PUBLICLY
AVAILABLE
SPECIFICATION

IEC
PAS 61975

Pre-Standard

First edition
2004-08

System tests for high-voltage direct current (HVDC) installations

Reference number
IEC/PAS 61975:2004(E)

Publication numbering

As from 1 January 1997 all IEC publications are issued with a designation in the 60000 series. For example, IEC 34-1 is now referred to as IEC 60034-1.

Consolidated editions

The IEC is now publishing consolidated versions of its publications. For example, edition numbers 1.0, 1.1 and 1.2 refer, respectively, to the base publication, the base publication incorporating amendment 1 and the base publication incorporating amendments 1 and 2.

Further information on IEC publications

The technical content of IEC publications is kept under constant review by the IEC, thus ensuring that the content reflects current technology. Information relating to this publication, including its validity, is available in the IEC Catalogue of publications (see below) in addition to new editions, amendments and corrigenda. Information on the subjects under consideration and work in progress undertaken by the technical committee which has prepared this publication, as well as the list of publications issued, is also available from the following:

- **IEC Web Site (www.iec.ch)**
- **Catalogue of IEC publications**

  The on-line catalogue on the IEC web site (www.iec.ch/searchpub) enables you to search by a variety of criteria including text searches, technical committees and date of publication. On-line information is also available on recently issued publications, withdrawn and replaced publications, as well as corrigenda.
- **IEC Just Published**

  This summary of recently issued publications (www.iec.ch/online_news/ justpub) is also available by email. Please contact the Customer Service Centre (see below) for further information.
- **Customer Service Centre**

  If you have any questions regarding this publication or need further assistance, please contact the Customer Service Centre:

  Email: custserv@iec.ch
  Tel: +41 22 919 02 11
  Fax: +41 22 919 03 00

PUBLICLY AVAILABLE SPECIFICATION

IEC PAS 61975

Pre-Standard

First edition
2004-08

System tests for high-voltage direct current (HVDC) installations

International Electrotechnical Commission, 3, rue de Varembé, PO Box 131, CH-1211 Geneva 20, Switzerland
Telephone: +41 22 919 02 11 Telefax: +41 22 919 03 00 E-mail: inmail@iec.ch Web: www.iec.ch

Commission Electrotechnique Internationale
International Electrotechnical Commission
Международная Электротехническая Комиссия

PRICE CODE XG

For price, see current catalogue

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

____

SYSTEM TESTS FOR HIGH-VOLTAGE DIRECT CURRENT (HVDC) INSTALLATIONS

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 provides no marking procedure to indicate its approval and cannot be rendered responsible for any equipment declared to be in conformity with an IEC Publication.
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) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

A PAS is a technical specification not fulfilling the requirements for a standard but made available to the public.

IEC-PAS 61975 was submitted by the CIGRÉ (International Council on Large Electric Systems) and has been processed by subcommittee 22F: Power electronics for electrical transmission and distribution systems, of IEC technical committee 22: Power electronic systems and equipment.

The text of this PAS is based on the following document:	This PAS was approved for publication by the P-members of the committee concerned as indicated in the following document
Draft PAS	**Report on voting**
22F/96/NP	22F/101/RVN

Following publication of this PAS, which is a pre-standard publication, the technical committee or subcommittee concerned will transform it into an International Standard.

An IEC-PAS licence of copyright and assignment of copyright has been signed by the IEC and CIGRÉ and is recorded at the Central Office.

This PAS shall remain valid for an initial maximum period of three years starting from 2004-08. The validity may be extended for a single three-year period, following which it shall be revised to become another type of normative document or shall be withdrawn.

PART 0: EXECUTIVE SUMMARY

Abstract

This document which gives guidance on all aspects of system tests for HVDC installations (excluding multiterminal HVDC systems), has been prepared by CIGRE WG 14.12. It is structured in eight parts.

The guide should give potential users guidance, regarding which course of action should be taken in planning commissioning activities.

Structure of the tests and a brief statement of the purpose of the individual group of tests is presented.

Introduction

Commissioning an HVDC system is a very complex task which may affect more than the actual contract parties. The complexity and the diversified areas of concern during system testing require thorough planning and scheduling, cooperation of all parties involved, and complete and structured documentation.

System testing completes commissioning of an HVDC system.

It allows the supplier to verify the suitability of the station equipment installed and the functional completeness of the system; adjustments and optimization can be made.

The user is shown that the requirements and stipulations in the contract are met and that there is correlation with studies and previous off-site testing.

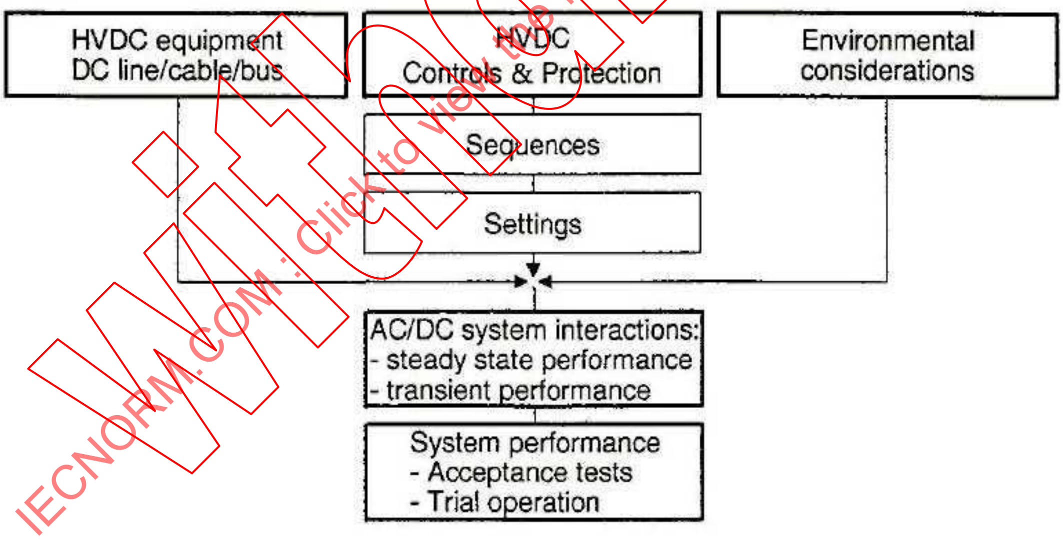
In adapting the HVDC system to the "real world" (the connected AC systems) various constraints may exist, which require coordination within the economic schedules of the AC system operators.

System testing proves to the public that tolerable values of phenomena concerning public interest are not exceeded.

Five (5) major aspects are subject to system testing:

- HVDC station equipment and DC line/cable/bus incl. earth electrode, if any
- HVDC controls and protection
- Environmental considerations
- AC/DC system interaction
- System performance

The following diagram shows the interrelation between these aspects:



Acceptance tests shall be defined between supplier and user in advance and may be performed at an appropriate time during the test schedule.

The testing sequence is best scheduled starting at local level with simple tests before Involving additional locations and the transmission system and more complex tests,

A system test plan has proven itself as a good means for planning and scheduling.

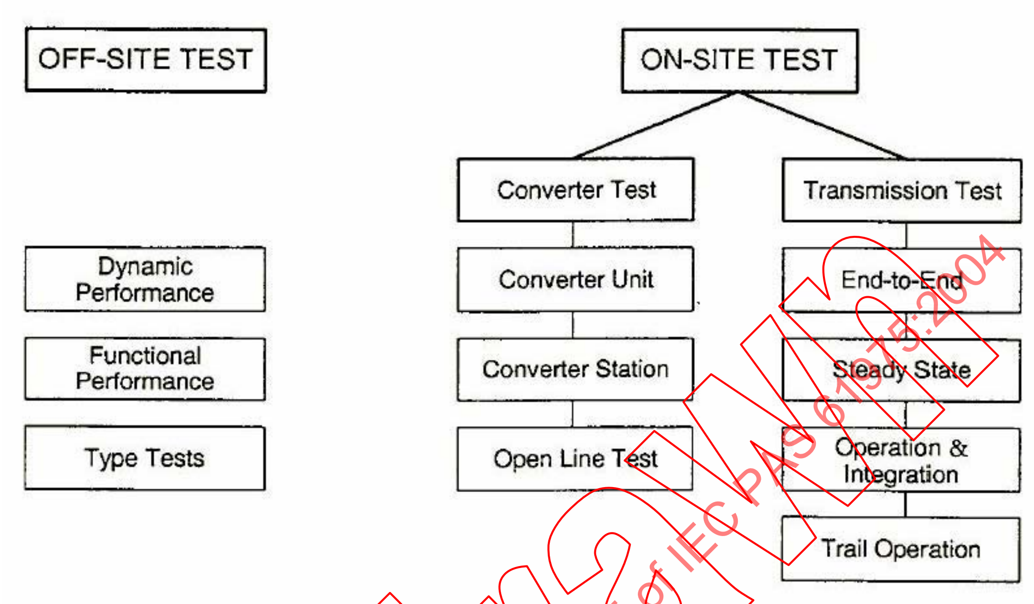
Complete and organized documentation of the system tests is to the benefit of both the supplier and the user, it shall form part of the project documentation and contain al! necessary oscillograms, logs, etc. and if necessary a commentary and references.

Structure of System Testing

System testing should follow the structure of the HVDC system, starting from the smallest, least complex operational unit and shall end with the total system in operation.

The first step, to ensure proper function, is to debug and to test the control system during off-site tests. Because of the complex nature of the HVDC system, this requires a simulator. Where applicable it is recommended to run commissioning tests and acceptance tests during the off-site tests in a similar way to those performed later at site. In such a way off-site tests can serve as reference for the site tests.

System Tests for HVDC Installations



Before system commissioning can begin at site, preconditions concerning subsystem tests, operator training and safety Instructions, system test plan and test procedures, and all necessary test equipment must be fulfilled.

After all preconditions are fulfilled, each converter unit is commissioned separately during the converter unit test. Open-circuit tests and/or short-circuit tests are possible for this purpose. Converter station tests also include energization of the AC filter, DC yard energization and back-to-back tests.

Back-to-back tests allow full active power with the nominal DC voltage, firing angles, harmonics, etc. whilst still disconnected from the second AC system. Certain control, relaying and instrumentation changes as welt as temporary DC switchyard changes may be required for back-to-back tests.

Before end-:o-end tests are performed, it is advisable to perform an open line test and shorted line tests with the DC transmission line. This test can be repeated from both ends to verify the integrity of the DC line.

End-to-end tests involve both stations and the transmission Tine. With this operation, power is transmitted for the first time. This test usually start on a monopolar basis, with full bipolar operation being the final step.

Having the complete system running properly, steady state verification tests can be performed. With normal operating ramp settings and automatic switching sequences in place the effect of a number of disturbances on the DC side of the system as well as in the AC systems may be checked.

Operation and Integration tests verify the transient and fault recovery behaviour of the HVDC system-Correct operation of the HVDC system over an extended period of time is checked during the trial operation.

The HVDC system tests are now completed, all functions have been verified and the HVDC system is ready to be handed over to the owners. The acceptance tests necessary to verify whether acceptance criteria have been met may have been performed all or in part during the commissioning period.

PART 1: GENERAL

Introduction

This document deals with all aspects of system tests of HVDC systems. System tests start when all relevant subsystems have been precommissioned and are ready for operation. They end with full acceptance of the system for operation in the power systems.

This document provides background information for IEC to produce standards for system testing. It is structured in eight parts:

1. General

2. Off-site Tests

3. Converter Tests

   Commissioning of converter units, verification of steady state performance of units, switching tests

   - converter unit tests
   - converter station tests.

4. End-to-End Tests

   Commissioning of the transmission system, verification of station coordination.

5. Steady-State Performance and Interference Tests

   Verification of steady-state performance and interference caused by the HVDC-system.

6. Operation and Integration Tests

   Operational and fault tests, verification of dynamic performance and interaction between the DC and AC systems.

7. Trial operation

8. System test plan and documentation

The guide also covers interrelation with off-site system tests. Preconditions of system tests wit] be established.

Part 1 General will address the purpose of this document, the HVDC system structure, the control and protection structure, the logical steps of commissioning and the structure of system testing of HVDC system. Parts 2 to 7 comprise individual paragraphs on general test objectives, information on test procedures, as well as detailed descriptions of the individual tests, including as appropriate the following;

- Specific objectives per test
- Test procedures
- Test acceptance criteria
- Preconditions for the test
- References to system studies/specifications
- References to off-site tests
- Special conditions

Part 8 describes the documentation normally required to adequately perform the system tests. This primarily consists of the following:

- Plant documentation
- Inspection and test plan (ITP)
- System study reports/technical specifications
- System test program
- Test procedures for each test
- Documentation of system test results

- Deviation report

The guide should give potential users guidance, regarding which course of action should be taken in planning commissioning activities. The tests described in the guide may not be applicable to all projects, but represent a range of possible tests which should be considered.

1.1 Statement of Purpose

System testing completes the commissioning of an HVDC system.

It allows the supplier to verify the suitability of the station equipment installed and the functional completeness of the system; adjustments and optimization can be made.

The user is shown that the requirements and stipulations in the contract are met and that there is correlation with studies and previous off-site testing.

For the user, the completion of system testing marks the beginning of commercial operation of the HVDC system.

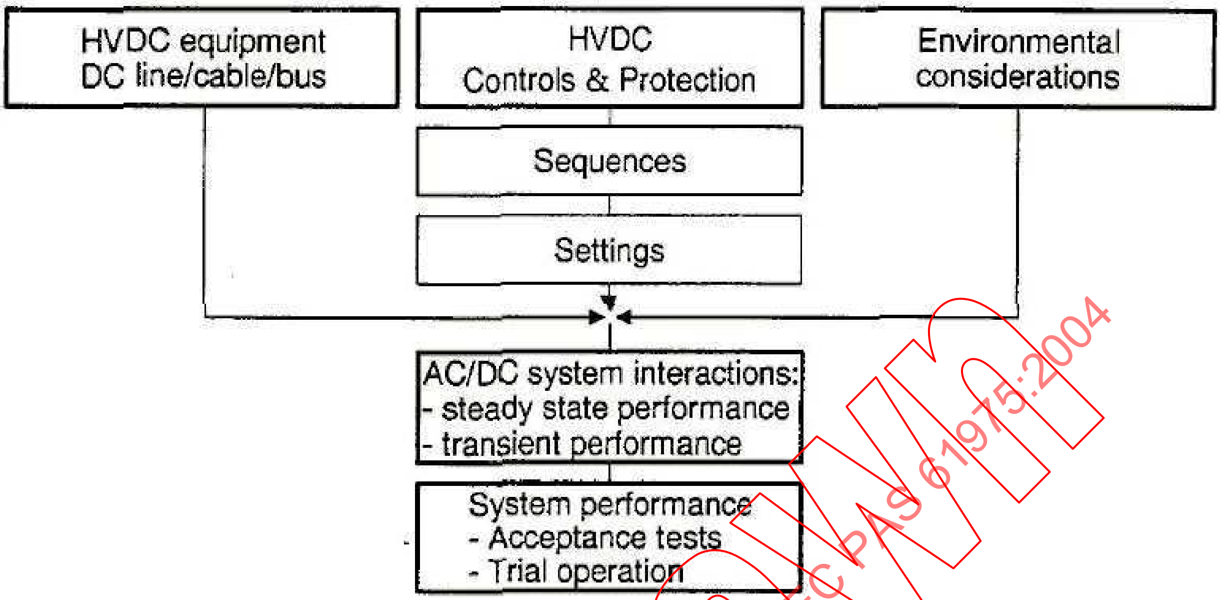
In adapting the HVDC system to the "real" world" (the connected AC systems) various constraints may exist, which require coordination within the economic schedules of the AC system operators.

System testing proves to the public that tolerable values of phenomena concerning public interest are not exceeded.

Five (5) major aspects are subject to system testing:

- HVDC station equipment and DC line/cable/bus incl. earth electrode, if any
- HVDC controls and protection
- Environmental considerations
- AC/DC system interaction –
- System performance

The following diagram shows the interrelation between these aspects:



Thorough and complete system testing of the above components can be achieved with the tests described in the eight parts of the guide.

Acceptance tests shall be defined between supplier and user in advance and may be performed at an appropriate time during the test schedule.

System testing may affect more than the actual contract parties. Those parties shall be informed in time.

