IEEE Guide for Commissioning High-Voltage Direct-Current (HVDC) Converter Stations and Associated Transmission Systems

Sponsor

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Abstract: General guidelines for commissioning high-voltage direct-current (HVDC) converter stations and associated transmission systems are provided. These guidelines apply to HVDC systems utilizing 6-pulse or 12-pulse thyristor-valve converter units operated as a two-terminal HVDC transmission system or an HVDC back-to-back system.
Keywords: high-voltage direct-current (HVDC) commissioning, HVDC transmission systems, off-site tests, on-site tests, precommissioning

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Introduction

[This introduction is not a part of IEEE Std 1378-1997, IEEE Guide for Commissioning High-Voltage Direct-Current (HVDC) Converter Stations and Associated Transmission Systems.]

This guide provides general guidelines for commissioning high-voltage direct-current (HVDC) converter stations and associated transmission systems. This guide provides assistance and guidance for developing an appropriate commissioning test plan that will need to be tailored to fit the requirements and application of the specific project.

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IEEE Guide for Commissioning High-Voltage Direct-Current (HVDC) Converter Stations and Associated Transmission Systems

1. Overview

1.1 Scope

This guide provides general guidelines for commissioning high-voltage direct-current (HVDC) converter stations and associated transmission systems. These guidelines apply to HVDC systems utilizing 6-pulse or 12-pulse thyristor-valve converter units (see Figure 1) operated as a two-terminal HVDC transmission system or an HVDC back-to-back system (see IEEE Std 1030-1987).[1] Excluded from this guide are guidelines for commissioning multi-terminal HVDC systems, synchronous compensators, static synchronous compensators, and static var compensators.

1.2 Purpose

The purpose of this guide is to provide guidance and assistance for developing an appropriate commissioning test plan for HVDC converter stations and associated transmission systems. Users of this guide will find that an HVDC commissioning plan will need to be tailored to fit the requirements and applications of the specific project.

1.3 Applications

Personnel qualifications, training, and the division of commissioning responsibility between the various users of the guide (utilities, manufacturers, consultants, and others) are not discussed, since each project will have contract-defined areas of responsibility. The HVDC commissioning guidelines included in this guide consider the following:

a) Commissioning planning
b) Off-site tests
    1) Routine and type tests
    2) Dynamic performance tests
    3) Functional performance tests

[1]Information on references can be found in Clause 2.

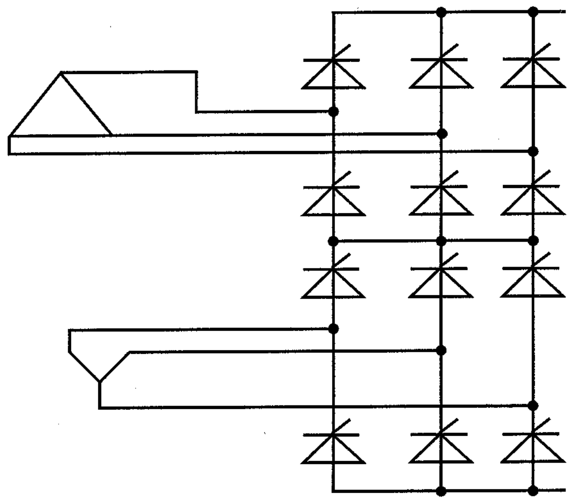

Figure 1— 12-Pulse thyristor-valve converter units

c) On-site tests
   1) Precommissioning
   2) Subsystem tests
   3) Converter station tests
   4) Transmission tests
   5) Trial operation
d) Acceptance tests
e) Documentation

2. References

This guide shall be used in conjunction with the following standards.

ANSI C63.2-1996, American National Standard for Electromagnetic Noise and Field Strength Instrumentation, 10 kHz to 40 GHz—Specifications.[2]

IEEE Std 1030-1987, IEEE Guide for Specification of High-Voltage Direct-Current Systems, Part I—Steady-state Performance (ANSI).[3]

IEEE Std 1158-1991 (Reaff 1996), IEEE Recommended Practice for Determination of Power Losses in HVDC Converter Stations (ANSI).[4]

IEEE P1126, December 1995, Draft Guide to Control and Protection of HVDC Systems.[5]

IEEE PC57.129/D10, October 1996, Draft Trial-Use General Requirements and Test Code for Oil-Immersed HVDC Converter Transformers.

[2]ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.
[3]IEEE Std 1030-1987 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181.
[4]IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.
[5]Numbers preceded by P are IEEE authorized standards projects that were not approved by the IEEE Standards Board at the time this publication went to press. For information about obtaining drafts, contact the IEEE.

3. Definitions and acronyms

3.1 Definitions

3.1.1 back-to-back test: A test of a bipolar station in which the transmission terminals of two converters are temporarily jumpered in the station. One converter is run as rectifier while the other converter is run as inverter.

3.1.2 circulating-power test: Operation of a bipolar HVDC transmission system so that power flows in the opposite direction in each pole. High power levels up to system rating can be used for test purposes with losses and net reactive only being supplied from the ac network. *Synonym:* **round-power test**.

3.1.3 dc converter load rejection: Tripping, blocking, or ramping HVDC converters to cause a significant reduction in transmitted power.

3.1.4 dc-side short circuit test: A test in which the dc terminals of a converter are temporarily jumpered. *Synonym:* **zero dc voltage test**.

3.1.5 disturbance testing: Tests performed to verify the dc system response to ac faults, dc line faults, loss of one pole (if applicable), and other dynamic response criteria.

3.1.6 dry-run test: A test of switching or tripping sequences with equipment not energized or “dry.”

3.1.7 dynamic performance test: Testing of the transient performance of a dc system either on the actual system or on a system simulator. Such testing includes fault recovery performance, step responses, and ac system interaction.

