at the same time, particularly those that require a high and steady active power level for a longer period of time. These tests include harmonic tests, interference tests, and audible noise tests, etc.

8.11.2 Test preconditions

Before the heat run test, the following minimum preconditions should be fulfilled:

a) All high and low power transmission tests are completed.
b) The duration of the heat run test is determined through the analysis of the thermal constants and characteristics of the major thermal elements within the converter unit, and agreed between the owner and supplier.
c) The necessary equipment and thermal measuring devices are set up or applied at the required locations on the high voltage equipment and throughout the converter units under test.
d) Redundant cooling equipment is switched off except under overload conditions.

8.11.3 Test procedures

The test procedures should include the following steps:

a) Energise and deblock both HVDC converter units as per normal sequences and procedures.
b) Ramp active power to the agreed maximum level and verify stable operation.
c) Hold the maximum active power level steady until stable temperature values are reached or the predefined test duration is elapsed.
d) During operation, the following parameters should be measured and monitored (as a minimum):
    1) Valve cooling system parameters, including coolant inlet and outlet temperatures.
    2) Interface transformers oil and winding temperatures.
    3) Phase reactors temperatures.

4) DC smoothing reactor temperatures.
5) Valve hall and reactor hall temperatures.
6) Ambient temperature.

e) On completion of the test, arrange safe access to the high voltage equipment and inspect all equipment inside the buildings and valve halls, interface transformers, reactors and wall bushings, including thermal measurement equipment and temperature indicators installed for the test.

f) Compare the thermal measurements and results against the designed values, including comparison of the recorded temperatures for individual high voltage equipment against its design maximum temperature and the overall results to any thermal or rating calculations performed.

g) Extrapolate the test results by calculation to the maximum ambient conditions to verify that the HVDC system can operate at the maximum power levels under the maximum ambient conditions.

8.11.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) No abnormal measurements and no protection operations shall occur.

b) Stable operation of the converters and HVDC system at high active and reactive power levels in accordance with the technical specifications for the required length of time.

c) The HVDC system shall be able to achieve the desired active and reactive power combinations at the limits of the PQ characteristic, and shall demonstrate stable operation at these levels.

d) Reactive power and active power levels shall remain within the PQ characteristic of the HVDC system.

e) All high voltage equipment and connections shall be below or equal to their maximum temperature limits.

f) Satisfactory operation of the valve cooling system, to keep valve temperatures and valve cooling temperatures within the specified requirements.

g) All equipment inside the buildings and valve halls, interface transformers, reactors and wall bushings shall be inspected and no overheated parts shall be observed.

h) Depending on actual site conditions, through modelling and calculation, the HVDC system shall be demonstrated to be capable of operation at the maximum power levels under the maximum ambient conditions.

8.12 Control system changeovers

8.12.1 Test purpose

The purpose of this test is to verify continued and stable operation of the HVDC system while switching between two redundant control systems.

This test should be performed first at low power level to reduce the adverse effect of any unexpected trip. It shall be performed in all major control modes as well as during a time of ramping of active and reactive power.

8.12.2 Test preconditions

Before the control system changeovers test, the following minimum preconditions should be fulfilled:

a) The first power transmission (8.3) and protective actions tests (8.4) are completed. (If this test is performed during converter station tests, the first deblock (7.2) and protective actions (7.3) tests are completed.)

b) The HVDC system is energised, deblocked and stable.

c) All redundant components which are identified to be tested are in a state to ensure successful changeover (i.e. either active or standby).

A test table should be developed and agreed between the owner and supplier prior to the commencement of the test, which defines the sequence of manual changeover or power off and on of the various redundant control and protection components.

8.12.3 Test procedures

The test procedures should include the following steps:

a) Manually switch the active system to standby, and after a while switch back according to the test table.

b) Power off and on the redundant components in the test table. Perform the following steps for each component to be tested, ensuring that the test is repeated for either or both redundant systems:

   1) Switch off the power supply to the standby component, and verify no disturbance of the HVDC system.

   2) Switch the power supply to the previously standby component back on and switch it into standby mode, and verify no disturbance of the HVDC system.

   3) Switch off the power supply to the active component.

   4) Verify correct switchover to the redundant system and wait until all sequence of events recorder messages are reported and all communication links are settled again.

   5) Verify stable operation of the HVDC system during and after the switchover.

   6) Switch the power supply to the previously active component back on and switch it into standby mode, and verify stable operation of the HVDC system.