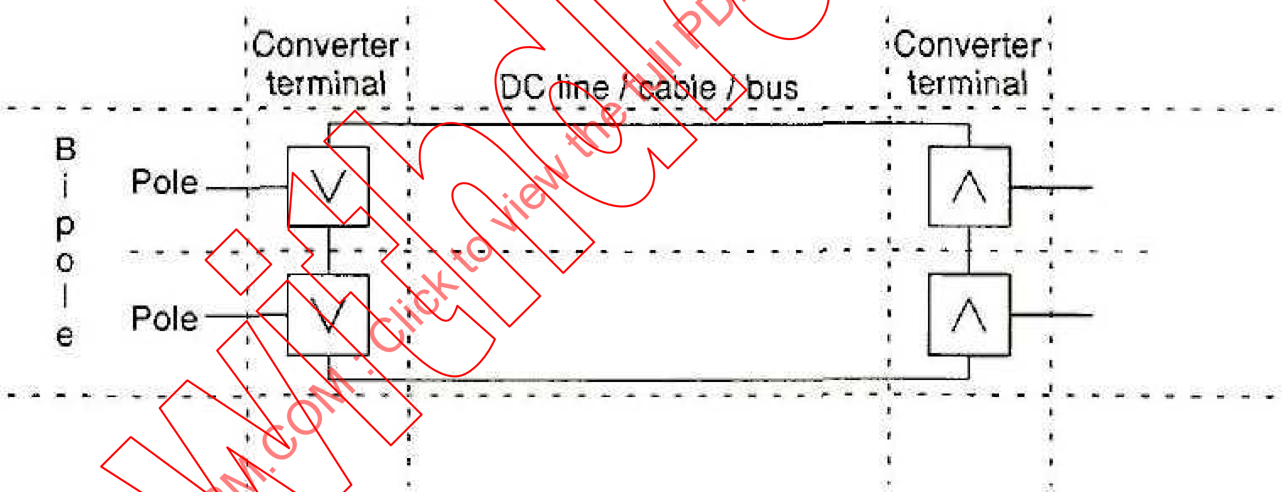
The complexity and the diversified areas of concern during system testing require thorough planning and scheduling, cooperation of all parties involved, as well as complete and organized documentation.

The testing sequence is best scheduled starting at local level with simple tests before involving additional locations and the transmission system and more complex tests. A system test plan (probably as part of a site test plan) has proven itself as a good means for planning and scheduling.

Complete and organized documentation of the system tests is to the benefit of both the supplier and the user, it shall form part of the project documentation and contain all necessary oscillograms, logs, etc., and if necessary a commentary and references.

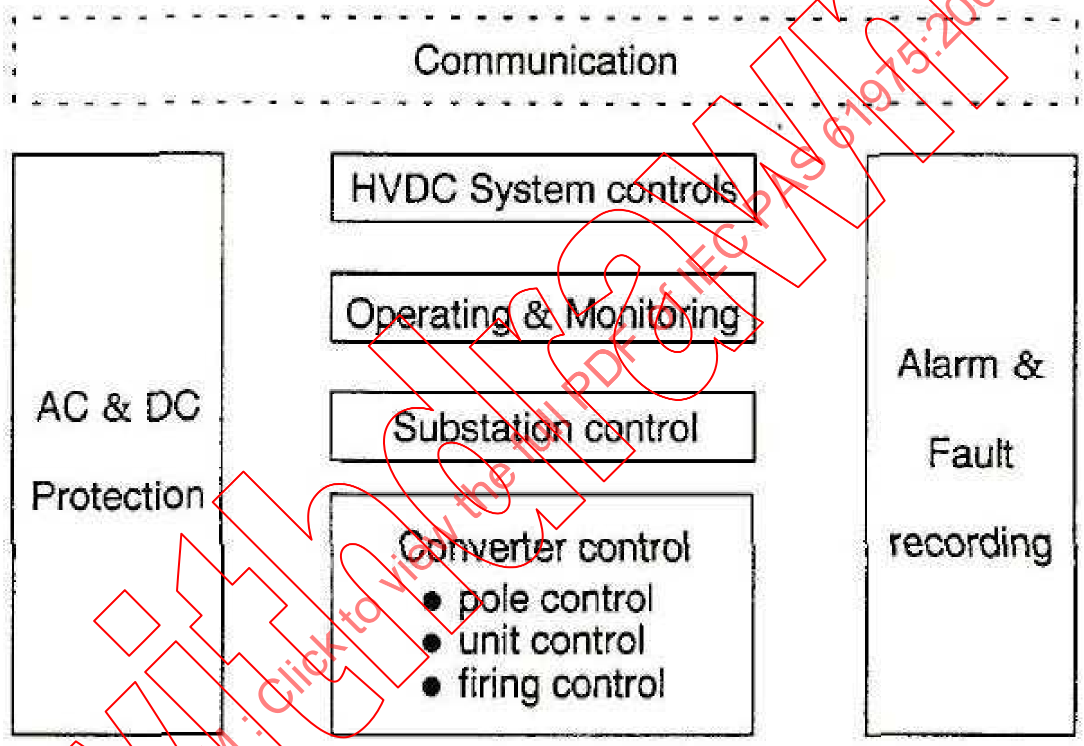
1.2 Structure of the HVDC System

From a functional point of view an HVDC system consists of a sending terminal and a receiving terminal, each connected to an AC-system. The two terminals have one or several converters connected in series on the DC side and in parallel on the AC side. The terminals are connected by a transmission line or cable or a short piece of busbar (Back-to-Back station). Multiterminal systems are not addressed in this document



1.3 Structure of the Control and Protection System

Each of the converter units can be controlled individually. To make the system function as a transmission system the converter units should be controlled in a coordinated way by a second level of the control system. Coordinated controls and protection are essential for the proper function of HVDC systems.



1.4 Logical Steps of Commissioning

System commissioning should follow the structure of the HVDC system, starting from the smallest, least complex operational unit, usually a 12-pulse converter, and shall end with the total system in operation.

The first step, to ensure proper function, is to debug and test the control system during factory system tests. Because of the complex nature of the HVDC system, this requires a simulator. Where applicable, it is recommended to run commissioning tests and acceptance tests in addition to ail limiting design cases on the simulator in a similar way to those done later at site. In such a way simulator tests can serve as reference for the site tests.

Before system commissioning can begin at site the following preconditions should be fulfilled.

- All subsystems tested and commissioned including AC filters and the converter transformers with special attention to possible transformer/AC filter resonance during energizing
- Sufficient training of operating personnel
- Operating instructions for the station available to the operators
- Personnel, plant safety and security instructions made
- System test plan and documentation (part 8) ready and agreed upon
- AC/DC power profiles agreed for each test
- Any AC/DC system operating restrictions identified
- Operator voice communications available
- All necessary test equipment calibrated and operational
- Procedures for the preparation and evaluation of test results agreed upon

After all preconditions are fulfilled, each converter unit is commissioned separately. Open-circuit tests and/or short-circuit tests are possible for this purpose. Steady-state performance and interference tests may start at this instant; however, they can be performed one by one at any convenient other place dying the system test program, in order to minimize duplication of tests.

If possible, as a next step the converters in each station should be connected back-to-back. This allows full active power with the nominal DC voltage, firing angles, harmonics, etc. whilst still disconnected from the second AC system. Certain control, relaying and instrumentation changes as well as temporary DC switchyard changes may be required for back-to-back tests.

Before full end-to-end tests are performed, it is advisable to perform an open line test and shorted line tests with the DC transmission line. This test can be repeated from both ends to verify the integrity of the DC line.

End-to-end tests will then be conducted. These tests involve both stations and the transmission line. With this operation power is transmitted for the first time. This test is usually done on a monopolar basis first, with full bipolar operating being the final step.

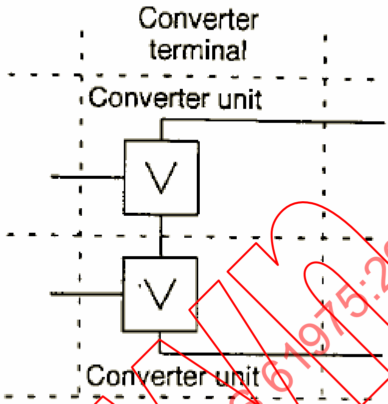
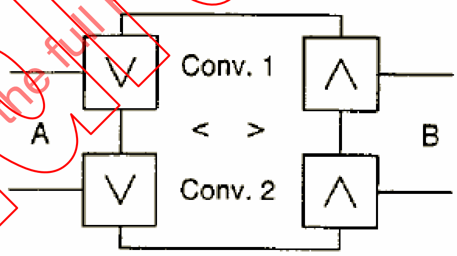
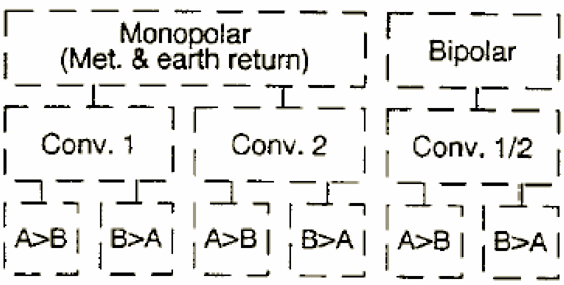
Having the complete system running properly in steady state operation, with normal operating ramp settings and automatic switching sequences in place the effect of a number of disturbances on the DC side of the system as well as in the AC systems may be checked. Operation and integration tests verify the transient and fault recovery behaviour of the HVDC system.

The HVDC system tests are now completed, all functions have been verified and the HVDC system is ready to be handed over to the owners. The acceptance tests necessary to verify whether acceptance criteria have been met may have been performed all or In part during the commissioning period- To avoid unnecessary duplication of such tests, careful consideration should be given in advance as to when acceptance tests are carried out.

If acceptance tests are still outstanding or acceptance tests have to be repeated due to modifications they should be performed at this time, or following trial operation, as appropriate.

Finally it has to be ensured that the system also operates correctly over an extended period of time. This is checked during the trial operation.

1.5 Structure of System Testing

	Tests	Configuration
ACCEPTANCE TESTS	Converter tests Converter unit tests • Energizing • Deblock/block • Current ramping Converter station tests • Start/stop sequences • Protection sequence • Current control response • Operation with full power Open line tests of the DC-transmission circuit	
	Transmission tests End to end tests • Changing the DC systems configuration, off voltage • Start and stop sequence • Protective blocking and tripping sequences • Power and current ramping • Reduced voltage operation Steady state verification tests • Harmonics • Audible noise / corona • Overload / temperature rise • Interference • Earth electrode Operation & Integration tests • Change of DC configuration • Control performance - step response - control mode transfer - AC system interact / control - commutation failure • Switching AC side filters and transformers • Loading test • AC and DC system staged fault tests • Loss of telecom / auxiliaries Trial operation	 Configuration 

PART 2: OFF-SITE TESTS

General

Introduction

This part describes the testing of the control equipment prior to it being shipped to site. The following tests are outlined:

2.1 Steady state performance of the controls

2.2 Dynamic performance tests

2.3 Functional performance tests

2.4 Type tests on the control and protection equipments

Subsequent to the Routine Testing of the HVDC-System Control and Protection equipment it is normal practice to check the steady state, the functional and the dynamic performance of this equipment prior to it being shipped to site. These tests provide the opportunity to set up the parameters of the control circuits (though these set tings may have to be fine tuned later at site) and to obtain a preliminary check on the performance of the equipment relative to the specified requirements.

Performance of the protective functions of the converter, during various simulated faults, can also be checked. This enables the equipment to be partly commissioned off-site. It also provides the opportunity to detect and correct hardware and software errors or deficiencies in the control and protection systems.

To carry out the dynamic performance tests it is necessary to have a real time HVDC simulator which includes representation of the AC systems, AC filters, converter equipment, DC smoothing reactors, DC lines and DC filters. The extent of the system representations should be sufficient to replicate resonances as determined from previous studies. In general, a comprehensive simulation will enable thorough fault tracing to be done and allow effective commissioning at site.

As defined in Part 1 of this guide the control equipment is arranged in a hierarchical structure and only the representative sections which will affect the dynamic performance would be used for the dynamic tests. These controls would be the closed loop control sections of the HVDC System Controls (Master Control), Station Control, Pole Controls and Converter Control. The telecommunication system and the valve base electronics would be appropriate. The Valve Base Electronics would be appropriately simulated. Conventional protection equipment would be omitted i.e. that for AC filters, DC filters and converter transformers but the protection for the DC system would be included. The control equipment as defined above needs not necessarily be that supplied for the contract.

The real time simulator may also be used for the functional performance tests but other forms of simulation e.g. by software models, are possible. For the functional performance tests the complete control system shall be tested. Fault recorders and Sequence of Event Recorders which are "stand alone equipments" may not be included for the Functional Performance Tests. If these recorders are not used the validity of output signals to these equipments would be checked during the tests.

Finding and correcting hardware and software errors in the control system is an important function of off-site testing. Such faults are easier to find and correct off-site rather than during commissioning. Correcting such faults reduces the probability of disturbing the Customers' power system during site commissioning.

The principles for off-site testing of the control system are as follows:

a) Controls, as defined above, should be present and connected in an identical manner to the final site configuration. Possible exceptions are simple interface equipment, Fault Recorders and Sequence of Events Recorders.

b) It is desirable that the test team acts independently from the equipment design team to verify correct operation of the control system. The test team shall include representatives from the commissioning group, the design group and the test group. It is recommended that the customer takes a significant role in this testing team in order to provide valuable experience in training customers staff.

c) During the test period the equipment being tested shall be under the control of the test team leader and no changes should be made without his approval. Changes to the equipment should be recorded in conformity with the defined Quality Assurance (QA) procedures, thus ensuring that the tests are carried out on a known state of hardware and software.

d) An off-site test plan including AC system representations, DC configurations and tests to be performed shall be mutually agreed between the manufacturer and the customer in advance of the commencement of the tests.

Type testing, if required, can be carried out to demonstrate performance over the specified environment, with variations of power supply voltage and simulation of faults on auxiliary systems, to demonstrate the stability of the control and the accuracy of protection settings. In addition it may be possible to demonstrate interference immunity of the control and protection equipment, together with the communication interface.

General Test Objectives

1. To check the steady state, the functional and the dynamic performance of the control equipment and, if required, to carry out some of the type tests for the control and protection equipment,

2. To make preliminary settings of the control parameters.

3. To provide confirmation of the design specifications and study results for the control and protection equipment and also to provide test data for comparison with that obtained during the operation and integration tests defined in PART 6 of the guide.

4. To find and correct errors and deficiencies in the control and protection hardware and software.

Preconditions for the Tests

1. For the functional performance tests the control and protection equipment shall have passed all its routine tests.

2. For the functional performance tests the control and protection cubicles shall be interconnected In the "as site" configuration.

3. An off-site test plan including AC system representations, DC configurations and tests to be performed shall be mutually agreed between the manufacturer and the customer in advance of the commencement of the tests.

4. The studies defining the control strategies shall have been completed.

2.1 Steady State Performance of the Controls

Introduction

Before the functional and the dynamic performance test can be performed, the steady state performance of the control equipment shall have been demonstrated.

2.1.1 Measurements

General

The following measurements should only be regarded as typical since they will vary with different control system designs.

Test Objectives

To confirm that the correct measurements are transmitted to the appropriate points within the control equipment.

Test Procedure

All measurements shall be checked for appropriate level, polarity, phasing and sequence at both source and destination.

- Line side voltage/test supply for valve firing;
- Valve winding currents;
- DC current and voltage;
- di/dt if applicable;
- Alpha and Gamma responses;
- Active and reactive power;
- Frequency.

2.1.2 Control and Protective Sequences

General

The sequences described in the Test Procedure can be checked with the converter system off-load.

Test Objectives

To ensure that the operational sequences of the valve control and protection are correct.

Test Procedure

Check that the correct sequence of events, with appropriate timings take place during deblocking/blocking of the converter system.

Check that the valve firing pulse sequences sent to the firing controls are correct

Check that forced retard, valve refire and blocking signals are generated in the correct locations and are transmitted to the correct locations.

Formation of bypass pairs should be checked if applicable.

2.1.3 Steady State Performance Tests Test Objectives

To ensure that the basic control functions meet the designed performance. The following tests should be regarded as typical since they may vary with different designs of control equipment.

Test Procedure

Verify the DC voltage and current static characteristics.

With the converter system deblocked check:

- Alpha and gamma order calibration;
- With the voltage and frequency of the AC systems varied over their normal ranges of operation confirm that the current order can be varied over the full range, DC voltage and current can be confirmed at different levels of currents order, and that any prescribed limits are maintained;
- that the power order can be varied over the full range, the derived current order may be confirmed at different levels of power order;
- block the rectifier and confirm the current error calibration and the correct response of the gamma control loop.