3.1.8 end-to-end test: A test series of all performance requirements with the dc system under normal operating conditions and, as conditions permit, under contingency operating conditions. *Synonym:* **transmission test**.

3.1.9 extended back-to-back test: A test of a bipolar station in which the transmission terminals of two converters are temporarily jumpered at the remote end of the transmission line. One converter is run as rectifier while the other converter is run as inverter.

3.1.10 functional performance test: Tests of the steady-state performance of control functions and sequences.

3.1.11 heat-run test: A test that verifies equipment to be within thermal design when operated for an extended period at maximum current. *Synonym:* **loading test**.

3.1.12 integration test: The testing of several subsystems that perform in combination.

3.1.13 loading test: *See:* **heat-run test**.

3.1.14 open-line test: A test that energizes a converter dc yard up to full voltage without energizing the remote station. The test can be configured to also test energize the transmission line.

3.1.15 round-power test: *See:* **circulating-power test**.

3.1.16 runback: The control of a dc system to reduce power to match loss of generation on the ac network.

3.1.17 transmission test: *See:* **end-to-end test**.

3.1.18 trial operation: A period of normal operation of the dc system near the end of commissioning.

3.1.19 zero dc voltage test: *See:* **dc-side short circuit test**.

3.2 Acronyms

CTS	cable terminal station
DFR	digital fault recorder
HVAC	heating, ventilating, and air conditioning
HVDC	high-voltage direct-current
MRTB	metallic return transfer breaker

MRTS metallic return transfer switch
OHTL overhead transmission line
OLT open-line test
PLC power-line carrier
RTU remote terminal unit
SCADA supervisory control and data acquisition
SER sequence of events recorder
TFR transient fault recorder
TNA transient network analyzer
VBE valve base electronics

4. General

HVDC systems (see Figure 2) have been developed for transfer of electric energy where ac transmission may not be the preferred choice or the most economic solution. Long overhead lines, relatively long undersea cable installations, or connections between asynchronous systems have been the conventional applications of HVDC transmission technologies.

HVDC commissioning tests are the continuation of a systematic test program that begins with off-site tests on each of the equipment items to be installed in the HVDC converter stations (see Figure 3). These tests involve routine and type tests (where applicable) as well as functional and dynamic performance tests of the HVDC control and protection system hardware and software. The test program continues with on-site precommissioning tests of equipment, subsystem tests, and converter station tests. The test program culminates in testing of the entire HVDC transmission system during end-to-end tests.

Precommissioning tests involve localized testing and checkout of individual equipment items. These tests are performed after equipment items are installed at the site.

Subsystems consist of pieces of equipment items that are grouped together according to common functions. The purpose of subsystem tests is to independently check the necessary functional performance of all HVDC subsystems before starting converter station tests.