8.12.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) The changeover to the standby system manually or by power off shall not lead to a trip or loss of the HVDC system.

b) No disturbance of the HVDC system during power off and on to the standby components.

c) Stable operation of the HVDC system during and after the switchover.

d) Respective error/alarm events shall be indicated whether the switchover is expected or not.

8.13 Change of control location

8.13.1 Test purpose

The purpose of this test is to verify that the interaction between the various control locations for the HVDC system, including any request/release procedures, operates according to the design and results in the continued and stable operation of the HVDC system when switching between each of the available control facilities.

8.13.2 Test preconditions

Before the change of control location test, the following minimum preconditions should be fulfilled:

a) The first power transmission (8.3) and protective actions tests (8.4) are completed. (If this test is performed during converter station tests, the first deblock (7.2) and protective actions (7.3) tests are completed.)

b) The HVDC system is energised, deblocked and stable.

c) The local and remote HMI facilities at each control location, and the communication systems connecting them, are installed, tested, commissioned and verified to be capable of successfully controlling and operating the HVDC system from that location.

8.13.3 Test procedures

Table 3 identifies the various combinations of control location changeover. This table assumes two converter stations and two remote control locations. The table should be reduced or expanded according to the specific HVDC system.

Table 3 – Control location combinations

Changeover matrix		**New control location**			
		Station A	Station B	Remote A	Remote B
Initial control location	Station A				
	Station B				
	Remote A				
	Remote B				

NOTE In the case of a back-to-back HVDC system, Station A and Station B location will be at the same location.

It is assumed that the selection of control location is made through a request/release procedure, in which the new control location is selected by a person at that location initiating a request to take control command, and the person at the location presently in control acknowledges this by issuing a release control command. Alternative mechanisms for transferring control may exist which are specific to each HVDC system, in which case the test procedures described herein should be adjusted accordingly.

The test procedures should include the following steps for the selected combinations of initial and new control location as defined in Table 3 for the HVDC system under test:

a) The operator at the new control location initiates a control request.

b) The operator at the new control location attempts to perform a few basic functions to verify it does not have control.

c) The operator at the current control location initiates a control release.

d) Observe and verify that the control location is successfully changed to the new control location and the HVDC system is stable.

e) The operator at the new control location performs a few basic functions such as deblock, ramping up and down, block, to verify having control.

8.13.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) The changeover to the new control location shall not occur until the control release is initiated.

b) The changeover to the new control location shall not lead to a trip or loss of the HVDC system.

c) Stable operation of the HVDC system during and after the changeover.

d) All operator settings previously in force shall be maintained throughout the transfer of control.

e) No alarms or other unexpected responses by the HVDC system during the transfer sequence.

f) The indications of the new control location shall be accurately indicated at all control locations.

8.14 Loss of auxiliary power supplies

8.14.1 Test purpose

The loss of auxiliary power supply test serves to verify the smooth changeover to the redundant auxiliary supply and distribution for the HVDC system in the event of the failure of the active system.

The purpose of this test is to verify that the performance and stability of the HVDC system is maintained during an outage of the active or standby auxiliary power supply system and that upon loss of all available sources of supply the converter shuts down in a safe and controlled manner.

8.14.2 Test preconditions

Before the loss of auxiliary power supplies test, the following minimum preconditions should be fulfilled:

a) The first power transmission (8.3) and protective actions tests (8.4) are completed. (If this test is performed during converter station tests, the first deblock (7.2) and protective actions (7.3) tests are completed.)
b) The HVDC system is energised, deblocked and stable.
c) All redundant auxiliary power supplies are active, healthy and available.

8.14.3 Test procedures

The test procedures shall be developed to trigger both a changeover to the standby auxiliary supply in the event of a loss of the active supply, and a controlled shutdown of the converter due to the loss of all auxiliary power supplies. The exact process for doing this will depend on the particular design of the auxiliary supply system for the HVDC converter stations, including the number and type of auxiliary power supplies.

Prior to shutting off all auxiliary supplies for the first time, ensure procedures and protocols are established and in place to intervene and trip the converter unit if the controlled shutdown of the converter does not occur within the expected time.

The test procedures should include the following steps:

a) For each AC auxiliary supply to be tested, ensure that primary power supply is active and that the standby system is available.
b) Switch off the primary supply.
c) Observe the changeover sequence to the standby supply.
d) Verify stable operation during and immediately following changeover.
e) Switch the original primary supply back on again.
f) Repeat the above for each AC auxiliary power supply, active and standby combination.
g) If required, switch off one AC auxiliary supply without an available redundant supply and observe a controlled shutdown of the converter.
h) For each redundant battery system, switch off the system and verify stable operation during and immediately following the loss of supply. Switch the battery system back in and repeat for all battery systems available.