Reduced DC Voltage Operation

Manual or automatic reduction of DC voltage may be required to reduce stresses on DC cables when the power transfer level is being reduced, or to reduce the possibility of flashover of overhead DC lines during extreme weather conditions or conditions of excessive contamination.

Manual reduction will simply be cone by a selector switch operating the tap changer control. With automatic operation check that the reduction occurs under the designed conditions.

Protective shut-down

With minimum current order setting and the converter system deblocked apply a protective blocking signal at the rectifier. Repeat with maximum continuous current order setting. Confirm that correct blocking sequence occurs followed by circuit breaker tripping if required. Repeat for protective blocking at the inverter and with reversed power flow if appropriate.

Test Acceptance Criteria

For all the above tests the performance should conform to the system studies and the design parameters.

2.2 Dynamic Performance Tests

Introduction

For the dynamic performance tests only the closed loop controls of the HVDC System Control (Master Control), Station Control, Pole Controls and Converter Controls would be used. The telecommunication system shall be adequately simulated. Protection for the DC system would also be included. Tests would be performed using a real time HVDC Simulator. The control equipment hardware used for the representation need not necessarily be that supplied for the Contractor, but should be functionally identical. If the idea is to check software and hardware problems, they should be supplied by the Contractor's equipment.

Test Objectives

1. To check that measurements for the controls are of the correct magnitude and phasing.

2. To check that the sequences for deblocking/blocking, the firing sequence for the valves, and the signals for forced retard, refire bypassing and blocking are correct.

3. To check the stability and response of the controls during transient disturbances.

4. To make preliminary settings of the control parameters.

5. To check the correct operation of the protective functions for various types of faults in the DC system and the associated AC systems.

6. To find and correct any hardware deficiencies and software errors.

7. To check the interaction between the AC and DC systems under all relevant operating conditions.

8. Crosscheck against digital studies for consistency.

Preconditions for the Tests

In addition to the general preconditions the following must be fulfilled.

1. The preliminary control parameters as defined by the controls design study have been installed.

2. The set points, thresholds and time delays of the protective relays as defined by the protection co-ordination study have been checked by injection tests.

3. The steady state performance defined in section 2.1 shall have been demonstrated.

Test Procedures

The procedure for each of the following tests will be described separately in each section.

2.2.1 Control - Step Response

2.2.2 Control Mode Transfer

2.2.3 AC System Interaction/Control

2.2.4 Commutation Failures and Valve Misfires

2.2.5 AC Filter, Transformer and Reactive Element Switching

2.2.6 AC and DC System Faults

2.2.7 Islanding

All tests for optimization and verification of the controls and protection dynamic performance require a similar recording and monitoring set-ups as listed below, in cases where additional or different set-ups are required these are listed in the individual sections.

The results of these tests will be used as references for the end-to-end tests and the operation and integration tests at site and it is desirable that similar recording equipment and test report formats are used for both test sequences.

Where practical the following should be monitored:

- Current or power order
- DC current
- DC voltage
- Alpha order
- Alpha response
- Gamma response
- Control mode identification
- AC busbar voltages and frequency
- Valve winding AC currents
- DC power
- Reactive power
- Forced retard, blocking and initiation commands
- Valve firing sequence
- Tap position indications (if available)

2.2.1 Controls-Step Responses General

The corresponding site tests are described in 6.2.1 of the operation and integration tests.

Test Objectives

To confirm that the control equipment operates in a stable manner during changes of current order, power order and converter control angle.

Test Procedure

The AC systems should be set up with the strongest rectifier system together with the weakest inverter system applicable, since these typically represent the most onerous operating conditions. However, other cases should be considered.

With current order setting of 0,1 pu, deblock and block the converter system. Confirm that the speed of response to achieve the ordered value conforms to the specification and that no significant overshoot occurs. The procedure should be repeated for both power flow directions, if appropriate.

If a prescribed ramping rate for current order is required apply a step change of 0,5 pu or 1,0 pu current order to confirm that the correct rates are achieved.

Current order step response

With the converter system in DC current control and current order settings of 0,15 pu, 0,5 pu or 1,0 pu apply a 0,05 pu step reduction in current order followed by a 0,05 pu step up. Sufficient time should be allowed between changes to allow stable operation to be achieved.

Inverter extinction angle step response

With the rectifier in its normal mode of control and the inverter in minimum constant extinction angle control, apply a step change in gamma to increase the reference. An equal step reduction in gamma to the original value should be applied.

Inverter current control step responses

With the rectifier in constant firing angle control (alpha minimum) and the inverter in constant current control mode apply a 0,05 pu step increase in current order, followed by a corresponding reduction after a suitable time period.

Power order step responses

With the converter system in power control and the order set at 0,15 pu, 0,5 pu or 1,0 pu apply a step down in order of 0,05 pu followed by a corresponding increase after a suitable period.

NOTE Other control loops, for example, constant DC voltage, may be tested similarly to the above, the general principle being that step changes shall be small enough that converter firing angles do not reach limits.

Test Acceptance Criteria

All controller settings should be adjusted such that the response and recovery times as specified or as defined by system studies are achieved.

No instability should be apparent in the step response tests and the responses shall be well damped without significant overshoot.

2.2.2 Control Mode Transfer

General

The most common transfers between control modes are:

- at the rectifier, from constant power control mode to constant current order mode and back;
- at the inverter, from constant extinction angle control mode to constant current control mode and back;
- at the rectifier, from normal alpha control mode to minimum alpha mode.

Additional control modes may be used:

- at the inverter, constant DC voltage control may be used for weak AC system applications;
- for both rectifier and inverter, control of AC system voltage may be used during temporary load rejection conditions.

The corresponding site tests are described in 6.2.2 of the operation and integration tests.

Test Objectives

Control mode transfer tests are performed to verify that the change from one control mode to another can be achieved without adverse interaction.

Test Procedure

The transfer from constant power control to constant current control and back can be done manually. The change from inverter constant extinction angle control to constant current control may be activated automatically by reducing the rectifier AC system voltage thus forcing the rectifier to minimum alpha operation. To demonstrate return to the inverter constant extinction angle control mode the rectifier AC system voltage should be increased. Similarly a change from inverter constant DC voltage control to constant current control can be activated automatically.

To activate the AC system voltage control either the "remote" converter should be temporarily blocked, or a three phase solid short-circuit should be applied to its AC busbars.

Test Acceptance Criteria

Control mode transfers should occur without inducing adverse interaction.

Step changes in power shall not occur during transfer from constant power control to constant current control.

Transfer from constant extinction angle control or constant DC voltage control to constant current control at the inverter must be stable.

Activation of the AC system voltage control should occur during temporary DC system shutdown.

2.2.3 AC System Interaction/Control

General

The flexibility of the controls of HVDC systems enables them to be used to enhance the performance of the associated AC systems. Examples of such features are:

- control of AC system frequency;
- modulation of transmitted power to assist in fault recovery;
- limitation of overvoltage during load rejection on the DC system;
- limitation of reactive power demand from the AC systems during load changes;
- AC system voltage control.

The corresponding site tests are described in 6.2.3 of the operation and integration tests.

Test Objectives

To check the performance of specific control functions which may be requirements of the Contract Specification.

Test Procedure

Power/Current Control Modulation

For AC system damping acquire an appropriate level of signal and frequency and inject this into the modulation control loop and confirm that the response varies in compliance with system studies. Inject an appropriate level of signal into the frequency control loop and confirm that the response varies in compliance with the specified requirements. Alternatively a frequency change may be induced by tripping a generator.

Limitations of AC System Overvoltage

With the maximum rating of reactive power elements connected, and at the maximum power transfer level block the inverter for a defined duration and check that the dynamic voltage is limited to the design level. Repeat by blocking the rectifier under the same operating conditions.

Control of Reactive Power Exchange with the AC Systems

Confirm that the reactive power elements are switched in or out, at the prescribed power transmission levels, as the power order is increased to its maximum value and then reduced to its minimum value. Check that the control angles at the rectifier and inverter remain within the defined bands during the power changes.

Test Acceptance Criteria

For all the above tests the performance should conform with the system studies and the design parameters.

No adverse interactions should occur

2.2.4 Commutation Failures and Valve Misfires

General

Because of the interaction of the DC system with both of the AC systems to which it is connected, various forms of valve faults should be applied to demonstrate either the adequacy of the recovery performance of the DC system after fault clearance, or that the correct protective actions leading to shutdown of part or all of the DC system are correctly performed.

The corresponding site tests are described in 6.2.4 of the operations and integration tests.

Test Objectives

To simulate commutation failure of a converter valve, the recovery procedure and performance.

To simulate misfiring of a converter valve and the operation of any specialized protection if this is applied.

Test Procedure

Some extra monitoring may be applied:

- timing signals allowing synchronization between recordings;
- one valve voltage on each converter group;
- crucial protection signals.

Commutation Failure

Valve commutation failure (which is most likely to occur at an inverter) can be simulated by blocking the start pulse at one valve. The duration of blocking the start pulse should be such that a single commutation failure occurs, then for a duration sufficient to activate valve overload protection (i.e. voltage dependent current limit), and finally for a duration sufficient to activate the persistent commutation failure protection.

Valve Misfire

Valve misfire at a rectifier can be simulated by blocking the start pulse to one valve. The duration should be sufficient to ensure that specialized protection, e.g. asymmetry protection or excessive harmonic protection, will operate.

Test Acceptance Criteria

The acceptance criteria are:

- for valve commutation failures the corrective action by the control or protective systems should be initiated and be successful over the entire range of power transfer. Operation of the line fault detection should not occur.
- for valve misfire the correct protective shutdown should occur.

2.2.5 AC Filter, Transformer and Reactive Element Switching

General

The corresponding site tests are described in 6.3 of the operation and integration tests.

Test Objectives

To confirm that switching of such elements will not have any adverse effect on the operation of the DC system, that AC system voltage disturbances are within the prescribed limits and that if resonances occur they are adequately damped. Proper recovery from commutation failure, if any, should be verified.

Test Procedure

The short circuit ratios of the AC systems should be at the specified minimum values or for resonant investigations at an appropriate value.

Additional recordings may be made of transformer primary current, and AC filter, shunt capacitor and shunt reactor currents during the appropriate parts of the test sequence.

If the system is bipolar then the transformer switching tests can be carried out in monopolar configuration using one of the transformers from the second pole. For a monopolar scheme a representation of a relevant system transformer of suitable rating should be used.

!f the scheme has two or more converter groups per pole then switching of one transformer with the remaining groups in service is possible provided the scheme filters are designed for this mode of operation.

Switching on and off each type of filter should be done in turn with the converter equipment energized.

If capacitor banks or shunt reactors form part of the overall scheme then switching of these elements singly or in appropriate combinations should be done with the converters energized.

The switching tests should be repeated for both rectifier and inverter terminals and with reversed power flow, if appropriate.

Test Acceptance Criteria

In all switching tests the HVDC system should continue in stable operation. The AC system voltage disturbances should be within the specified limits.

During a switching operation commutation failure may occur but should be limited to only one event

2.2.6 AC and DC System Faults

General

Because of the interaction of the DC system with both of the AC systems to which it is connected, various forms of AC and DC faults should be applied to demonstrate either the adequacy of the recovery performance of the DC system after fault clearance, or that the correct protective actions leading to shutdown of part of all of the DC system are correctly performed.

Local AC system faults, which give 100 % voltage reduction in one phase, or all 3 phases, and remote AC system faults which give, say, 30 % voltage reduction in one phase, or all 3 phases, should be applied, each being applied for the specified fault duration.

Due to current inrush conditions during recovery period the voltages may be severely distorted, but this should not affect the correct performance of the control and protection systems.

During some AC system faults commutation failure of the converter system is inevitable, but this condition must be of limited duration and must not adversely affect the recovery performance of the complete system.

For DC line faults the normal clearance procedure is to suppress the DC voltage by means of converter control action, with a preset time to allow deionization at the fault and then reapply the DC voltage.

If the fault is not cleared, a preset number of such sequences can be repeated including (if applicable) a restart at reduced voltage before permanent shutdown is applied. For DC cable faults it is assumed that such faults are permanent and shutdown of the affected cable is immediate.

The corresponding site tests are described in 6-5 of the operation and integration tests.

Test Objectives

To apply single-phase and three-phase faults to either AC system, in locations close to or distant from the converter terminals, in order to demonstrate the performance of the converter system during the faults and the recovery performance subsequent to the faults.

To apply DC line (or cable) faults at different locations to demonstrate the protective actions taken by the converter controls are correct.

To apply simulated faults at different points within the DC terminals and demonstrate correct protective action and shutdown.

To verify that the correct protection co-ordination was achieved.

To check that the pole loss compensation system (if applicable) operates correctly.

Test Procedure

Some extra monitoring may be applied:

- timing signals allowing synchronization between recordings;
- one valve voltage on each converter group;
- crucial protection signals.

AC System Faults

The sequence of faults should be as follows.

- 1-phase busbar fault at the rectifier, repeated at 0,1 pu and 1,0 pu load;
- remote 1-phase fault at the rectifier, repeated at 0,1 pu and 1,0 pu load;
- local 3-phase fault at the rectifier, repeated at 0,1 pu and 1,0 pu load;
- distant 3-phase fault at the rectifier, repeated at 0,1 pu and 1,0 pu load;
- repeat of the above 1- and 3-phase faults applied at the inverter AC system;
- repeat of the above 1- and 3-phase faults at specified locations within either of the AC systems if there are locations of special interest;
- repeat all of the above tests if the system has reversed power flow;
- repeat some of the tests with a different fault duration and with the specified power overload.

DC System Faults

The sequence of faults should be as follows.

- temporary fault application to the DC line at a point adjacent to the rectifier terminal, at the mid-point of the line and at a point adjacent to the inverter terminal. For cable connections permanent faults should be applied at these three locations;
- apply permanent faults to demonstrate bushing flashovers of say DC reactor, HVDC wall bushing or transformer valve winding bushing of the star and delta windings;
- apply a short circuit between phases on the valve side of the converter transformer,
- verify that back-up protection operates correctly if the primary protection is disabled.

Test Acceptance Criteria

AC System Faults

The acceptance criteria are:

- the DC system shall remain stable during and after clearing of the fault;
- the time for DC power recovery shall within the specified limits;
- no spurious operation of protection relays should occur;
- transient AC and DC voltages should be contained within the specified levels;
- permanent faults should result in correct shutdown of the remote station without the use of telecommunication signals;
- inverter AC system faults should not cause inadvertent operation of the DC line protection.

DC System Faults

The acceptance criteria are:

- For DC line faults the correct fault clearance sequence should occur and operation of protection on the converter side of the DC line reactors or the line protection in the unfaulted pole should not occur.
- For DC cable faults safe protective shutdown should occur.
- For bushing flashovers within the converter terminals the correct protective shutdown should occur at both stations with and without telecommunication.
- For transformer valve winding faults the correct protective shutdown should occur.
- The pole loss compensation scheme operates correctly.

2.2.7 Islanding

General

The term Islanding can cover several operating conditions associated with HVDC systems. Two examples of islanding are:

- isolation of the inverter terminal of the HVDC system due to switching out of a single AC transmission line which connects the HVDC system to the main AC system;
- loss of the main AC system leaving one or more rotating machines connected to either terminal of the HVDC system.

In the first example power transmission would continue in the HVDC until the problem was identified and corrected and would result in severe overvoltage on the AC filters, other components used for reactive compensation, the converter transformers and valves at the inverter terminal, if no protective action was taken.

In the second example, loss of the main system would result in the remaining machines being unsynchronized. Depending on whether the main system had been supplying power to or absorbing power from the HVDC system the remaining machines could quickly reduce or increase speed unless the HVDC system had suitable controls to prevent such changes in frequency.

Test Objectives

To demonstrate the effective action of the protection or control action of the HVDC system when some form of Islanding occurs.

Test Procedure

In the first example given above, the HVDC system should be run at minimum power transfer with the AC system at minimum short circuit capacity and the AC circuit breaker at the remote end of the single AC transmission line, which is connected to the inverter terminal, should be opened.

The action of the HVDC system will depend on whether or not auto-reclose of the AC circuit breaker is applicable. If auto-reclose of the breaker is applicable, the protection of the HVDC system should detect that the breaker has opened and initiate action in the HVDC system controls to avoid any excessive overvoltage. The HVDC system should then be held in readiness for power restoration following reclosure of the breaker, if auto-reclose is not applicable then the HVDC system protection should initiate action in the HVDC system controls to avoid excessive overvoltage and then safely shut down the HVDC system. The test should be repeated at other levels of power transfer.