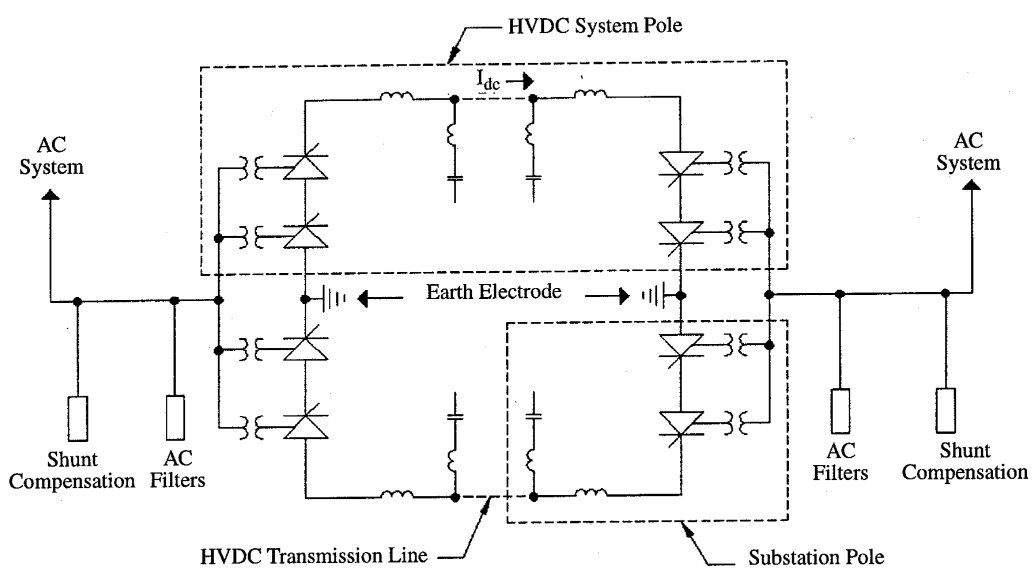

Figure 2— Example of bipolar HVDC transmission system

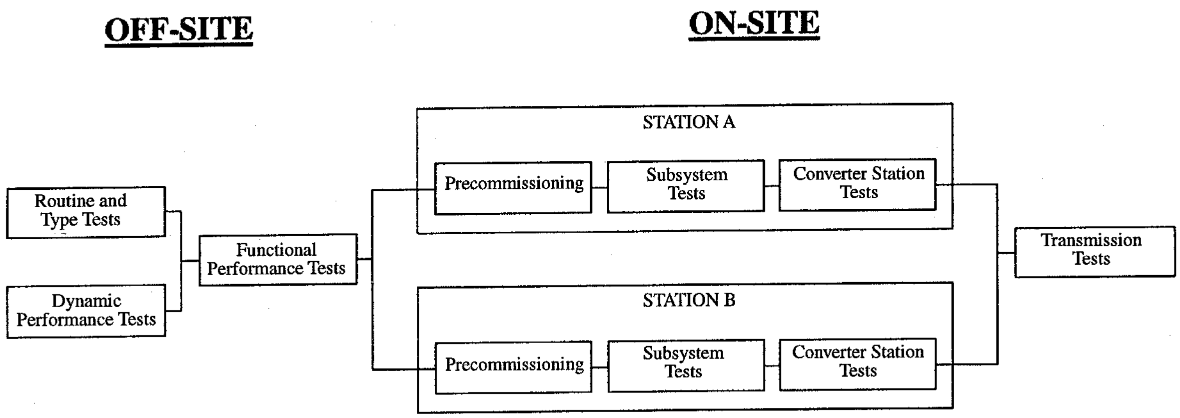

Figure 3— HVDC system commissioning sequence

Converter station testing includes converter terminal tests (without dc power transmission) to verify that subsystems interact and function according to the station's specific requirements. These tests involve high-voltage energization of all equipment at one station and require coordination with system operators. Load tests in the form of back-to-back or round-power tests require special attention. Open-line tests (OLTs) of the dc switchyard and OLTs of the transmission circuit are also part of the converter station tests.

Transmission testing includes testing power transmission at power flows up to the rating of the stations involved. Various HVDC system configurations, power flow directions, and other HVDC system operational parameters are tested to confirm specified performance.

Test responsibilities of the supplier and user should be defined in project contract specifications. Acceptance tests may be performed at an appropriate time during the on-site test schedule.

4.1 Commissioning planning

Commissioning HVDC systems is a complex and diversified task requiring planning of the commissioning sequences, procedures, and load schedules as well as teamwork and cooperation between all parties involved. Areas of responsibility and authority for operations, reporting, and documentation should be clearly defined.

Commissioning plans should provide an effective document taking into consideration issues that include test locations, interactions with interconnected ac systems, ambient conditions, and public interests. The availability of an overall commissioning plan that includes planned schedules, testing matrices, detailed commissioning procedures, and instructions can be very helpful.

4.2 Ambient conditions

In general, test results and performance of electrical systems can be significantly influenced by variations in such ambient conditions as temperature, barometric pressure, and humidity. In situations where tests are performed under different ambient conditions, meaningful interpretation and comparison of results may only be possible if data concerning these conditions are properly recorded. Off-site testing normally occurs under controlled ambient conditions that are well defined and recorded. On-site ambient conditions can vary significantly and should be recorded during all commissioning tests.

5. Off-site tests

Off-site tests are performed to verify proper performance of individual components and equipment items prior to shipment to the site. These tests are typically classified as routine and type tests for equipment hardware with additional dynamic and functional testing of the control and protection equipment normally performed to verify software performance. Routine tests are made for quality control to verify that components and equipment items meet the specified requirements. Type tests are made on nonstandard equipment to verify that component parts and equipment items of special design meet assigned ratings and operate satisfactorily under required service conditions.

Equipment standards and tests have been developed by several organizations such as the International Electrotechnical Commission (IEC), Institute of Electrical and Electronic Engineers, Inc., (IEEE), and American National Standards Institute (ANSI). The routine and type tests developed in these standards should be used (when specified) for the development of off-site test programs to meet the specific needs of individual installations. Routine and type tests of component parts and equipment items covered by existing standards are not addressed in this guide.

Off-site testing of the HVDC control system (IEEE P1126 , December, 1995) and protection equipment is a four-step process that normally involves the following:

- Routine and type tests
- Steady-state performance tests
- Dynamic performance tests
- Functional performance tests

Steady-state, dynamic, and functional performance testing of actual control, protection, operating, and monitoring hardware, cabling, and software (deliverable, identical, or functionally equivalent equipment items, as specified) are performed on a simulator or transient network analyzer (TNA). In these tests, the complete HVDC system control, protection, operating, and monitoring subsystems are tested with all cubicles connected together. Steady-state, dynamic, and functional performance tests provide the opportunity to set preliminary parameters of control circuits. They also allow preliminary verification that the equipment performs according to specified requirements. This provides an opportunity to detect and correct hardware and software errors or deficiencies and ensure correct and reliable performance prior to on-site system testing. Additionally, the test results can be used to confirm study results and provide benchmark data for on-site tests as well as provide training opportunities for the user’s operating, commissioning, and technical staff. Steady-state, dynamic, and functional performance tests should be basic preconditions prior to on-site system tests and can be performed at any location mutually agreed upon by user and supplier.

Steady-state, dynamic, and functional performance testing incorporate the actual control, protection, operating, and monitoring hardware and may include valve base electronics (VBE), operator controls, automatic fault recorders, sequence of events recorders, local area networks, analog interfaces, binary interfaces, and telecommunications.

This complete subsystem is connected to a simplified HVDC simulator model consisting of 6-pulse or 12-pulse converter units and, for the dynamic performance tests, to scaled ac and dc transmission networks. The extent of the ac and dc transmission network simulation should be sufficient to replicate any significant resonant frequencies determined from studies. The interface to the simulator converter valves can be made using simulated valve electronics (on the thyristor level) and VBE. For the functional performance tests, status signals from ac and dc switchgear, valve hall air conditioning, and other subsystems may be generated by a digital simulator in real time while analog inputs to the HVDC system control and protection cubicles are simulated from modeled instrumentation. It should be noted that analog inputs and protective settings to the HVDC system control and protection cubicles are again checked and calibrated during on-site precommissioning tests (Clause 6.).

Once the cabling of the system and precommissioning of each cubicle is complete, steady-state, dynamic, and functional performance testing can begin. When tests have been satisfactorily completed, the equipment items may be classified as a tested subsystem. However, on-site precommissioning, subsystem, converter station, transmission, and additional acceptance tests of these equipment items are still necessary as indicated in Clauses 6., 7., 8., 9., and 11. of this guide.