8.14.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) The loss of one redundant AC or DC auxiliary power supply shall not lead to a trip or loss of the HVDC system.
b) Stable operation of the HVDC system during and after the loss of the primary AC or DC auxiliary supply.
c) Appropriate alarms shall be indicated at the sequence of events recorder and that these shall be reset on return of healthy auxiliary power supplies.
d) Where all AC auxiliary supplies are switched off, the HVDC converter/system shall shut down in a controlled manner in accordance with the design, within the required times.

8.15 Loss of telecommunication

8.15.1 Test purpose

The behaviour of the HVDC control and protection system under telecommunication (i.e., the communication link between the converter stations) failure scenarios will depend on the specific requirements of that system and the implemented characteristics as designed, including what may or may not be done locally.

The purpose of this test is to verify stable operation of the HVDC system in the event of the loss of telecommunication.

8.15.2 Test preconditions

Before the loss of telecommunication test, the following minimum preconditions should be fulfilled:

a) The active power control (8.5) and reactive power control (8.6) tests are completed.
b) The HVDC system is energised, deblocked and stable.
c) The telecommunication link is in service, and any backup communication links are identified.

8.15.3 Test procedures

The test procedures should include the following steps:

a) With the HVDC system in operation, initiate a failure of the telecommunication link and confirm that the HVDC operating status (mode, configuration, demand settings, etc.) are either unchanged, or changed as expected with the de-activation of power modulation or frequency control.
b) Manually operate HVDC system, such as change the settings, control modes, shutdown, etc (if applicable).
c) Restore the communications and verify that the change to healthy status is indicated on the operator HMIs.

8.15.4 Test acceptance criteria

The test acceptance criteria should include the following:

a) The loss of telecommunications shall not lead to a trip or loss of the HVDC system.
b) Stable operation of the HVDC system during and after the loss of telecommunication.
c) Appropriate alarms shall be indicated at the sequence of events recorder and that these are reset on return of healthy communications.
d) Manual changes in settings, and control modes shall be possible (if applicable).
e) Manual shutdown shall be possible (if applicable).

8.16 Black start (if applicable)

8.16.1 Test purpose

A black start is the act of energising a dead AC busbar and supplying an AC system with power from the other side of the HVDC system, where the converter in the islanded grid is controlling the AC voltage and frequency and acting as a stiff voltage source.

The purpose of this test is to verify the functionality of black start, which is generally to energise the converter and the converter bus from the DC side to the AC circuit-breaker and even to restore the agreed portion of AC grids step by step.

The black start sequence will differ between projects and different suppliers and the test procedure will need to be adjusted to fit the specific HVDC system's black start functionality.

8.16.2 Test preconditions

Before the black start test, the following minimum preconditions should be fulfilled:

a) The active power control (8.5), reactive power control (8.6) and loss of auxiliary power supplies (8.14) tests are completed.
b) An AC system for the test has been determined, arranged and agreed by the relevant affected parties.
c) The AC network in the islanded station is prepared for a black start, i.e., the AC test-system is de-energised and disconnected from the remaining grid.
d) The auxiliary power supply is disconnected from the medium voltage network and supplied by the diesel generator.
e) The two converter units are connected to each other via the HVDC transmission line.
f) Protections settings in the AC test system are adjusted for a black start test, if required.
g) The converter in the supporting station is ready for a black start of the other station, remains connected to the AC network and is in operation.
h) If the black start test involves the energisation of an AC network (with or without local loads), network energisation scenarios should be planned and developed by the owner and exchanged with the supplier.
i) If mobile load banks are utilised, the operator of the load banks has completed the protection test and dry-run sequence test of the load bank switching.

8.16.3 Test procedures

The test procedures to be followed will depend greatly on the specific design of the HVDC system and the requirements of the black start function, including for example the configuration and source of auxiliary power supplies. The test procedures would include the following steps:

a) Activate black start mode in the converter station connected to the dead AC network (inverter). Depending on the sequence for the particular HVDC system, the following steps might be automatic.
b) The converter in the "healthy grid" (rectifier) goes into black start supporting mode.
c) The rectifier energises the DC side of the blocked inverter.
d) The VSC valves at the inverter are energised in the blocked state.
e) The inverter deblocks and energises the AC side of the converter to the AC circuit-breaker.
f) Check and verify correct frequency and voltage setpoints of the islanded test grid.
g) If the test involves energisation of a bus or a local load:
   1) Close the AC circuit-breaker.
   2) Do stepwise connection of lines and load or load banks. Give sufficient time between each step to observe stable operation.