In the second example the HVDC system should be run at a power level consistent with the rating of the connected AC machines, at the appropriate converter terminal, plus low power being supplied by the connected main AC system. The breaker connecting the main AC system should be opened. The HVDC system controls should operate to regulate the frequency of the machines to the prescribed value. The test should be repeated with higher levels of power being supplied by the main AC system and then with power being absorbed by the main AC system.

Test Acceptance Criteria

Depending upon the type of islanding applicable to the HVDC system, protection and/or control action shall be taken by the HVDC system to ensure, if it is appropriate to the application, that overcurrent or overvoltage damage, or significant frequency deviation of the connected AC machines do not occur.

2.3 Functional Performance Test Introduction

As discussed in the general introduction for the functional performance test the complete control system including telecommunication interface will be tested against some form of simulation of the HVDC system including the DC switchgear and the AC switchgear. The appropriate telecommunication time delays shall be simulated.

General

The control system hardware and software shall be the actual and complete deliverables.

The simulation can be by a real time simulator, software modules or a combination of both.

Test Objectives

1. To check that all individual control cubicles function properly.
2. To check that all control cubicles interact properly.
3. To check that all interfaces between the control cubicles and all other equipment are correct.
4. To check that all transfers to redundant controls are smooth and do not affect the operation of the on-line equipment.
5. To verify that power supplies with redundant elements do not affect controls or protection operation in case one element is shut down.
6. To verify that failed elements can be removed and replaced without affecting the operation of the on-line equipment.

7. Where redundancy is applied it shall be verified that:

   - single contingency failures do not cause a shutdown;
   - failure of one element of a redundant system initiates changeover to the standby element;
   - failure of all redundant elements should result in safe shutdown.

Preconditions

1, The simulator must represent the defined HVDC system, the DC switchgear and the AC switchgear and be operational.

2. The control equipment to be tested must have passed the factory routine test and must be available for operation at the test site.

3. The test arrangement shall be defined and agreed upon between the user and the manufacturer.

4, A test plan shall be mutually agreed upon between the user and the manufacturer before commencement of tests.

5. Metering and recording equipment shall be available and connected to the test.

6, The deliverables for the control system including cubicle interconnections shall be installed and connected to the simulator.

7. The steady state performance defined in 2.1 shall have been demonstrated.

Test Procedure

Each cubicle and the operators interface shall first be commissioned separately and then be connected with each other.

The function listed below should be tested for normal operating conditions. It will also be necessary to test some of these functions in contingency operation conditions. Normal operation applies to undisturbed operation of the HVDC System. Contingency operation exists if a single failure occurs fn the HVDC-System but the System can continue operation within specified limits or a disturbance occurs in either AC-System which requires a specified action in the HVDC System.

In order to create contingency operating conditions malfunctions shall be deliberately simulated at the simulator. Typical functions are:

- change of HVDC system configuration;
- change status of operation;
- change energy transfer level and energy direction;
- change preselections;
- steady state converter control;
- switching of reactive power compensation elements;
- loss of redundancy and power supplies for the Controls and Protection;
- apply various invalid inputs to the control system and check that invalid signals are alarmed to the operator;
- runback functions;
- power modulation;
- loss of end-to-end telecommunication;
- change of control location.

Test Acceptance Criteria

- all functions of the control system must work properly. Initiated signals must follow the designated signal path, generate the appropriate command and create the checkback signal to indicate the execution of the correct action on the operators interface.

- loss of a redundant element for control or protection should not affect the DC system operation.
- loss of a redundant element of the power supplies should not affect the DC system operation;
- for loss of both elements of a power supply system with redundancy the DC system should shut down safely;
- normal transitions between redundant elements for control or protection should not disturb the AC systems. Non-allowable combinations should either be impossible or result in safe shutdown of the DC system;
- failure of a single input measurement, where measurements are redundant, should not result in disturbance to the AC or DC systems;
- failure of an unduplicated measurement, or both duplicated measurements, should result in safe shutdown of the DC system.

2.4 Type Tests on the Control and Protection Equipments

Introduction

Some of the type tests, if specifically required for the contract, may be carried out on the control and protection equipment, together with communication interfaces. These tests would demonstrate the equipment performance over the specified environmental conditions together with specified variation of the auxiliary supply voltage. In addition the immunity of each equipment to electromagnetic and electrostatic disturbances may be demonstrated.

Since these tests are carried out with the control and protection equipment in an operational state it may be convenient to carry out these type tests white the equipment is connected to the HVDC simulator, though alternative methods would be equally acceptable.

Test Objective

To demonstrate that the control performance is not affected by operation at various environmental conditions and within the prescribed operating range of the power supply.

To demonstrate that the protection settings and timings are not affected by operation at temperatures and within the prescribed operating range of the power supply.

To demonstrate that the specified levels of electromagnetic and electrostatic disturbances do not cause misoperation of control and protection equipments-

To demonstrate that hand held communication equipment does not cause misoperation of control and protection equipment.

Test Procedure

The following procedure covers type testing with respect to Control Cubicles:

- temperature;
- power supply variations;
- electromagnetic and electrostatic disturbance;
- hand held communication equipment.

Enclose the cubicle to be tested within a thermally insulated housing with a heat source.

Operate the HVDC system at 1,0 pu load.

With the cubicle temperature initially at room ambient:

- Check that the DC voltage and current measurements are stable during all control modes;
- Check the accuracy of all the control loops by comparing their respective settings with their responses;
- Check the transient response by applying step changes in current order.
- Vary the voltage (and frequency if appropriate) of the power supply to the

control equipment, to the specified maximum and minimum levels and at each voltage level recheck the steady state and transient performance and compare results;

- Raise the temperature within the housing to the highest specified ambient temperature, preferably for several hours;
- Recheck the steady state accuracy and transient performance and compare results;
- Vary the voltage (and frequency if appropriate) of the power supply to the control equipment to the specified maximum and minimum levels and at each voltage level recheck the steady state accuracy and transient performance and compare results;
- Reduce the temperature within the housing to nominal ambient;
- Recheck the steady state and transient performance and compare results.

With the DC system operating at 1,0 pu load, subject the control equipment to the appropriate electromagnetic and electrostatic interference, and demonstrate that there is no disturbance to the operation of the DC system.

Protection Cubicles

Enclose the protection cubicle to be tested within a thermally insulated housing with a heat source.

With the cubicle temperature at room ambient:

- Check in turn each protection operation for setting and timing;
- Vary the voltage (and frequency if appropriate) of the power supply to the protection cubicle to the specified maximum and minimum levels and at each voltage level recheck in turn each protection operation for setting and timing;.
- Raise the temperature within the housing to the highest specified ambient temperature, preferably for several hours.
- Recheck in turn each protection operation for setting and timing.
- Vary the voltage (and frequency if appropriate) of the power supply to the protection cubicle to the specified maximum and minimum levels and at each voltage level recheck in turn each protection operation for setting and timing;

- Compare the results with the previous study;
- Lower the temperature to normal ambient and recheck in turn each protection operation for setting and timing.

With the DC system operating at 1,0 pu load, subject the protection equipment to the appropriate electromagnetic and electrostatic interference and demonstrate that misoperation of the protection does not occur.

Test Acceptance Criteria

The steady state accuracy and transient performance results for all the tests shall be within the design tolerances.

The setting and timing results for each protection shall be within the design tolerances.

PART 3: CONVERTER TESTS

General

Introduction

This part describes the testing of each converter station as a unit and the verification of the HVDC transmission line prior to transmitting power. This group of tests precedes the end-to-end testing. The following tests are outlined:

3.1 Converter unit tests

- HV energization of converter transformer

3.2 Converter station tests

- HV energization of AC-filters and shunt banks
- Open line test (HV energization) of the DC switchyard
- Load tests: Back-to-Back testing
  Short circuit testing (optional)

3.3 Open line test of the DC transmission circuit

During the test program, conformance with environmental specifications should be included where applicable. Preliminary observations of audible noise, radio and PLC interference levels may be done. This is described in Part 5 of the guide. Temperature rise of major equipment can be monitored. However, the actual measurement of the above mentioned quantities are conducted during end-to-end operation.

Test of Back-to-Back stations is covered in part 4 of this guide whereas back-to-back testing referred to in section 3.2 is accomplished by a temporary connection between the converters of a bipolar long distance HVDC station.

Statement of Purpose

The purpose of the Converter Tests is to verify the correct operation of an individual converter station and the proper insulation of all main circuit equipment before starting the end-to-end testing.

General Test Objectives

The converter tests may be divided into high voltage energization and load tests. The test objective of the HV energization is to verify that proper voltage insulation is achieved in the AC and DC main circuit equipment.

Load tests (back-to-back or short circuit tests) may be conducted to get a provisional verification of the control system, the valve cooling capability and the main circuit with respect to temperature rise, audible noise and radio interference. Final verification will be made during end-to-end testing.

General Preconditions

Before beginning the Converter tests, the following equipment must be verified off voltage and be available:

- AC switchgear;
- AC filters, capacitor banks and shunt reactors;
- DC filters and switchgear;
- Converter transformers;
- Thyristor valves and cooling system;
- Station auxiliary service;
- Fire protection system;
- AC and DC protection systems;
- Control system;
- DC line or cable (for open line test);
- Sequency of event ;
- Recorder and Alarm System;
- Transient Fault Recorders.

In order to verify the converter firing control, the valve base electronics and the valve main circuit connections, prior to HV energization, it is recommended to conduct a low voltage energization test. The test may be performed by applying 0.5 - 10 kV to the primary side or to the valve side of the converter transformers with all but a few thyristors short-circuited in each valve position. An appropriate resistor may serve as a load on the DC-side.

Prior to the converter tests detailed procedures and plans should be prepared. As the tests may involve some disturbance or increased risk to the connected AC systems, the operators of the systems should be consulted.

3.1 Converter Unit Tests Introduction

This test is the HV energization of the converter transformer with blocked valves and is performed on each individual converter unit in a HVDC station.

Test Objectives

The test objective is to verify that insulation voltage withstand is achieved and to check that the electrical phasing is correct.

Preconditions

Before conducting the HV energization the following preconditions shall be fulfilled.

- All controls and protections associated with the high voltage equipment shall be verified and in service. A trip test shall be made shortly before high voltage energization.
- Monitoring instrumentation shall be connected and ready.
- All clamp joints shall have been tightened and the insulators wiped clean.
- The HVDC transmission line disconnect switch shall be opened and locked.
- All safety procedures shall have been carried out.
- A final visual inspection of the high voltage equipment shall be performed and the arrester counter numbers shall be recorded.
- The low voltage side of the valves shall be grounded.

Test Procedures

During the test, AC voltage, steady-state and inrush-currents may be recorded. Inspect the equipment during the test for abnormal sounds and corona discharge. The following test sequence is recommended:

- Energize the converter transformer with the valves blocked and check the electrical phasing through the control system.
- The converter transformer tap changers should initially be at highest position (lowest valve side voltage) and then stepped to rated voltage.
- Keep the transformer energized for a minimum of 24 hours.

Test Acceptance Criteria

No abnormal sounds or corona discharge shall occur in the energized equipment. No protections shall operate improperly.

3.2 Converter Station Tests Introduction

This group of tests includes HV energization of AC fillers, capacitor banks and shunt reactors, open line test of the DC switchyard and load tests of the converter station and back-to-back or short circuit test. If there are multiple groups in each pole, they should be initially energized individually and then together.

3.2.1 HV Energization of AC filters, Capacitor Banks and Shunt Reactors Introduction

This section deals with the first energization of AC filters, capacitor banks and shunt reactors individually for the first time. Combined switching of these elements is dealt with in 6.3.

Test Objectives

The test objective of the HV energization is to verify that proper voltage insulation is achieved and that the AC filters, capacitor banks and shunt reactors are balanced between the three phases and each phase for itself. Confirmation of the onload currents and voltages of the protections may be conducted at this time.

Preconditions

Before conducting the HV energization the following preconditions shall be fulfilled.

- All controls and protections (main and backup) associated with the high voltage equipment shall be verified and in service. A trip test shall be made shortly before high voltage energization.
- AC filter tuning shall be completed.
- AC filters and shunt capacitors shall have been balanced.
- All clamp joints shall have been tightened and the insulators wiped clean.
- All safety procedures shall have been carried out

- A final visual inspection of the high voltage equipment shall be performed, and the arrester counter numbers shall be recorded.

Test Procedure

During the test, AC voltage, steady-state and inrush-currents may be recorded. Inspect the equipment during the test for abnormal sounds, corona discharge or partial discharge arcing. The following test sequence is recommended.

- Energize the AC filters, capacitor banks and shunt reactors one by one.
- Keep each AC filter, capacitor bank and shunt reactor energized for a minimum of 2 hours.

Test Acceptance Criteria

No abnormal sounds or corona discharge arcing shall occur in the energized equipment. No protections shall operate improperly. The AC filters and capacitor banks shall be balanced within design tolerances.

3.2.2 Open Line Test of the DC Switchyard Test Objectives

The test objective of the open line test of the DC switchyard is to verify that proper insulation voltage withstand is achieved. This open line test will also show that the converter firing control and the valve base electronics function properly.

Preconditions

Before conducting the open line test the following preconditions must be fulfilled:

- The converter transformers shall have been energized,
- All controls and protections associated with the converter transformers and the DC switchyard including the DC voltage dividers shall be verified and in service. A trip test shall be made shortly before high voltage energization. Preferably a low voltage energization shall have been performed.

- Monitoring instrumentation shall be connected and ready.
- All clamp joints shall have been tightened and the insulators wiped clean.
- The HVDC transmission fine disconnect switch shall be opened and locked.
- All safety procedures shall have been carried out.
- A final visual inspection of the DC switchyard shall be performed and the arrester counter numbers shall be recorded.
- DC filter tuning shall be completed.

Test Procedures

During the test, AC and DC voltage and current shall be recorded. Inspect the equipment during the test for abnormal sounds, corona discharge or partial discharge arcing. The following test sequence is recommended:

- Connect the neutral side of the converter to ground or the electrode (if available).
- Energize the converter transformer at the lowest valve side voltage and step the tap changers to rated voltage,
- Deblock the converter in the open line test status of operation and ramp the DC voltage slowly to rated value.
- Keep the DC equipment energized for a minimum of 2 h.
- After the successful completion of the test, decrease the DC voltage to zero and block the converter.
- Repeat the open line test of the DC switchyard with the appropriate DC filters connected one by one and then together.
- If there are multiple valve groups in each pole they should be initially energized individually and then together.

Test Acceptance Criteria

No abnormal sounds or corona discharge shall occur in the energized equipment. No protections shall operate improperly.

Confirm that the designed DC voltage can be achieved.

3.2.3 Load Tests

3.2.3. 1 Back-to-Back Test

Introduction

For bipolar HVDC systems back-to-back testing may be considered since this provides the least disturbance to the connected AC system. Back-to-back testing is accomplished by operating a bipolar terminal with one converter as rectifier and the other as inverter. The connection between the converters may be within the station or may include part or all of the DC transmission circuit. In the latter case it is recommended to conduct an open tine test of the transmission circuit, as described in 3.3, prior to the test. Back-to-back testing gives an effective general check of converter operation up to the specified maximum load and is preferably conducted at all converter terminate.

It shall be noted that the telecommunication system is not required for these tests. Adjustments to the control system may be necessary.

Test Objectives

The test objective of the back-to-back test is to get a provisional verification of the control system, the valve cooling capability and the main circuit with respect to temperature rise.

The back-to-back tests do not reduce the end-to-end test requirements. The tests should permit troubleshooting at the individual terminals to provide for a more efficient end-to-end test procedure. Current control, power control and reactive power control checkout may be performed with each converter pole operating both as rectifier and inverter.

Preconditions

Before beginning the tests, the following preconditions must be fulfilled:

- The energization tests of the AC filters, capacitor banks and shunt reactors shall have been successfully completed.

- The converter transformers, the valves (and the DC switchyard filters if available) and switchgear shall have been energized.
- A temporary connection between the converter or a part of the DC transmission circuit is required.
- The DC-reactor shall be included in series with the converter units.
- Some control parameters may have to be temporarily adjusted for back-to-back testing if appropriate.
- All safety procedures shall have been carried out.

Consideration must be given to a possible trip of the converters during testing. If a trip occurs, a protection scheme shall ensure that the station AC bus is adequately protected by limiting the level and duration of the voltage rise to acceptable values. This may be achieved by putting a limit on maximum allowable direct current. For AC systems with low short circuit ratio (refer to CIGRE Planning Guide for weak AC-systems, Publication Number ..,) it is recommended to install a tripping arrangement (if not already included) that removes all filters should a converter block.