5.1 Routine and type tests

Routine tests are generally performed on each piece of equipment. Type tests are generally performed on one sample unit. Routine and type testing of individual hardware components and cubicles typically include the following:

a) Routine tests
   1) Visual
   2) Wiring
   3) Power supply variation
   4) Binary and analog inputs/outputs
   5) Operational performance test
   6) Insulation (steady state and impulse voltages)
b) Type tests
   1) Temperature
   2) Electromagnetic interference
   3) Tests required due to new or extrapolated design

5.2 Steady-state performance tests

Steady-state performance tests should be performed to verify that the HVDC system control and protection perform properly together with the simulator prior to dynamic and functional performance testing. Although tests and procedures vary with different applications, the following should be regarded as typical:

a) Verify that instrumentation reads correctly.
b) Perform simulator dc-circuit and static/dynamic parameter tests of the ac network/machines and dc line (if required).
c) Perform tests on control and protection systems.
d) Perform HVDC voltage and current steady-state tests. With the converter system deblocked, these tests could include:
   1) Tests to verify alpha and gamma order calibration.
   2) Perform tests with the voltage and frequency of the simulator ac systems varied over the specified normal ranges of operation. Confirm that the current order can be varied over the full range. DC voltage and current should be confirmed at different levels of current order. All prescribed limits should be maintained.
   3) Perform tests that confirm that the power order can be varied over the full range. The derived current order should be confirmed at different levels of power order.
   4) Block the rectifier and perform tests to confirm the current error calibration and correct response of the gamma control loop.
e) Perform tests to validate reduced dc voltage operation. These tests simulate manual or automatic reduction of dc voltage when required to reduce stresses on dc cables or overhead dc lines during extreme weather conditions.
f) Perform tests to confirm correct blocking sequences at the rectifiers and inverter, during an automatic shutdown from protective relays, including trip sequences for breakers.
g) Perform tests to verify that stress levels for ac and dc arrester and thyristor valves are within specified tolerances.

5.3 Dynamic performance tests

For dynamic performance tests, closed-loop control and protection software of the HVDC system control is optimized. Should the actual protection be designed as a main/backup system, then the simulator should have main/backup controls and protection. The following tests should be performed during dynamic performance testing:

— Tests to optimize all closed-loop control responses (e.g., dc-current order, inverter-extinction angle, inverter-current control, and power order).
— Tests to verify control mode transfers (e.g., at rectifier: constant power to constant current and back; at inverter: constant extinction angle to constant current, and back, etc.).
— Tests to verify ac system interactions (e.g., modulation, overvoltage control, and reactive power exchanges).
— Tests to verify that there are no commutation failures and misfires.
— Tests to verify proper HVDC system response during converter transformer energization and ac filter/reactive element switching.
— Tests to verify proper HVDC operation during unusual ac transmission network configurations. Apply faults to the ac and dc system, if specified, to test dynamic performance during faults, including minimum and maximum short-circuit ratios and islanding (where applicable).

5.4 Functional performance tests

Functional performance testing includes the simulation of all subsystems relevant to the respective converter station and the telecommunications interface with appropriate time delays simulated. The following should be done during these tests:

— Check interlock sequences.
— Check alarm functions.
— Trip test all protection.
— Check remote control interface including change of control locations.
— Check telecommunication interface including loss of end-to-end communications.
— Confirm correct dc switching sequences with and without switchgear misoperation.
— Check correct executions of operator inputs (limits, ramps, and control modes).
— Check that a first contingency fault of redundant power supplies does not affect the operation of controls or protection.
— Check that all transferring of redundant operator controls, converter controls, and VBE have minimum effect on power transmission.
— Check that loss of one protection system does not cause a trip.
— Check that loss or out-of-range faults of a single measurement does not effect transmission.
— Check performance during loss of one bridge.
— Check performance during loss of one pole.

The HVDC system response to changing network conditions such as ac faults, dc line faults, and loss of one pole should be verified. Dynamic performance may be tested off-site on a TNA without potential risk to the transmission networks. The representation of the respective ac networks, HVDC system, and dc controls should be verified with actual system measurements and digital performance studies. These type of benchmark comparisons should verify the results of digital studies, off-site tests, and on-site testing.

6. On-site precommissioning

Precommissioning tests are performed on-site to validate that individual equipment items have been properly installed and are functionally operating prior to subsystem tests. Precommissioning testing does not require high-voltage energization but may require station service power (ac and dc). Precommissioning tests typically include:

- Tests that verify that equipment is installed in accordance with manufacturers instruction books and station design drawings.
- Tests that verify wiring, fiber optics, and grounding connections.
- Tests that verify insulation.
- Test that verify capacitance, reactance and resistance measurements.
- Test that verify turns ratio and polarity tests.
- Test that verify timing checks on circuit breakers and switches.
- Tests that verify contact resistance measurements on disconnects and circuit breakers.
- Tests that verify transformer turns ratio measurements on every tap changer position.
- Tests that verify frequency response of carrier traps.

6.1 Preconditions

All equipment to be precommission tested should be completely installed. Prior to precommissioning the following should be available:

- Station service power (ac and dc where applicable)
- Precommissioning test plan
- All applicable instruction manuals, equipment drawings, and specifications
- Predetermined device settings from studies
- Test reports of off-site tests
- Calibrated test equipment
- Safety grounds and tags applied
- Buildings and valve halls including fire detection and suppression
- Personnel, plant safety, and security instructions prepared and disseminated

6.2 Verification of equipment installation

A visual inspection should be performed on all equipment installed in the subsystems. Examples of typical subsystems include buildings and valve halls, station service power, ac yard, ac filters, reactive power compensation, converter transformers, thyristor valves, dc yard, dc filters, and the dc transmission system. The inspection should compare the installation to that required by project documentation. All equipment should be completely installed with all accessories attached. Proper adjustments should be verified. All insulating and cooling liquid or gas should be installed to the proper level and pressure. High-voltage disconnect switches should be properly aligned. All nuts and bolts should be at the correct torque. Raceway and grounding systems should be completely installed. All moving parts should be checked for speed and timing.

6.3 Verification of connections

All connections to equipment should be checked. Wires, fiber optics, and grounding connections should be complete and properly terminated in accordance with the project documentation. One way to perform test phasing of the thyristor valves, valve control, and converter transformers is by operating them energized with a low-voltage ac source with most of the thyristor levels bypassed. Primary and secondary injection testing to check the proper phasing of transducers, instrument transformers, and protections can be performed as separate precommissioning or subsystem tests.

6.4 Insulation tests

Insulation tests generally include insulation resistance and/or power factor tests and can include megger or high potential tests. Insulation of all wires and cables should be tested as well as each high-voltage equipment item in the subsystems.

Proper valve cooling-fluid piping and fiber optic lead insulation levels are required. Phase-to-ground and phase-to-phase insulation levels should be verified on all ac high-voltage equipment. Positive-to-ground, negative-to-ground, and positive-to-negative insulation levels should be verified on all dc high-voltage equipment.

6.5 Control, protection, and monitoring

All relays, control devices, data recorders, and alarm devices should be set at predetermined settings and tested (as required) prior to subsystem tests.

Protective relays should be set at predetermined settings as defined by calculations and simulator tests. All pressure, flow, and level devices on power equipment should be set in accordance with manufacturers recommendations with settings verified during precommissioning. Devices that should be set and tested include:

- Protective relays
- Alarm settings
- Programmable logic controllers
- Pressure relief valves
- Sudden pressure relays
- Liquid level alarms
- Gas pressure relays/alarms
- Flow relays
- Annunciators
- Sequence of events recorders
- Fault recorders
- Temperature detectors
- Conductivity meters

6.6 Capacitance, reactance, and resistance measurements

Precommissioning includes verification of the reactance, capacitance, and resistance of filter components. Tests may also be made to check filter impedance over an appropriate frequency range to demonstrate correct filter tuning.

6.7 Turns ratio and polarity tests

Turns ratio of all instrument transformers as well as the proper polarity of each winding should be checked. Turns ratio tests should be performed on all power (auxiliary and converter) transformers and include tests at each tap position of the no-load tap changer and load tap changer.

6.8 Switching devices

Disconnect switches and grounding switches should be mechanically aligned and all auxiliary contacts set. Limit switches of motor operators should be set. Mechanical interlocks should be adjusted. Power circuit breaker travel times should be measured and recorded. Contact resistance tests should be performed on all high-voltage disconnects and circuit breakers.

7. On-site subsystem testing

Each subsystem consists of equipment items that are grouped together according to common functions. Subsystem tests verify proper performance of the equipment, its associated control, protection and interconnecting cabling or communications. Subsystem tests do not involve high-voltage energization of apparatus. Active and reactive power requirements are limited to station service loads that may require coordination with system operators. Subsystem tests begin following completion of precommissioning tests. This level of testing includes operational tests, calibration, checking of all trip paths, alarm points, interlocks, status points, and interfaces with external equipment making extensive use of the facility circuit diagrams. This clause describes typical subsystems.

7.1 Preconditions

Prior to subsystem tests, the following should be available:

— Subsystem test plan for each subsystem
— Criteria for successful subsystem test completion
— All required test equipment, calibrated and operational
— Safety instructions and tagging in place

7.2 AC and DC station service power

Station service power subsystems include all equipment required to provide and distribute both operating and control power throughout the converter station. This category of equipment typically includes auxiliary power transformers, switchgear, motor control centers, batteries, battery chargers, uninterruptable power supplies or inverters, and ac and dc distribution panels. Also included in this subsystem are the control, protection, alarm, and monitoring equipment associated with the station service power apparatus, such as undervoltage transfer schemes. Since so many other subsystems are dependent on station service power, this subsystem is usually completed right after the building is accessible.

7.3 Building and valve halls

These subsystems typically include heating, ventilating, and air conditioning systems, lighting, humidity control equipment, air filtering, and building pressurization systems, fire detection and prevention systems, paging systems, intercoms, and telephone and various maintenance support equipment. Transformer fire protection deluge systems could also be included.

7.4 AC yard, AC filters, reactive power compensation, and converter transformers

The ac yard subsystems comprise all equipment located in the ac switchyard of the converter station. This category typically includes buswork, ac disconnects and grounding switches, ac circuit breakers or load-break switches, ac filters, shunt capacitor banks and shunt reactors, ac arresters, ac power-line carrier (PLC) filters, and converter transformers. Also included in this subsystem are primary and secondary transducers, conventional control, protection, and monitoring equipment associated with the ac switchyard apparatus. Protective devices are calibrated (where applicable) and settings are verified. The ac bus, each filter group, and each capacitor bank and shunt reactor used for reactive power compensation could be regarded as separate subsystems.

Connections and interfacing with the ac system voltages feeding the converter stations should be considered a separate activity when commissioning the protection timing, tripping, and closing of the main ac circuit breakers including, primary, redundant, backup, and breaker failure protection equipment.