Test Procedure

The two converters must be temporarily interconnected. The interconnection must be adequate for maximum test current. The reactive power should vary with direct current similarity to expected values during end-to-end operation. The harmonic AC filters and shunt banks shall be utilized to reduce maximum variation of reactive power exchange with the AC network. Tests and measurements should be made to verify:

- Deblocking and blocking of converters.
- Ramping up to maximum test current including check of current measuring circuits.
- Proper functioning of current control, power control, automatic tap changer control and reactive power control.
- The measured quantities for the AC-filters protection and for the transformer protection. Make adjustments if necessary.
- Acceptable equipment temperatures and absence of hot spots.

- Steady state and transient properties of the cooling system of the valves are correct.
- Switching sequences in the auxiliary power system are correct and these should be done initially at low DC-current levels.
- Correct operation of redundancy arrangements, for instance by simulation of faults in units or functions, where redundancy is built into the equipment

During back-to-back operation, even though the rectifier angle is kept close to nominal, the angle may vary with different levels of direct currents and thus vary the phase angle between the harmonics from the rectifier and the inverter. At some point of operation some harmonics may be in phase opposition to each other, which will result in the filter current being very small. This should be kept in mind during the observation of loading of the AC filters.

Test Acceptance Criteria

Demonstration of proper converter operation.

Equipment temperatures shall be within specified limits. No hot spots may exist.

Initial assessment of the cooling capability of the thyristor valves, transformers, reactors, building and valve hall shall demonstrate no abnormalities.

No protection shall operate improperly.

3.2.3.2 Short Circuit Test Introduction

The short circuit test may be conducted on a monopolar DC system or in cases where schedules or constraints do not allow both converters of a bipolar station to be used for back-to-back testing.

Test Objective

To provide minimal verification of the control system before end-to-end testing.

Preconditions

The preconditions for the short circuit test are the same as for the back-to-back test, described in sections 3.2.3.1. The DC smoothing reactor must be included in series with the converter unit when creating the short circuit.

The DC circuit must be operated short circuited with alpha at approximately 90 degree (U_d = 0) during this test. The large delay angle results in much higher than normal losses in the valve circuits. As a precaution it is recommended to limit the duration of the test and to have adequate cool down time between tests.

Control and protection systems that would have operated as a result of the conditions during the test must be disabled in a safe manner.

Test Procedure

The test should be made with the converter transformer tap changer in highest position (lowest valve side voltage). Tests may be made to verify:

- Deblocking and blocking;
- Current control stability;
- Response to a step change.

Test Acceptance Criteria

Demonstration of response and stability of the current control system.

3.3 Open Line Test of the DC Transmission Circuit Introduction

Open line test of the DC transmission circuit can be performed from either end of the HVDC system but one at a time, it is normally done from the converter that becomes first available but preferably from the terminal with the highest operating voltage. The open line test is an excellent test to demonstrate the condition of the HVDC line and cables. Both short-circuit and open line conditions can be detected over the entire length of the circuit.

The open line test is mainly conducted to verify the insulation of the DC transmission circuit prior to transmitting power. The test is not only important for the initial start up of the System but may also be used for test purposes following a permanent fault on the system before returning to commercial operation.

Test Objectives

The test objective is to verify that the HVDC transmission circuit is not opened or grounded anywhere over its entire length. The open line test should also verify that proper voltage insulation of the DC transmission circuit is achieved.

Preconditions

Before conducting the open line lest the following preconditions shall be fulfilled.

- The DC switchyard shall have been successfully energized.
- All control and protection systems shall have been verified and be operational.
- The DC transmission circuit shall be available.
- Check that the other terminal is isolated.
- Voice communication system shall be in service.
- All safety procedures shall have been carried out.
- The neutral side of the converter shall be connected to the earth electrode and the high voltage side to the line or cable.

Test Procedures

During the test AC and DC voltage and current shall be recorded. Inspect the switchyard equipment during the test for abnormal sounds or corona discharge. The following test sequence is recommended.

- Apply a ground to the remote end of the DC line or cable,
- Energize the converter transformer and step the tap changers to rated voltage.
- Deblock the converter in open line test status of operation and try to ramp the DC voltage. If this is possible, the DC transmission circuit is opened somewhere.
- Block the converter, deenergize the converter transformer and remove the grounding at the remote end.
- Energize the converter transformer and step the tap changer to rated voltage.
- Deblock the converter in open line test status of operation and slowly ramp the DC voltage up to the desired level. Make sure that the DC voltage level does not exceed the voltage insulation level at the other end.
- After the successful completion of the test, decrease the DC voltage to zero and block the converter.
- Repeat the test for each line or cable and each polarity, if applicable.
- Keep the DC transmission circuit energized for a minimum of 2 h.

Test Acceptance Criteria

No protections shall operate improperly.

The DC voltage shall build up when the fine ground connection at the remote end is removed.

PART 4: END-TO-END-TESTS

General

Introduction

The end-to-end tests constitute a basic set of verifications at low power that are to be conducted when the converter terminals are connected for the first time by the DC transmission circuit

Since power will be transmitted, tests must be arranged to limit the potential impact to the HVDC system equipment and to the interconnected AC systems.

It will be necessary to perform end-to-end tests in all applicable HVDC system configurations. The general test procedure is shown in the flow chart of Figure 4.1.

It is necessary that some verifications are done off voltage or "dry" prior to testing at any power level. In particular the transfer between different DC system configurations and the verification of protective tripping sequences should be done "dry", before tests at minimum power transfer level can start.

The HVDC system may be operated in the following different configurations:

- Monopolar Earth Return;
- Monopolar Metallic Return;
- Bipolar Operation;
- Integration of Parallel or Series Converters.

The following tests are outlined:

4.1 Changing the DC system configurations, off voltage.

4.2 Start and stop sequences and Steady State Operation at minimum power.

4.3 Protective Blocking and Tripping Sequences.

4.4 Power and current ramping.

4.5 Reduced Voltage Operation.

If no back-to-back test has been performed, verification of the performance of the valve cooling system must be done as power is increased.

The operating conditions of the HVDC system can be:

- Normal operation. This includes synchronous and islanded operation if applicable.
- Contingency operation, which exists if a single failure occurs but the HVDC system can continue operation within specified limits. Loss of telecom represents a typical example.
- Emergency operation as per project specific definitions. This does not normally need to be tested in the actual system during commissioning. However it is advisable to test during off-site testing.

Operator control actions can be initiated from various locations. Such typical locations are:

- Local control, which applies when the control functions can be initiated from the local control room at either converter terminal.
- Remote control, which applies when the control functions can be initiated from a control centre remote from either converter terminal.

The operator can accomplish a change of operational status by using one of two different control methods:

- Automatic Control
- Manual Control

In automatic control the operator initiates a change of operational status, a change of configuration or a change of power (current) reference selection and the respective controls execute the correct order. The successful completion is verified by monitoring.

In Manual, the control of the converter terminal is performed in discrete steps from one operational status to another. Compared to the automatic control mode, the operator is offered a choice of additional intermediate steps and intervention in the control sequences. Completion of any control sequence will be verified by monitoring.

The control level denotes the hierarchical level of HVDC system control. A distinction is made between:

- System control level (Joint control available).
- Station or Bipole control level (Joint or Separate control Available).
- Pole or Converter control level (Joint or Separate control available).

At the System control level the complete HVDC system can be controlled jointly from one of the remote or local operator control locations, hence telecommunication is required at this level.

At the Station (or Bipole) control levels each HVDC station/Bipole is controlled separately when telecommunication is not available. The stations can be jointly controlled from one location when telecommunication is available.

At the Pole (or Converter) control level each pole/converter is controlled separately when telecommunication is not available. The poles of the two stations can be jointly controlled from one location when telecommunication is available.

General Preconditions

The following activities must have been completed before the end-to-end tests can proceed:

- Off-site Tests.
- Converter Tests for both stations.
- Back-to-back Test or Short Circuit Tests when possible,
- Open Line Test of the DC transmission circuit.
- Electrodes and electrode lines checked and cleared.
- Telecommunication system and telephone system operational.
- The overall test procedures, safety rules, dispatch coordination and test responsibilities have been established.
- Fire protection and detection systems have been fully checked and in service.
- All Control, Protection, Metering, Sequence of Events and Fault Recording systems must be in service.

General Test Objectives

End-to-end tests are intended to verify the proper co-ordination and interstation interlocking of the basic HVDC control and protection functions at low power levels. The tests shall be performed with various AC and DC system configurations and for applicable contingencies. Changing the DC system configuration (as described in part 6) or the status of operation for the first time must be tested without high voltage (Dry Run Test or Off Voltage Test),

The tests should be organized in such a way that all the control modes, control levels and control locations will be tested without unnecessary duplication of tests.

4.1 Changing the DC System Configuration, OFF-Voltage

Introduction

Changing the DC system configuration can be relatively simple in a point to point system which has a single converter per pole. The switching operations become more complicated if the station poles have parallel or series converters. This test is intended to demonstrate that equipment, breakers, disconnects or grounding switches are operated in the correct sequence and, are properly interlocked. Changing the DC system configuration on load is described in part 6.

Transfers between different DC system configurations can be initiated automatically and jointly or manually from local control or from a remote dispatch centre. In manual or separate control, the operators need to coordinate these actions via voice communication.

Test Objectives

The purpose of the tests is to verify that the DC system configuration can be safely changed as specified prior to transmitting power for the first time.

Preconditions

Before conducting the test the following preconditions must be fulfilled:

- Off-site tests verifying DC system configuration change shall have been completed.
- All necessary AC and DC switching equipment shall be operational.
- Operator instructions and test procedures shall be available.

Test Procedures

The transfer between specified DC System configurations shall be demonstrated. The most logical approach is to perform the changes of configuration from the initial conditions defined below:

- Monopolar earth return.
- Monopolar metallic return.
- Bipolar operation.
- Integration of parallel or series converters.

The tests shall first be performed with telecommunication out of service, and then with telecommunication in service:

- Establish voice communication with the operator of the other terminal.
- Switch off the telecommunication.
- Reset all alarms.
- Select the initial DC system configuration in accordance with the operating instructions. The procedure will have to be done in steps involving operators at both terminals.
- Verify the appropriate switching action on the operator control interface and sequence of events recorder. Simulate failures in the Switching Sequence.
- Repeat the test for all applicable DC system configurations.
- Restore telecommunication.
- Repeat the tests, now in automatic and joint control mode.

Test Acceptance Criteria

- Switching sequences shall correctly transfer between all applicable DC system configurations, with and without telecommunication.
- All Switching sequences shall be safely and correctly completed.
- The interlocking of disconnectors, switches and breakers of the AC and DC yards shall be in accordance with the technical specifications.
- It should be possible to initiate a change of DC system configuration from local and, if available, from remote control locations.
- An incomplete sequence shall be terminated in a safe condition.

4.2 Start and Stop Sequences and Steady State Operation at Minimum Power

Introduction

Great care must be exercised when going through the start and stop sequences for the first time. The thyristor valves will be deblocked at the rectifier and inverter end and current will be established in the DC transmission circuit.

The sequences for starting and stopping the converters are not identical for all HVDC systems and can vary depending upon the design philosophies of the supplier and the system requirements of the customer. The general sequence of bringing a converter from STOPPED status to DEBLOCKED is defined below.

- The STOPPED status is generally characterized by the following conditions:
  - Converter control and protection may be energized or de-energized;
  - Valve cooling system switched off;
  - Transformer and smoothing reactor cooling systems switched off;
  - Tap changer control inhibited;
  - Converter transformer circuit breaker open;
  - DC filter disconnector can be open;
  - AC filter circuit breaker open;
  - Firing pulses to the converter blocked.
- The STAND-BY (or DE-ENERGIZED) status is generally characterized by the following conditions:
  - Converter Control and protection must be energized;
  - Valve cooling system switched on;
  - Transformer and smoothing reactor cooling systems switched on;
  - Power or current control setpoint selection available;
  - Tap changer operational and in correct position;
  - AC filter disconnector closed, circuit breaker open;

  - DC filter disconnector closed;
  - Converter Transformer disconnector closed, circuit breaker open.
- The BLOCKED (or READY FOR OPERATION) status is generally characterized by the following conditions:
  - Converter transformer circuit breaker closed;
  - Tap changer control activated;
  - AC filter circuit breaker open or closed ;
  - Thyristor precheck completed.
- The DEBLOCKED status is generally characterized by the following conditions:
  - AC filter circuit breakers closed;
  - Valve Firing pulses deblocked;
  - Rectifier and/or inverter in operation.

Test Objectives

The general purpose of this test is to deblock both converters of the HVDC transmission system and transmit minimum power for the first time, in both directions if applicable. Other purposes are to:

- Verify for each pole, that control actions associated with each status change, start and stop sequences are executed in the right order.
- Verify, that minimum power can be established and stopped smoothly and reliably in all applicable HVDC system configurations.
- Verify correct system measurements during steady state operation at minimum power.

Preconditions

Before conducting the tests some preconditions must be fulfilled:

- The DC system configuration has been established by means of a successful off-voltage test.
- Off-site tests for start and stop sequences have been successfully completed.
- Converter tests for both stations have been successfully completed.
- Appropriate AC and DC filters are available.
- The valve cooling equipment has been verified and is operational.
- No alarm are present.
- Thyristor monitoring shows thyristor redundancy is not exceeded.
- Protective blocking and tripping sequences should have been successfully tested off voltage. All protective lockouts shall have been reset.
- Operator's instructions and test procedures shall be available.
- The connected AC systems shall be capable of delivering or accepting the transmitted power without affecting their stable operation.

Test Procedure

The start and stop test must be preceded by establishment of one of the AC and DC system configurations off voltage. The test must then be repeated for all applicable system configurations and in both synchronous and islanded operation.

- When the HVDC system configuration is established, the operational status can be tested beginning with "stopped" or "stand-by". This change of status is done off voltage. By changing the operational status for both ends to "blocked", voltage will be applied to the converters.
- Establish voice communication between the operators at each end and put telecommunication out of service.
- Establish operation at minimum power by first deblocking the inverter and then the rectifier.
- Remain at minimum power for a short period. Then block the rectifier and the inverter.
- Restore telecommunication.

- Establish operation at minimum power in automatic and joint mode. Remain at minimum power for at least 1 h and verify measurements of DC currents, voltage etc. It is advisable to perform switching of redundant controls and other elements at minimum power level in order to verify that there is no impact on the HVDC transmission or the AC network.
- Special attention shall be given throughout the test to verify that no hot spots develop. The equipment inside the valve hall, the converter transformers, smoothing reactors and the wall bushings are among the critical items to check. Also verify that the valve cooling system maintains the valve temperature within specified limits.
- If applicable, transmission of power in the reverse direction shall be tested.

Test Acceptance Criteria

- Starting and stopping at minimum power must be safely and reliably accomplished in each applicable HVDC system configuration.
- All control actions shall take place in correct order and timing. Interstation interlocking shall function properly.
- No malfunction may occur.
- Equipment rating shall not be exceeded.
- No AC and DC system disturbance may occur.
- The cooling system shall keep the valve temperature within specified limits.
- Switching between redundant elements shall have no impact on the HVDC transmission.

4.3 Protective Blocking and Tripping Sequences

Introduction

HVDC systems can be exposed to various types of faults of permanent or temporary nature.

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

- Instantaneous advancing of the inverter firing angle (commutation failures);
- Transfer to redundant control (if applicable);
- Retarding the firing angle of the rectifier;
- Blocking of the converter valves blocking (with or without selection of by-pass pairs);
- AC breaker tripping (converter transformers and possibly AC filters);
- Pole isolation by opening DC switches;
- Blocking of remote station.

Protective control sequences may also be initiated as a consequence of load rejection.

Test Objectives

- Verify that proper blocking or protective tripping sequences take place selectively when clearing a fault or equipment malfunction.
- Verify that DC protective actions are properly co-ordinated with the AC breaker
  operation and other protections,
- Verify that control actions reestablish system transmission as specified.

Preconditions

- The co-ordination between the protective systems and the control systems shall have been demonstrated during off site tests.
- The AC and DC protection systems have been exercised during subsystem and converter station tests.
- All redundant control and protection systems are in service.
- All monitoring and alarm systems are in service.
- Test personnel are well informed on each protection and on the protective actions to expect.
- Telecommunication system is in service.
- The connected AC systems shall be capable of delivering or accepting the transmitted power without affecting their stable operation.
- The AC and DC equipment are energized.