7.5 Thyristor valves

Thyristor valve subsystems include the thyristor valves and the associated thyristor valve control and valve monitoring. Valve cooling is an equipment item within the thyristor valve subsystem. It includes all equipment related to cooling the thyristor valves. This category typically includes coolers or cooling towers, heat exchangers, pumps, fans, strainers, deionizers, valves, water treatment, transducers, and instrumentation. Also included are the valve cooling control, protection, alarm, and monitoring equipment associated with the valve cooling apparatus. Although parts of this equipment are often shipped to the site on skid-mounted modules after off-site testing, the complete subsystem should be re-tested on-site after all connections have been completed. Testing should begin with static pressure tests with the thyristor valve cooling system connected followed by final flushing of the complete cooling system.

7.6 DC yard and DC filters

DC yard subsystems comprise all equipment located in the dc yard. This category typically includes dc disconnectors and grounding switches, dc line switches, dc filters, dc arresters, primary dc transducers, smoothing reactors, and equipment associated with the neutral/electrode line.

7.7 Control and protection

The control and protection subsystem typically includes the converter firing control, closed-loop current and voltage controllers, pole control, transformer tap changer control, power control, master control, pole protections, reactive power control, remote telecommunications interface, and the operator interface. The operator interface consists of local and master displays or mimic boards, supervisory control and data acquisition (SCADA), remote terminal unit (RTU), sequence of events recorder (SER) and alarm system, and transient fault recorder (TFR). Local communication equipment as well as equipment for interfacing with the utility system is included in this category. Special control functions such as frequency control, modulation controls, generator interfacing, runback, tie-line scheduler, etc. may be included. The control and protection system and inter-cubicle cabling or communications are normally already thoroughly tested on a simulator prior to delivery to the site, therefore much of the subsystem testing of the control and protection system is in conjunction with other subsystems with which there is an interface.

7.8 DC transmission system

The dc line can be an overhead transmission line, a dc transmission cable, or any combination thereof. Subsystem tests should be performed on any primary transducers that are connected directly on the dc line such as harmonic current shunts. DC cables may have termination stations that are remote from the converter station.

7.8.1 HVDC cable terminal station (CTS)

For some HVDC systems, cables are necessary to cross large bodies of water and are terminated in an HVDC CTS connecting to an overhead transmission line (OHTL). The CTS normally includes an oil treatment plant, ac and dc station service supplies, protection and monitoring systems, and surge arresters. When parallel cables are used, high-voltage disconnect switches, as well as measuring and protective equipment, are normally installed. Telecommunication and line fault location equipment may also be installed in CTSs. The CTS equipment and system should be commissioned immediately after installation of the cables and prior to being energized from the OHTL and converter stations.

7.9 Earth electrode

Most HVDC systems (except back-to-back) are designed to operate with ground current flow, either continuously or for contingencies. In these systems an earth electrode is required for each station that is sufficiently remote from the station to prevent any significant dc flow in the converter station ground grid. The commissioning work for ground current operation can be expected to be significant when one or more electrodes are either located in areas where geologic conditions are unfavorable or significant amounts of nearby underground facilities exist.

Generally, the electrodes are connected to the converter station neutral via an overhead line. Arresters, disconnects, and equipment for electrode line fault detection and protection may be installed at the electrode site. Temporary or permanent monitoring of the electrode to verify current distribution between elements and/or electrode temperatures may be provided. The commissioning of the electrode equipment should be performed prior to transmitting power on the HVDC system.

In cases where there is concern about the electrode capability, it may be possible to run current-injection tests at the precommissioning stage. However, such tests provide limited data, and it is generally not possible to completely determine the adequacy of the electrode design and related mitigation measures until the HVDC system is available for operation in ground return mode.

8. On-site converter station tests

Converter station testing consists of local station tests utilizing many or all the different subsystems together. Switching and initiation of local sequences will be from the local and master operator controls. Testing begins without ac system voltage connected to the converter station with local operational and emergency trip sequences being tested prior to applying ac system voltage. These tests give system operators an opportunity to become familiar with the switching procedures and operator interfaces before actual equipment energization.

Converter station tests are confined to the local station and do not require the dc line or scheduling of power transfer between the converter stations in case of a two terminal HVDC system. Back-to-back HVDC systems require limited converter station tests. The only power requirements for converter station tests are for station service and converter station losses. However, there will be reactive power demands for these tests. AC voltage variations associated with reactive power demand will also be experienced. Expected reactive power demands and consequential system voltage variations should be documented in the respective commissioning test description. Steps can be taken to minimize the impact of high reactive power surpluses resulting from dc converter load rejection (following trip tests or inadvertent blocking) by ensuring that ac filters are tripped shortly thereafter.

When energization tests are performed, the ac yard equipment is normally energized starting with the ac bus followed by individual banks of shunt reactive power compensation and the ac filters, depending on the respective ac system conditions and the consequential start-up procedure. Next, the converter transformers and converter valves are energized with ac system voltage.

The converter valves can then be used in an OLT configuration. This allows up to rated dc voltage to be connected to the dc yard equipment starting with the smoothing reactors and dc bus and then followed by energization of the different dc filter banks. In a bipolar HVDC system with clearly separated poles, ac yard testing can be sequential, starting when the first pole is completed. DC yard energization, however, is normally done only after the entire dc yard is completed. Once the dc yard has been successfully energized, the OLTs can be extended to the HVDC transmission system, first from one and then from the other terminal. Polarities may be changed if so designed and equipped.

DC-side short circuit testing or zero dc voltage testing, in which the dc terminals of the converter are temporarily jumpered on the dc side, can replace the low-voltage operation described in 6.3. Low-voltage energization is generally preferred however, to ensure proper phasing of the firing pulses prior to deblocking with full ac system voltage. DC short circuit testing, if performed, will create heavy demand on reactive power from the supply system.

For bipolar systems, yard energization is usually followed by an optional period of back-to-back testing. Back-to-back testing involves operating one pole as a rectifier and the other as an inverter and circulating power through a temporary jumper connecting the two poles at the high-voltage bus, preferably outside the outermost set of dc current transducers so that the dc bus differential protection can remain in-service. For monopolar systems or staged bipolar systems where back-to-back testing is not possible or convenient, dc short circuit testing can be performed instead. Where restrictions on reactive power consumption or valve operation at 90° must be observed, temporary dc current limitations or operational time constraints may be imposed during the dc short circuit tests.

During back-to-back testing, all the converter protective circuits are checked to ensure proper analog input quantities, measurements, displays, and proper performance of protective blocking and trip sequences. The proper functioning of the valve firing controls, current and voltage regulators, the reactive power control, and the tap changer control can also be verified on a limited basis. Back-to-back tests also provide a means to test the valve and transformer cooling systems. During back-to-back testing, the converters are gradually brought up to rated current over several hours.

Back-to-back testing usually requires temporarily bypassing various interlocks provided for preventing operator error. Back-to-back testing is particularly useful when the ends of a transmission have large differences in construction schedule. Final control adjustment is not possible because the dc line voltage drop is not included with the back-to-back test. Much of the work done will be repeated during transmission testing.

9. On-site transmission testing

Transmission tests include end-to-end testing, which consists of testing all performance requirements under normal operating conditions and, as conditions permit, under contingency operating conditions. The applicable HVDC system configurations should be changed, and the status of operation should be tested with all preselections (control location, control mode, control level).

End-to-end transmission tests require scheduling of power up to the rating of the associated converter stations. All specified HVDC system configurations, such as bipolar, monopolar earth return, monopolar metallic return, parallel and series converter unit operation, and reduced voltage operation (if required), should be tested. Active as well as reactive power variations will be experienced. Tests can be carried out in different directions of power and with different power levels that automatically lead to a variation of reactive power and to different firing angles. Expected real and reactive power profiles should be given in the appropriate commissioning plans. Transmission tests include:

a) Low-power tests
    1) Start and stop sequences
    2) Steady-state operation at minimum power and current
    3) Trip and block sequences
b) High-power tests
    1) Power and current ramping
    2) Steady-state operation at rated and maximum power and specified overload current
    3) Operation and integration tests
    4) Reduced voltage operation
c) Trial operation

9.1 Dry-run tests

It may be advisable to perform some tests off voltage or “dry” prior to any power level. In particular, the transfer between different dc system configurations and the verification of tripping sequences should be done “dry” before tests at minimum power transfer level can start.

9.2 Extended back-to-back tests

An alternative to round-power tests, to enable up to full current through the dc transmission line without requiring both converter stations to be available, can be accomplished on a bipolar system by jumpering the two poles at the opposite end of the line from the operating converters. This special test configuration can be viewed as an extended back-to-back test with the jumper being moved to the other end of the line. Line losses would have to be provided just as with round-power operation. Due to the double line drop, converters would operate at different dc voltages. At higher currents, some limitation with tap changer position may be encountered.

9.3 Round power/circulating-power tests

Sometimes economic power system operation or availability of power for transmission testing limits the amount of time for which the system can be used for transmission. One way around this restriction for a bipolar system is to operate in the so called “round power” set-up where one pole is operated with power in one direction and the other pole is operated with power in the other direction. Under this scheme it is possible to operate at high current and power levels as far as the equipment is concerned while only having to schedule system losses since the net power transfer is zero. If round power operation is a possible option, however, it should be stated well in advance since it usually requires special provisions in the control system such as bypassing interlocks intended to prevent operator errors and modifying the reactive power control or tap changer control for a peculiar non-commercial operating mode. Depending on the ac system capabilities, special cross tripping of the two poles may be required to quickly reduce end-to-end power transfer after a pole trip.

10. On-site trial operation

Trial operation provides an opportunity for sustained operation of the HVDC system together with the connected ac systems for an extended period of time that may start prior to any warranted operating periods. The trial operation time period is typically between 2 to 4 weeks. The operation profile should be as close as possible to expected operating conditions. This period is a time for accurate observation of the completed HVDC system and all associated components. The HVDC system should be operated by the user’s personnel. Trial operation affords the user a first indication of the HVDC systems availability under real operating conditions.

Trial operation should verify that the HVDC system is capable of reliable operation with the connected ac systems for an extended period of time without misoperation. Therefore, during trial operation, the HVDC system should be operated under expected operating conditions (i.e., operated by trained operators and dispatchers). During trial operation, the HVDC system should demonstrate its capability to ride through any disturbances in the ac systems or the communication systems that the HVDC system is designed for and specified. While it is not the intention to stage line faults or ac disturbances during trial operation, such events, if they occur during the normal course of operation, should be used to evaluate the proper performance of the HVDC systems. If possible, the HVDC system and ac network should be operated in various steady-state configurations for extended periods of time. This provides the HVDC system extended exposure to different ac system operating conditions prior to commercial operation.

10.1 Preconditions

Preconditions for the trial operation period normally include the following:

- All subsystem tests and transmission tests completed and all subsystems fully operational.
- Training of operators and other necessary personnel is sufficient for operating the HVDC system and to respond to typical station alarms.
- All HVDC system and station instrumentation are available for service (e.g., sequence of events recorders, TFRs, display panels, alarm panels, etc.).
- All end-to-end tests that verify the HVDC system can operate properly under specified ac system conditions have been completed.
- Dispatching arrangements are coordinated and permission to begin trial operation has been granted.