Test Procedure

In order to verify the proper function of a protective blocking or tripping sequence the faults will have to be simulated.

It is advisable that testing the protective sequences begins with tests off voltage.

After successful completion of the off voltage tests, trips shall be simulated at minimum power in all applicable system configurations and with the telecommunication system in and out of operation.

The following signals shall be recorded:

- AC voltages and currents on each phase;
- DC voltages on both poles;
- AC currents in the Valve winding on each phase;
- DC currents on each pole and on each DC neutral connection;
- AC currents in filter banks;
- Main sequencing signals;

- Protection signals;
- Firing and extinction angles order and measurements;
- Current order.

During each simulated fault, test personnel must check that the correct circuit breaker trips and that the corresponding alarm and sequence of event recorder signals are initiated.

Operators must confirm that both terminals are stopped safely.

Test Acceptance Criteria

For each simulated fault, the corresponding protective blocking and tripping sequence shall operate in accordance with the technical specifications and system studies.

The consequential outages of a fault must be limited to the smallest possible zone and properly isolated from the rest of the HVDC system.

Correct alarms are announced, sequence of event recorder and transient fault recorder should show that the correct sequence has taken place.

Safe isolation of a pole and/or converter is accomplished with and without telecommunication.

The impact to the HVDC system and the connected AC systems must be within specified Performance Criteria.

4.4 Power and Current Ramping

Introduction

This test is intended to demonstrate that the HVDC system power can be smoothly ramped up from minimum power to approximately 0,3 pu. and down, in both power and current control. The test is normally conducted with telecommunication in service. However, if applicable, ramping shall also be demonstrated with telecommunication out of service.

Test Objectives

The general purpose of this test is to verily that smooth ramping at different rates can be executed for each pole and, if applicable, for the bipole. It is also to verify that:

- Transfer between operation with and without telecommunication is smooth.
- Transfer between power and current control is smooth.

Preconditions

To perform the ramping test, the following preconditions should apply:

- The HVDC system has been energized and operated at minimum rated current;
- The protective blocking and tripping sequences have been verified;
- The connected AC systems shall be capable of delivering or accepting the transmitted power without affecting their stable operation.

Test Procedure

The ramping test shall be performed in monopolar metallic and ground return configuration for each pole and then, if applicable, in bipolar operation.

If possible, ramping shall first be tested without telecommunication in service.

Having established voice communication operators deblock the converters individually and allow the HVDC system current to stabilize at its minimum rated value.

- Operate at this current level for a short time. The current can then be ramped to the next preselected level. The system is again allowed to settle. This procedure is repeated until the current has reached 0,3 pu.
- Special attention shall be given throughout the test to all current paths to verify that no hot spots develop. The equipment inside the valve hall, the converter transformers, smoothing reactors and the wall bushings are among the critical items to check. Also verity that the valve cooling system maintains the valve temperature within specified limits.
- Ramp down to minimum current and restore telecommunication.
- Repeat the above test in automatic control mode and joint control.
- Transfer to power control and repeat the test.

Test Acceptance Criteria

The following test acceptance criteria shall be fulfilled.

- Smooth ramping of the HVDC system current and power shall be possible for all applicable DC system configurations.
- AC and DC currents and voltages shall at all times be stable and remain within specified limits. Verify the control system keeps the firing angle within specified limits and that transformer tap changer control operates correctly.
- No hot spots should occur in the AC and DC yard equipment or in the valve hall.
- The valve cooling system maintains the valve temperature within specified limits. Smooth transfer between current and power control or vice versa.
- If applicable, it should also be verified that the control system schedules the necessary reactive power elements in the appropriate order to keep the AC voltage and reactive power interchange within the specified limits.

4.5 Reduced Voltage Operation

Introduction

Manual or Automatic reduction of the DC voltage may be required to reduce stresses on cables when the power transfer level is reduced, or to minimize the possibility of flashover of overhead DC lines during adverse weather conditions or conditions of excessive contamination.

Test Objectives

The purpose of the test is to verify that transfer to and from reduced voltage operation, and that steady state operation at reduced voltage can take place in a stable manner.

Preconditions

Before conducting reduced voltage tests the following preconditions must be fulfilled.

- Off-site tests with reduced voltage operation successfully completed.
- The DC transmission has been operated at nominal voltage.
- The power and current ramping tests have been completed.
- The telecommunication should be in service.

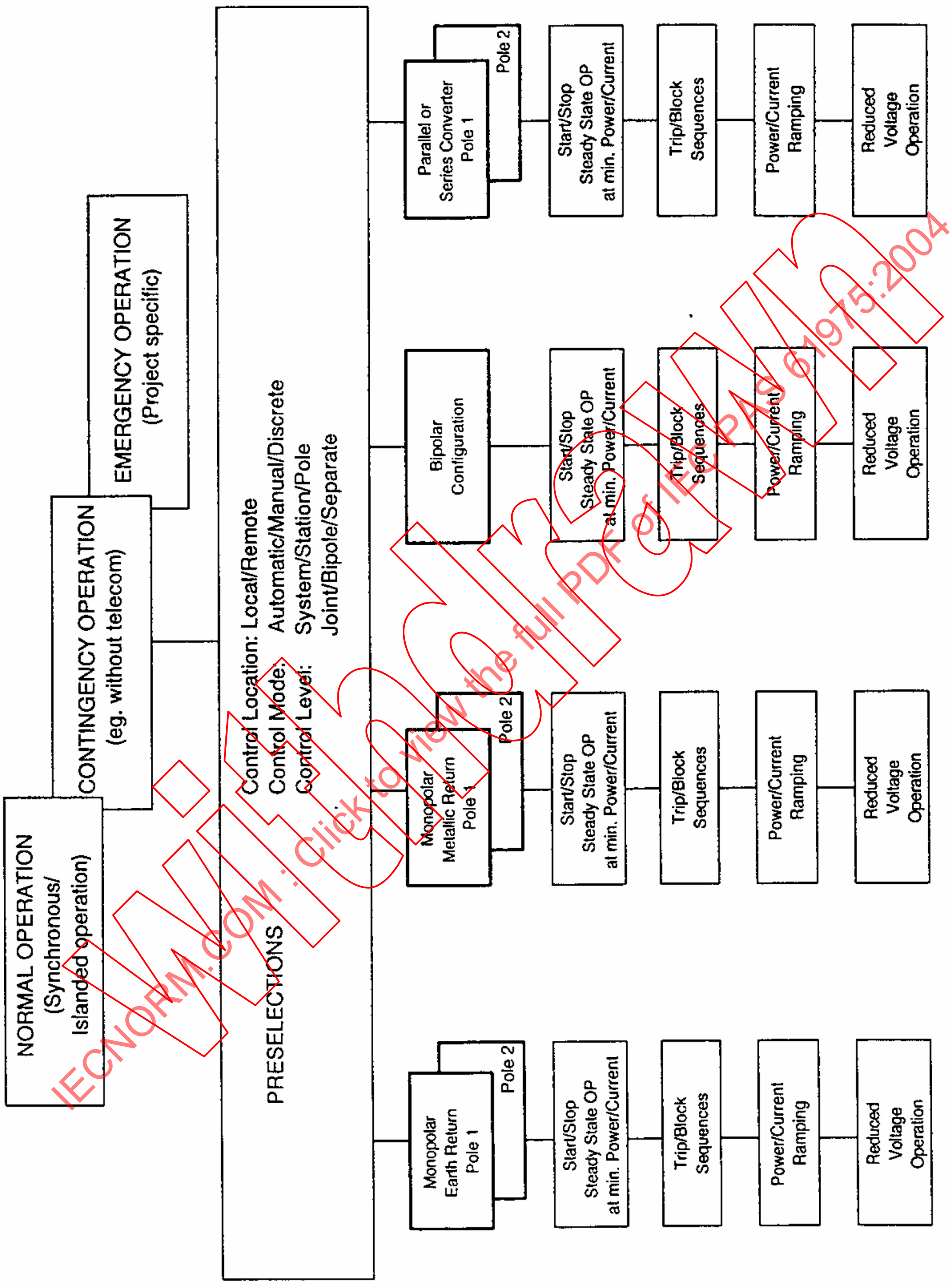


Figure 4.1 – Sequence for end-to-end tests

Test Procedure

Reduced voltage operation shall be tested in all AC and DC system configurations.

- Start the DC transmission to minimum current and nominal voltage. Transfer to reduced voltage operation and maintain steady state condition for one hour. Transfer back to nominal voltage operation. Both manual and automatic initiated transfer to reduced voltage operation (e.g. after DC line faults) should be tested.
- Repeat the test at a higher current level.
- Repeat the test in power control.
- Correct functioning of the control system and adequate performance of the valve cooling system should be observed for all current levels.

Test Acceptance Criteria

- Transfer to and from reduced voltage operation takes place smoothly and does not disturb the connected AC network.
- Steady state operation with reduced voltage is stable.

PART 5: STEADY-STATE PERFORMANCE AND INTERFERENCE TESTS

General

Introduction

In this part HVDC system steady-state performance and interference tests are described- These are system tests which seek to verify steady-state performance parameters of the HVDC system and verify that electrical and audible noise interference caused by the HVDC system are within specified limits. It is important to coordinate in advance with all parties that may be affected by operation of the HVDC system. For these steady-state and interference tests, such parties may include telephone utilities, railroad companies, pipeline companies, etc.. Steady-state performance and interference tests are normally performed prior to the operation and integration tests. Previous commissioning tests, including converter tests and end-to-end tests, have verified that the DC equipment being commissioned functions correctly. The following tests are outlined:

5.1 Harmonic performance and filter components rating

5.2 Audible noise

5.3 Overload/temperature rise

5.4 Interference

5.5 Earth electrode

General Preconditions

The following activities should have been completed before the Steady-State Performance and Interference Tests can proceed:

- Commissioning tests of ail converter units.
- Commissioning tests of transmission system as required for stable operation.
- Commissioning tests of reactive power control system.

Statement of Purpose

The purpose of the Steady-State Performance and Interference Tests is to verify stable operation of the HVDC system within the limits given by the specifications and verification of environmental considerations.

General Test Objectives

Steady-State Performance and Interference Tests are intended to verify that the AC and DC harmonic levels, audible noise/corona and interference levels conform with the specified levels. In addition, the tests verify the overload/temperature rise and earth electrode performance conform with the design targets.

5.1 Harmonic Performance and Filter Components Rating

Introduction

The power conversion process in HVDC systems results in the generation of harmonic currents and voltages which can affect the interconnected AC systems, DC network, and third party electrical systems. Factors considered in the design and harmonic studies of HVDC systems to minimize the level of harmonics propagated from the HVDC system into the AC and DC network include the following:

- AC system network impedance.
- Harmonic frequencies of concern (characteristic and uncharacteristic).
- Harmonic magnification (resonance) on the AC network.
- Valve firing angle.
- Converter transformer reactance and firing angle unbalance.
- Unbalanced impedances of AC system and harmonic filters.
- Transformer saturation effects and stray capacitance,
- AC system distortion and interference limits.
- Sensitivity of adjacent open-wire systems.
- HVDC control system instabilities and interactions with other active devices.
- Pre-existing harmonics on the AC network.
- HVDC configuration and ground resistivity.
- Ambient temperature range.
- Phase angle relationship between AC systems.
- AC and DC filter design.

AC harmonic filters connected to the AC bus reduce the harmonic voltages appearing on the interconnected AC network and the harmonic currents injected into the AC network to specified levels.

For HVDC systems with overhead transmission lines, smoothing reactors together with DC filtering circuits are typically installed in the DC circuit to reduce the harmonic currents to levels which will prevent interference with third party telephone or electrical systems.

The loading of the AC and DC harmonic filters must be checked and the filter components ratings verified.

Test Objectives

The objective of the harmonic tests is to confirm that the harmonic voltages and currents produced by the HVDC system are reduced by the AC and DC filters to conform to specified limits and verify the harmonics do not cause unacceptable interference with third party telephone or electrical systems. Additionally, the tests demonstrate that harmonic performance is acceptable when operated in various configurations and under required contingency modes.

The loading of the filter components shall be verified to be within the individual component ratings.

Preconditions

Before conducting the tests the following preconditions must be fulfilled:

- AC network conditions within specified limits.
- Study results available which estimate the levels and spectrum of harmonics from the HVDC system.
- AC and DC filter design study results available.
- Inductive coordination study results available.
- Measurements available which establish pre-existing background levels and spectrum of harmonic levels.
- Precommissioning test data available for the AC and DC filter parameters.
- Test instrumentation and data acquisition system available.
- Specialized harmonic measuring equipment available.

Test Procedures

The harmonic measurements should be performed in those HVDC system configurations and modes of operation which are specified. A test plan which identifies these configurations and modes of operation along with the physical locations for the harmonic measurements should be established, considering the following HVDC system operating conditions:

- Stand-by operation.
- Operation at minimum and rated power and at each power level which initiates switching of a filter or reactive power component, and overload HVDC power transfer levels.
- Various HVDC and AC system configurations.
- Any special condition generating maximum harmonics.
- Reduced HVDC voltage operation.
- Normal operation with specified filter configurations.
- Operation at larger-than-normal firing angles.
- Operation with filter banks or reactive power banks unavailable.
- Steady-state range of AC power frequency and voltage.
- Extremes of ambient (as far as possible).
- Automatic filter tuning.

DC harmonics testing should consider the following additional items:

- Equipment safety from induced voltage.
- Data transmission and railway signalling circuit effects.
- Voice communication circuit effects.
- Excitation of resonance conditions between the HVDC line and electrode line.
- Converter transformer DC currents in the neutral.
- Harmonic impact on minimum current operation.
- Bipolar and monopolar operation (with and without ground or metallic return).

During the harmonic measurement tests, the environmental conditions need to be noted and recorded due to the sensitivity of the harmonic filters to ambient temperature conditions or weather.

Test Acceptance Criteria

The results of the performance measurements should verify that the AC and DC harmonic voltages and currents are within the limits required and interference to third party electrical systems is within acceptable limits. Additionally, the tests should confirm that operating restrictions of the HVDC system and AC and DC filter configurations are within specified limits. The AC and DC filter components must not be overloaded.

5.2 Audible Noise

Introduction

HVDC systems emit noise in the audible-frequency spectrum. The source of the audible noise (AN) in HVDC systems is from terminal equipment and HVDC transmission lines and can be categorized as follows.

- Component generated audible noise:
  Related to converter transformers, DC smoothing reactors, shunt reactors, AC and DC harmonic filter reactors and capacitors, thyristor valves, cooling system, and auxiliary equipment. AN will vary with loading conditions and firing angle changes.

- Conductor generated audible noise:
  Related to corona phenomena on HVDC transmission lines, substation buswork, and outdoor equipment. This source of AN is associated with ionization phenomena near conductive surfaces when the electric field strength is high enough to cause a breakdown of the surrounding air. As such, corona generated AN can vary with environmental and ambient conditions due to conductive surface irregularities and contamination. AN from DC generated corona is usually higher under dry ambient conditions.

- Impact generated audible noise:
  Related to operation of equipment such as power circuit breakers, disconnect switches, etc.

AN limits within the converter station facility, including building interiors, and along the perimeter of the HVDC system are specified to ensure applicable regulations and codes of practice are met. In some cases, special noise abatement measures may be required to reduce the levels and spectrum of AN from the HVDC system.

Test Objectives

The objectives of the AN tests are to measure and verify that the AN caused by the HVDC system is within specified limits.

Preconditions

Before conducting AN tests the following preconditions must be fulfilled:

- Defined locations for pre- and post-construction measurements.
- Measurements available which establish preconstruction background levels and spectrum of AN levels.
- Study results available which estimate the levels and spectrum of AN from the HVDC system,
- Factory AN test results available of applicable equipment
- Test instrumentation and data acquisition system available.

Test Procedures

AN tests should be performed at predetermined locations in those HVDC system configurations and modes of operation specified. A test plan which identifies these configurations and physical locations for the AN measurements should be established, considering the following HVDC system operating conditions:

- Stand-by operation.
- Minimum, intermediate, rated, and applicable overload HVDC power transfer levels.
- Any special condition generating maximum AN.
- Long term measurement considerations (when required).

The presence of corona can create AN. Corona can be observed by visual inspection with the use of binoculars or located with the use of ultra sonic corona detection devices.

During the AN tests, the environmental conditions need to be noted and recorded due to the sensitivity of AN measurements to ambient conditions, such as air temperature, barometric pressure, relative humidity, wind speed and direction, and background acoustic noise.

Instrumentation and AN measurement procedures should follow the specified requirements or applicable standards.

Test Acceptance Criteria

Test criteria for AN levels resulting from HVDC systems are project specific and depend to some degree on surrounding environments. The AN levels measured with the HVDC system in operation must be within the design limits specified.

5.3 Overload/Temperature Rise

Introduction

HVDC systems may be designed and allowed to operate in an overload condition where the HVDC power transfer level is greater than the rated value. Overload operation may result in reduced performance of the HVDC system for the following reasons:

- Equipment life expectancy reduced due to increased thermal stresses.
- Reduced reliability due to use of redundant equipment during overload operation.
- Limited ambient temperature operating range.
- Restricted performance range for such critical operating parameters as reactive power compensation and harmonic filter performance.
- Control and instrumentation limits.

Operating conditions and design requirements of the AC and HVDC system should be able to support the overload operation without component damage. Major equipment which can be directly affected by overload operation include the thyristor valves, valve cooling system, converter transformers, harmonic filters, smoothing reactor, current and voltage transformers, bushings, bus work, and transmission systems.

Test Objectives

The objective of the overload/temperature rise tests are to verify the HVDC systems overload performance capability and confirm the temperature rise of the individual equipment is within acceptance limits.

Preconditions

Before conducting the tests the following preconditions shall be fulfilled.

- Factory heat-run test results of major equipment available.
- AC and DC transmission systems prepared for overload tests.
- Temperature monitoring equipment inplace.
- Ambient conditions are compatible with requirements.

Test Procedures

The HVDC system should be operated at rated load prior to commencement of the overload tests for a period of time necessary to achieve thermal equilibrium of major electrical components such as converter transformers, DC smoothing reactors, thyristor valves, AC and DC harmonic filters, and valve cooling system.

After the temperature of the major equipment items has thermally stabilized at full load (typically 12-18 hours), the HVDC system can be operated under the overload condition which is compatible with the existing ambient conditions and the temperature rise of major electrical components recorded. In addition, the valve cooling system performance should be monitored and temperature monitoring devices should be employed to check the buswork, connection points, terminations, neutral connections, and switch contacts.

Test Acceptance Criteria

The maximum operating temperatures and temperature rise of the equipment shall be within specified limits. The maximum operating temperature of equipment being tested may have to be corrected to maximum ambient temperature to compensate for lower ambient temperatures during test.

5.4 Interference

Introduction

HVDC systems produce voltages and currents in conductors which may cause interference from both the conducted energy and radiated energy. Conductor corona pulses and partial discharges on insulators are also potential sources of electrical interference from HVDC systems.

Filtering devices, shielding, and noise suppression techniques are implemented to minimize interference. Since electrical interference has the potential of affecting third party electrical systems, the commissioning test program should include coordinated tests with operators of interference-sensitive equipment-Design criteria for interference levels resulting from HVDC systems are project specific and depend on the surrounding environments and regulations. Interference limits imposed typically consider the following:

- Radio interference (RI).
- Television interference (TVI).
- Telephone carrier interference (TCI).
- Microwave communication system interference (MCSI),
- Railroad signal interference (RSI),
- Power line carrier interference (PLCI).

Test Objectives

The objectives of the interference tests are to measure and verify that the interference levels caused by the HVDC system are within required limits and establish that there is no degradation of low-level electric circuits (e.g. telephone networks, computers, radio and television systems, railroad signal equipment, and other electronic apparatus).

Preconditions

Before conducting interference tests the following preconditions shall be fulfilled.

- Measurements available which establish pre-existing background interference levels.
- Study results available which estimate the levels of interference expected as a result of HVDC system operations.
- Coordination established with operators of interference-sensitive equipment.
- HVDC system operating with all interference mitigating equipment in service.
- HVDC station controls and protection verified to be immune from interference.
- Test instrumentation and data acquisition system available.

Test Procedures

Interference tests for the HVDC system can be broadly classified into the following separate groups:

- HVDC converter station tests with measurements taken within and adjacent to the fenced boundary of the facilities.
- Transmission line tests with measurements taken along a perimeter of the AC and DC transmission lines servicing the HVDC system.

The interference tests should be performed at predetermined locations and in those HVDC system configurations and modes of operation specified. A test plan which identifies these configurations and levels along with the physical locations for the interference measurements should be established, considering the following HVDC system operating conditions:

- Stand-by operation,
- Minimum, intermediate, rated and applicable overload HVDC power transfer levels.
- Any special condition generating maximum interference,
- Number of points and number of measurements.
- Test plan which identifies the bandwidths and measuring techniques, correction factors, accuracy, antenna types, standards (where applicable), frequency scans and spectrums, operating configurations and modes of the HVDC system, ambient weather conditions, voltages, conductor configuration, structure type and material),and elevation.

Test Acceptance Criteria

The interference levels measured with the HVDC system in operation must be within the specified design limits and cause no degradation of low-level electric circuits.

5.5 Earth Electrode

Introduction

The earth electrodes for a bipole configured HVDC transmission system provide a ground reference for the neutral bus at each converter station. The earth electrodes are generally designed to permit the HVDC system to operate for a limited time period in the monopolar ground return mode when one pole of the bipole is out of service. Earth electrodes for monopole systems are designed to permit continuous operation. Since earth return operation may interfere with third party communication circuits and may cause corrosion of underground structures, the commissioning test program should include coordination with third parties.

Test Objectives

The objectives of the earth electrode test is to verify the design of the earth electrodes and establish the maximum measured interference levels in various operating modes. Design criteria for HVDC earth electrodes are project specific and depend on the local soil conditions, anticipated operating modes, and duration of earth return operation in the worst case scenario- Design criteria typically considered include the following:

- Current rating.
- Temperature rise.
- Thermal time constant.
- Current distribution between electrode wells.
- Current density at the electrode surface.
- Earth resistivity design value.
- Resistance of electrode to remote earth.
- Electrode resistance.
- Overload current capability.
- Step and touch potential.

Preconditions

Before conducting the tests the following preconditions shall be fulfilled.

- Earth electrode precommissioning tests including measurement of structure-to-soil potential, current-in-structure, soil potential, soil resistivity, structure-to-remote electrode-potential, and background interference level.
- Test stations for cathodic protection and stray current measurements established,
- Coordination established with all participants, e.g., railroad operators, telephone companies, municipalities, underground utility operators, electrode supplier, and HVDC supplier.
- Test coordination center and communication method established.
- Test instrumentation and data acquisition system available.

Test Procedures

System tests for commissioning of the earth electrodes can be broadly classified into the following separate groups:

- low current tests with a direct current of 10-20 % of the rated direct current to determine the basic earth electrode characteristics and identify the areas of potential interference;
- full rated tests of the earth electrodes with the direct current being increased above the low current test level in incremental steps up to the full current rating. Periodic cycling of the direct current and the magnitude of the direct current incremental steps should be based upon a test schedule/plan.

Recording instruments need to be installed at all test points and areas of special concern that are identified during the low current tests. The duration of the tests at each direct current level must be appropriate for the thermal time constants of concern and allow for the following test measurements to be taken.

- Stray current magnitude caused by test current in affected structures.
- Change in stray current flow caused by test current in affected structure.
- Change in potential caused by test current of structure-to soil.
- Current distribution in each earth electrode well or electrode section.
- Temperature rise versus test time to establish limits of full current test.
- Induced voltage on communication circuits.
- Stray currents in AC system transformer neutrals.

Structure-to-soil potential should be measured with the reference electrode directly above buried structures or within one foot of above ground structures such as railroads, and towers.

Test Acceptance Criteria

The characteristics of the earth electrodes must be within the specified design limits including temperature rise, voltage distribution, resistance, and uniform current distribution among different electrode wells or electrode sections. The results of the coordinated tests need to be analyzed and any unusual results investigated and resolved between the affected parties.

PART 6: OPERATION AND INTEGRATION TESTS

General

Introduction

In this part the operation and integration tests are described. These are the system tests which seek to prove the response to change of configuration and the transient behaviour of the AC and HVDC systems including recovery from faults. Operation and integration tests are the final group of system tests before the period of trial operation. Previous commissioning tests, including converter tests and end to end tests have verified that the DC equipment being commissioned functions correctly. The tests described are those recommended only for two terminal and back to back HVDC systems. The following tests are outlined:

6.1 Changes of DC configuration

6.2 Control performance

6.3 Switching AC side filters and transformers

6.4 Loading tests

6.5 AC and DC system staged fault tests

6.6 Loss of telecommunications, auxiliaries, or redundant equipment

Integration testing may also include all tests that would verify proper interaction and coordination between the HVDC system under test and such other on-line equipment as static VAR compensators, other HVDC systems, torsional interactions, etc.

General Preconditions

The following activities shall have been completed before the operation and integration tests can proceed:

- Off-site tests including AC/DC simulator tests
- Terminal tests including converter unit tests and converter station tests
- End-to-end tests to verify sequences and inter-station coordination
- Steady state operation including verification of steady state performance and interference effects

Detailed procedures and plans should be prepared. As the tests may involve some disturbance or increased risk to the connected AC systems, the operators of the systems should be consulted.

The connected AC systems shall be within their specified range of parameters and be capable to deliver the active and reactive power for the HVDC system required for the particular test/ Important parameters include.

- AC voltage and frequency
- Short circuit capacity
- AC system configuration

Statement of Purpose

The purpose of the operation and integration tests is to verify the correct operation of the HVDC system in combination with the associated AC systems, within the limits given by the specification, under transient and change-over conditions.

General Test Objectives

Operation and integration tests are intended to verify the effects of changes in DC main circuit configuration, control performance, switching and connection of AC side equipment, AC and DC staged faults where required and the loss of telecommunications and auxiliary functions.

6.1 Changes of DC Configuration

Introduction

Most HVDC long distance transmission schemes can be operated in several DC configurations such as monopolar earth electrode return, monopolar metallic return, bipolar normal and in parallel operation. Each of these configurations can contain one or more DC filters.

If series connected converter units per pole are used switching in and out of these groups should be demonstrated. If the HVDC system uses polarity reversal, this should be verified. Manoeuvres involving two or more terminals can normally be performed with or without telecommunication.

Back-to-back stations do not require changes of DC configuration.

The test objectives, preconditions and test procedures are similar for the tests under 6.1.1 through 6.1.3.

Regarding denomination of switches and their function refer to document CIGRE WG 13/14.08: "Switching devices other than circuit breakers for HVDC systems", Part 1.

Test Objectives

- Verify coordinated switching between converter terminals and for DC bus reconfiguration and thus prevent switching conditions which can cause severe stresses on the DC equipment.

- Switching of DC filters, if permitted, should not disturb the power flow of the HVDG transmission more than specified.

Preconditions

Before conducting the tests the following preconditions must be fulfilled:

- All sequences checked on the non-energized system
- All AC and DC equipment energized
- End-to-end tests completed

Test Procedures

During all tests AC and DC voltages and currents should be recorded. Outdoor observations of sound and light phenomena should be made.

The timing of the various switching sequences should be verified. All switching sequences should be performed step by step. If applicable, the sequences should also be executed automatically. If two or more terminals are involved telecommunication will then be required.

Where appropriate, additional tests may be performed at lower than nominal power and at minimum power.

Test Acceptance Criteria

The HVDC transmission should not be permanently disrupted by any change of DC configuration. Currents and voltages should coincide with the results from corresponding simulator tests and be in accordance with the specification.

6.1.1 Tests from Monopolar Metallic Return Operation

From this configuration the following changes can be made:

- Connection and disconnection of DC filters
- Transfer to monopolar earth electrode return
- Transfer to bipolar configuration
- Paralleling and deparalleling of another pole

Connection and disconnection of DC filters (if permitted):

- Record the DC filter harmonic current
- Operate at nominal power and disconnect one DC filter
- Connect the DC filter again
- Repeat the procedure for all DC filters

Additional test criteria:

- Rating of remaining filters should not be exceeded
- No burn marks should occur on the disconnects

Monopolar earth electrode return:

- Operate at nominal power
- Close the MRTB (Metallic Return Transfer Breaker)
- Open the GRTS (Ground Return Transfer Switch)

Bipolar operation:

- Operate at nominal power
- Close the MRTB
- Open the GRTS
- Close line pole disconnect of the non-operating pole
- Deblock non-operating pole
- Verify the current balance in both poles

Paralleling/deparalleling:

- Operate one pole at nominal power
- Close paralleling disconnect of the non-operating pole
- Deblock the non-operating pole
- Verify the current balance in both poles

6.1.2 Tests from Monopolar Earth Return Mode

Monopolar earth return may only be allowed during a limited period of time. From this configuration the following changes can be made:

- Transfer to monopolar metallic return
- Transfer to bipolar operation

Transfer to monopolar metallic return:

- Operate at nominal power
- Close the GRTS
- Open the MRTB

Transfer to bipolar operation:

- Operate at nominal power
- Close the line pole disconnect of the non-operating pole
- Deblock the non-operating pole
- Verify the current balance in both poles

6.1.3 Tests from Bipolar Operation

From this specific configuration the following changes can be made:

- Connection/disconnection of DC filters
- Monopolar earth electrode return
- Monopolar metallic return

Connection and disconnection of DC filters (if permitted):

- Record the DC filter harmonic current
- Operate at nominal power and disconnect one DC filter
- Connect the DC filter again
- Repeat the procedure for all DC filters

Additional test criteria:

- Rating of remaining filters should not be exceeded
- No burn marks should occur on the disconnects
- No adverse transient effects

Monopolar earth electrode return:

- Operate up to maximum specified power, for monopolar operation
- Reduce the current in one pole to a minimum but keep the bipole power constant
- Block the pole with minimum power
- Open the line pole disconnect in the blocked pole

Monopolar metallic return:

- Operate up to maximum specified power
- Reduce the current in one pole to a minimum but keep the bipole power constant
- Block the pole with minimum power
- Open the line pole disconnect in the blocked pole
- Close the GRTB
- Open the MRTB

6.2 Control Performance General

In HVDC systems various control loops are utilized. This chapter describes the recommended system tests to prove the steady state and dynamic performance of the control system.

Test Objectives

The site tests are performed to fine-tune the response of each control loop following a change in the reference value and to verify the control behaviour during disturbances causing changes in the actual measured quantities (DC current, DC voltage etc.) of the respective control loop.

The tests are designed to verify that the controllers will not interfere with each other or cause disturbances to the AC and/or DC systems. Controllers insensitivity to AC system disturbances should also be verified. The following sections will describe the tests necessary for control performance verification under:

- Step response
- Control mode transfer
- AC system interaction / control
- Commutation failure

Preconditions

Before conducting all the tests the following preconditions must be completed:

- Off-site testing of the control system
- Converter unit tests
- Start/stop sequences checked
- Protection sequences checked
- Communication system operational

All the equipment from the DC system necessary for power transmission of one pole must be available. The AC systems should be set up as close as possible to the minimum design effective short circuit ratio.

Test Procedures

The procedure for each test will be described in each section separately. All tests for optimization and verification of the control performance require a similar recording and monitoring set-up. This monitoring and recording set-up is listed below. In cases where additional or different set-ups are required this is outlined in the individual sections. The control performance tests would have been performed during the off-site tests and can be used as a reference for all site tests. It is also recommended to use the same recording equipment, monitored signals and test report sheets as were used during the off-site tests. The variables which should be monitored, include:

- Current order fat the current controller input)
- Actual DC current (at the current controller)
- Output of current controller
- DC voltage
- Extinction angle at the extinction angle controller
- Output of extinction angle controller
- Final control voltage to tiring controls (alpha order)
- Identification of active controller
- AC busbar voltage (3 phases)
- DC power
- Force retard command
- Stabilizing (damping) control signals (if any)

6.2.1 Step Response Introduction

This type of test will depend on the various control modes in the HVDC system.

There are different modes of operation for each terminal of an HVDC system. The most common ones are:

- Constant current control
- Constant minimum extinction angle control
- Constant DC voltage control
- Current error control
- Constant power control

Some of these control modes are only valid for operation as a rectifier or an inverter.

Based on the large variety of possible HVDC system controls it is difficult to design one test to cover all possible control scenarios. Thus the tests will be described for the most common control loops.

If we consider the case of an HVDC system where the rectifier is in constant current control and the inverter is in constant minimum extinction angle control, then the controllers to be optimized in this case are:

- Rectifier current controller
- Inverter extinction angle controller
- Inverter current controller (margin current control)
- Rectifier extinction angle controller
- Constant power controller
- Voltage dependant current order limiter (VDCOL)

Test Objectives

The objective of a step response test is to optimize the individual controller which is active in a specific mode of operation to achieve stability.

Preconditions

Before conducting step response tests the following preconditions shall be completed:

- Off-site testing of the control system
- Converter unit tests
- Start/stop sequences
- Protection sequences
- Communication system

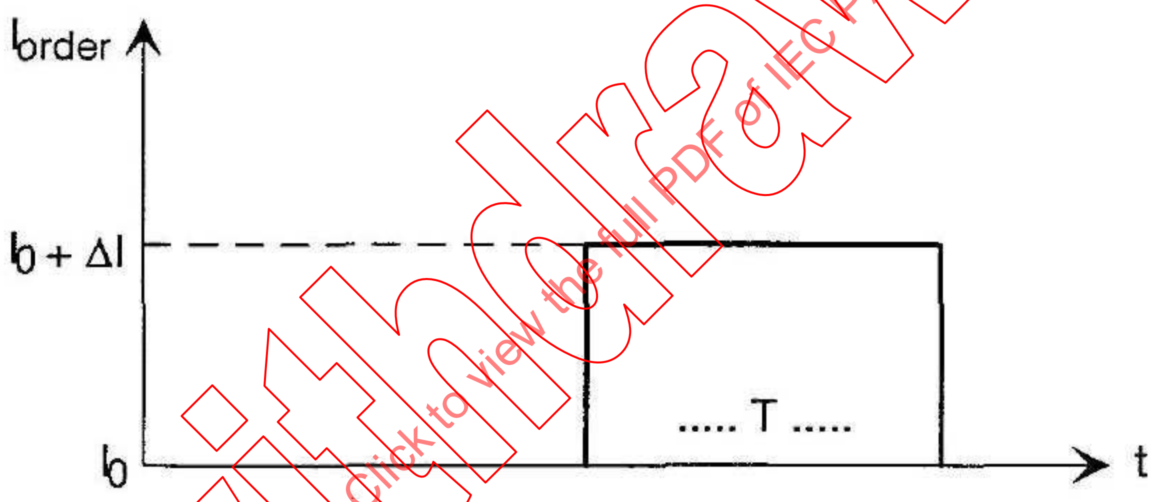
Test Procedures

It has proved to be good practice to implement the control settings obtained from the off-site tests on the simulator and then fine tune them during the step response tests with the real HVDC system.

Step response tests are performed at all controllers beginning at the converter level and continuing toward station and system level.

Rectifier Current Controller

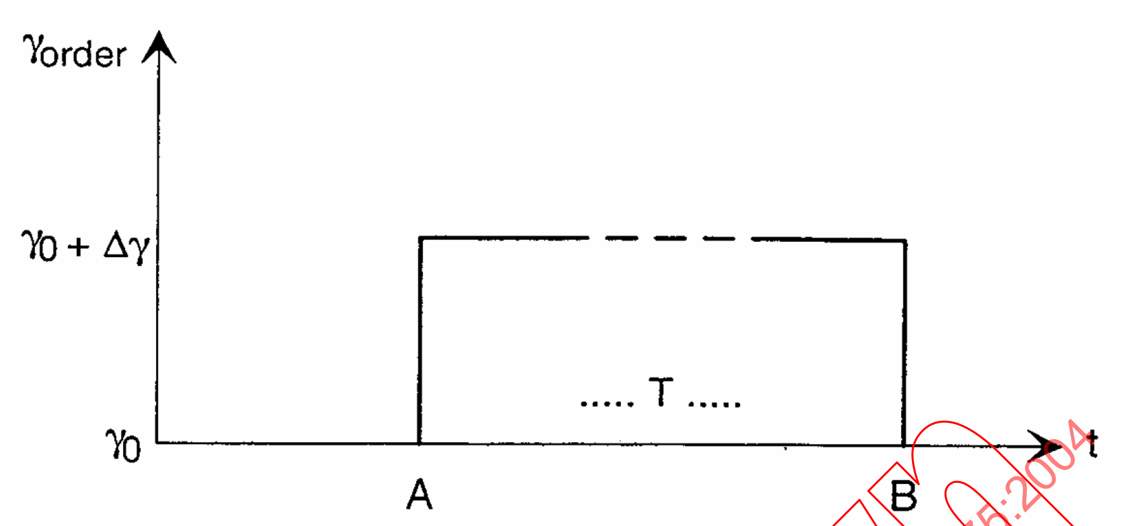
Several methods can be used to fine tune the current controller at the rectifier The typical one is to apply a step change in the current order. The duration of the applied step (ΔT) should be long enough to allow the system to stabilize following the change in current order. The level of the current order (I_o) prior to the step change should be chosen keeping in mind that during the application of a step-up in the current order (ΔI) no limits are encountered. The location of application of the current order step should be as close as possible to the input of the current controller. During the test the rectifier must always be in DC current control and the current controller at the inverter should be prevented from interfering.



Inverter Extinction Angle Controller

In order to optimize this controller at the inverter the rectifier will be in its normal mode of control and the inverter should be in the minimum constant extinction angle control- A step change in the extinction angle reference at the controller should be applied. The first step change, A) should be applied only in the direction of increasing the reference to avoid commutation failures. The magnitude of the step ($\Delta\gamma$) should be such that reaching any extinction angle limits is avoided.

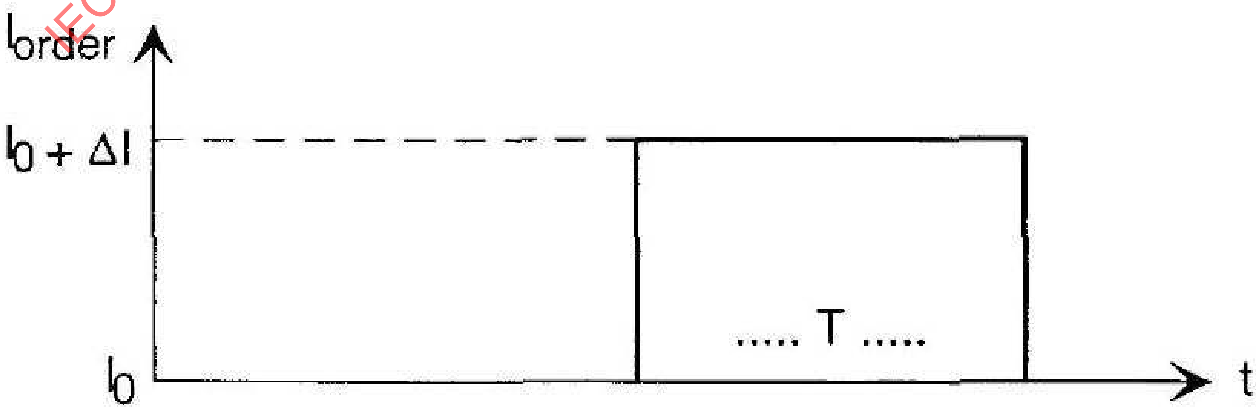
After optimization of the controller parameters a second step change B) from $\gamma_o + \Delta\gamma$ back to γ_o should be applied.



It should be noted that in the case where the controller has other inputs, which will affect the extinction angle, the process should also be repeated for these inputs. For example if there is an input that will increase the extinction angle due to a sudden increase in DC current or a sudden decrease in the AC voltage, then these functions should be checked following the optimization with step changes in the extinction angle.

Inverter Current Controller (Margin Current Controller)

During this test the rectifier has to be in constant firing angle control (alpha minimum) and the inverter is in constant current mode of operation. A step change in the current order at the input of the inverter current controller is applied. The duration of the step (T) is long enough to achieve stable operation following its application. Before applying the step, the magnitude of current (I_O) is such that no current order limits are encountered when a step ΔI is applied.



Rectifier Extinction Angle Controller

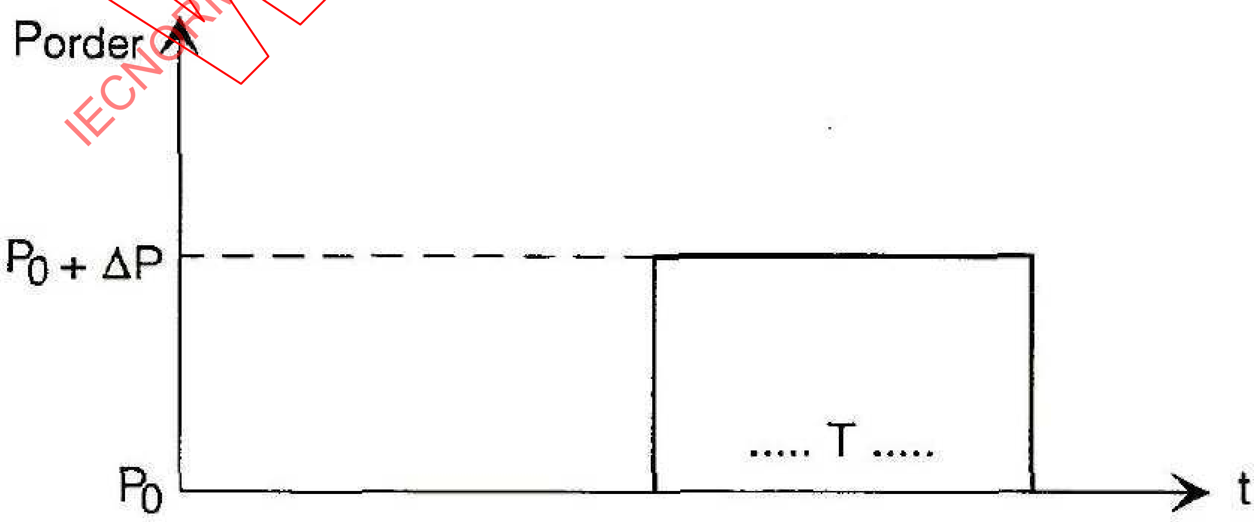
In order to fine tune the extinction angle controller at the rectifier, two situations can be considered.

1. In the case of a transmission system where the direction of power is always constant. One terminal is always a rectifier and the other is always an inverter. Then the function of this controller will be limited to the situation when force retard is applied. The response of the controller should be checked during the application of force retard.

2. In the case of an HVDC system where power reversal is used the optimization of the controller at the second terminal should be performed during transmission in the reverse power direction.

Constant Power Controller

In order to optimize this controller a step change in the power order (ΔP) is applied. The duration of the applied step (T) should be long enough to allow stable operation to be achieved. The level of the power order (P_o) prior to the step change should be chosen, keeping in mind that during the application of a step up in power order ΔP no limits are encountered. The step size of ΔP should be chosen such that the change in current order exceeds the current margin. Additional tests with smaller ΔP may be conducted to check for instability and interaction with other control loops.



Test Acceptance Criteria

All controller settings must be adjusted such that recovery times and design criteria as determined in system studies and requested by the specifications are not exceeded.

All control system parameters shall be similar to those obtained during the off-site tests. Deviations between the real DC system and the off-site tests can occur, but must be explained.

Optimization shall be such that the response of the DC system to the step change will be in a manner that shows the least amount of overshoot and the shortest settling time.

No instability shall occur during the step response tests.

6.2.2 Control Mode Transfer

Introduction

The basic control mode transfer can be divided into two general types:

- From constant power control mode to constant current control mode and back.
- From constant extinction angle control mode or constant DC voltage control mode to constant current control mode and back at the inverter.

Additional control modes may be applied for special applications. Their control mode transfer needs to be tested with respect to the particular application. The test criteria, however, are anticipated to be similar as for the basic control mode transfer as discussed here after.

HVDC systems are typically operated in constant power order control mode.

Under certain conditions it will be necessary to transfer from constant power control mode to constant current order control mode. At the pole control level it is a typical configuration to operate the rectifier in constant current control and the inverter in constant extinction angle control.

It is common practice to have the inverter also equipped with a constant current controller. During certain AC system conditions a transfer from constant extinction angle control mode to constant current control mode and back will be required at the inverter.

Test Objectives

Control mode transfer tests are performed to verify that the HVDC control system will transfer from one control mode to another smoothly and without any adverse effect on the power system.

Preconditions

Before conducting control mode transfer tests the following preconditions shall be completed:

- Off-site testing of the control system
- Converter unit tests
- Start/stop sequences
- Protection sequences
- Communication system

The step response tests will have been completed and the individual controllers are optimized.

Test Procedures

For DC systems where the transfer from constant power order control mode to constant current order control mode is a manual function, the DC system will be started in constant power order control mode. The transfer to constant current order control mode must only take place when the actual DC current and the new DC current reference value match. The matching can be performed manually or automatically.

In some cases the transfer from constant power order control mode to constant current order control mode is also activated automatically during any decline in the AC bus voltage, in order to avoid power/voltage instability. If such a feature is available this control mode transfer shall be checked. This can be performed by simulating AC undervoltage or during AC system faults.

The control mode transfer from constant extinction angle control to constant current control at the inverter can be checked by operating the rectifier at its minimum firing angle and forcing the inverter into current control. A typical means to perform this test is through the use of tap changer operations.

This test can be performed in constant current order control mode or in constant power order control mode.

Test Acceptance Criteria

The control mode transfer is expected to be a smooth transition with stable operation during and after the transfer from constant power control to constant current control and back.

Step changes in power shall not occur during the control mode transfer.

The control mode transfer from constant extinction angle control to constant current control at the inverter shall be stable.

6.2.3 AC System Interaction / Control Introduction

The controllability of HVDC systems is an important advantage of this technology. Additional DC controls also make it possible to operate HVDC systems with weak AC systems. This feature can be valuable in improving the dynamic performance of large AC systems.

To achieve these advantages, the control systems must perform appropriately for various disturbances and system conditions. The control loops shall not interact unfavourably with each other.

To obtain adequate control performance, operation at higher than nominal rectifier firing angles or higher than minimum inverter extinction angles may be required.

Commonly specified AC system interaction/control functions are:

- Frequency control
- Reactive power regulation
- AC voltage control
- Temporary overvoltage control
- Damping of frequency or power oscillations
- Frequency or power dependent power changes
- Special controls during faults

Test Objectives

The objectives are to optimize the individual controller active in a specific mode of operation to achieve stability with the actual HVDC transmission system.

Preconditions

Before conducting the tests of AC system/interaction control functions the following shall be completed:

- Off-site testing of the control system
- Converter unit tests
- Start/stop sequences checked
- Protection sequences checked
- Communication system operational

The step response tests will have been completed and the individual control loops are optimized.

AN control mode transfer tests shall have been completed. The AC system should be set up in a condition which refers to the specific AC system interaction/controller.

Test Procedures

The test procedures for the AC system interaction controllers may differ for the individual application and functions.

Where applicable it has proved to be good practice to implement the control settings obtained from off site tests on the simulator and then fine tune them to the real HVDC system.

Testing the control behaviour during disturbances shall be planned very carefully. The execution involves the connected AC system and can have a serious impact on it.

AC system disturbances or HVDC operating mode changes to check the interaction of the HVDC system with the AC system may be initiated by:

- Load rejection (simulated DC line faults)
- AC line switching
- Generator tripping
- Ramping of DC power
- Power reversal
- Transformer energizing
- Filter switching
- AC or DC line faults
- Modulation of generator excitation system

Some of the above mentioned initiating functions are also dealt with in 6.3 and 6.5.

Test Acceptance Criteria

All controller settings must be adjusted such that recovery times and design criteria as determined in system studies and requested by the specifications are not exceeded.

All control system parameters shall be similar to those obtained during the off-site tests. Deviations between the results from site tests and the results from off-site tests can occur, but shall be explained.

No instability shall occur during the AC interaction/control tests.

-

6.2.4 Commutation Failures Introduction

Commutation failures on a DC system can be caused by either:

- AC system disturbances
- Converter control malfunction

Commutation failures may occur only once (single commutation failure), or during a number of consecutive periods (multiple commutation failure), or may be persistent (persistent commutation failure). Commutation failures by converter control malfunction will be simulated during the tests described in this part. Trial operation provides a useful further test with regard to normal system disturbances (rather than those simulated).

Test Objectives

To observe and confirm that the control system is stable during and after commutation failures and valve misfires, and that recovery is achieved within the prescribed time period.

In the case of a DC system where the DC power circuit is resonant at a frequency close to the fundamental, the commutation failures may excite oscillations on the DC side. The tests will demonstrate that the control system will be able to damp such oscillation upon the removal of the excitation. In addition the tests will demonstrate that these oscillations will not be magnified due to the action of the control system.

To check the commutation failure protection and any valve overload protection such as voltage dependent current limits.

In the case of HVDC systems with overhead lines or cables, the tests are designed to ensure that the DC line or cable protection will not operate during these disturbances.