10.2 Power scheduling operation

During trial operation, the HVDC system should be operated in a manner as required by the owner’s intended use and as specified in the design specifications. Power transfer limits of the converter equipment (if any) should be clearly and fully identified prior to the trial operation period. Power transfer levels and their profiles (as long as they are below the power transfer limits) during trial operation should be determined by the owner's dispatching personnel based on real time requirements of the connected power systems or as can be coordinated among the interconnected utilities.

All disturbances during trial operation should be monitored, recorded, and analyzed to determine the causes and their impact. All alarms should be investigated and proper operation verified. False or phantom alarms can be more problematic than real alarms. The response of the HVDC system to disturbances and alarms should be carefully monitored. Additional test instrumentation (in addition to station instrumentation) should be available for monitoring purposes. Data of the ac system configuration during trial operation should be available. Forced outages of the HVDC system should not occur during trial operation due to malfunction of the equipment. In addition, outages due to any specified abnormal operating conditions should not occur.

11. On-site acceptance tests

Acceptance tests described in this clause include testing of various performance requirements typically included in HVDC system specifications. The tests may be performed as a separate test series or may be combined into an integrated test program of on-site testing, as appropriate, to eliminate test duplication and reduce overall commissioning time.

Acceptance tests measure the overall performance of the HVDC system. The tests demonstrate that the design is correct and that the as-built system meets the requirements of the specifications. Successful completion of the tests should result in customer acceptance of the HVDC system.

During acceptance tests, the owner and the supplier have the opportunity to agree upon repeating certain tests or performing additional testing felt necessary to verify specified performance of the HVDC transmission system. For example, it may be desirable to perform staged ac and/or dc fault testing, or perform audible noise measurements under different conditions.

11.1 Preconditions

With respect to on-site testing, construction of the system should have been completed along with subsystem tests. The ac and dc systems should be operational in the final configurations. Each test should be prescheduled and coordinated with power system schedulers, and neighboring utilities as appropriate.

11.2 Steady-state ratings

Steady-state tests with normal operating conditions of the ac and dc system configurations are typically performed to verify continuous and overload ratings, reduced voltage and reverse power operation, reactive compensation and voltage control, ac and dc harmonic filter performance, interference with communication systems (radio, TV, PLC, signal, and control systems), audible noise, and guaranteed electrical losses. These tests cover all operational sequences, preselections (control modes, control locations, control levels) and HVDC system operating configurations as well as transitions between the different preselections and HVDC system configurations. Ramping between different power levels from minimum to maximum power should be exercised under the different available HVDC system configurations, and with the respective preselections.

11.2.1 Loading tests

All components in an HVDC system are designed for maximum permissible operating temperatures and are either cooled naturally or require forced cooling. Loading tests, which include heat-run tests, verify the proper operation of all cooling systems including control and redundancy functions and should be performed over an extended time period to ensure that all components will have reached steady-state operating temperatures. For large oil-filled equipment this may take four to six hours or longer. Redundant cooling systems may be required during overload tests when the cooling systems are designed to use supplemental cooling under elevated ambient conditions. During the heat-run tests, all major HVDC system components should be monitored to verify that operating temperatures do not exceed design limits. Following the loading tests, gas-in-oil analysis should be performed on the major oil-filled components.

11.2.2 Harmonic and interference performance

The process of dc conversion generates harmonic frequencies that can radiate or propagate over the dc line or ac system. Converter station designs include harmonic filters that should reduce interference to an acceptable level. Measurements made during acceptance testing can demonstrate adequacy of design and identify any unexpected interference difficulties.

11.2.2.1 AC system interference

Harmonic filters are provided on the ac side of the converter stations to prevent harmonic currents of predominate harmonics generated by the conversion process from being injected into the ac system. Tests usually include measurement of harmonic current flow into the ac system at specified harmonic frequencies. Measurements may also be made of voltage distortion over the same frequency range. These tests should result in measurements that are at or below the specified values. Coordination should be made with local telephone companies and others that use this portion of the frequency spectrum to verify that unexpected interference is not experienced. Measurements should include the use of all available operating modes such as metallic return or reduced voltage operation.

11.2.2.2 DC line interference

Harmonic filters are provided on the dc side of HVDC converter stations to prevent harmonic interference from coupling into circuits that may parallel the dc line. Measurements may be made using a parallel test line. The test should be coordinated with telephone utilities, railroads, and others that operate telecommunication systems near the dc line. Tests should include different modes of operation. Tests should also check for harmonic coupling and resonance phenomena in the neutral bus and electrode line circuit.

11.2.3 Electrical noise performance

High-frequency interference can be generated from valve switching transients and high-voltage generated corona. This can result in direct radiation from the station or lines, or propagation over the ac or dc transmission line.

11.2.3.1 PLC interference

PLC systems operate over the frequency range of 20–200 kHz. Tests should be made at different operating modes and power levels. Measurements of PLC noise should be made on transmission lines leaving the station. The operation of PLCs should be observed for interference or loss of margin both near the converter station and at remote PLC locations.

11.2.3.2 Radio interference

With the HVDC system in operation, radiated noise measurements should be made on a contour around the station that has been defined in the specification. Noise radiated from the station should meet the specified values. Noise measurements are usually made during dry weather conditions (see ANSI C63.2-1996).

11.2.3.3 Television and broadband communications interference

With the HVDC system in operation, radiated noise measurements should be made on a contour around the station that has been defined in the specification. Noise radiated from the station should meet the specified value. Noise measurements are usually made during dry weather conditions (see ANSI C63.2-1996).

11.2.4 Audible noise performance

11.2.4.1 Equipment proximity audible noise

Equipment noise levels in areas of the station where personnel are permitted should not exceed the specified level to avoid hearing damage. Noise measurements should be performed at high noise intensity locations within the station.

11.2.4.2 Overall station audible noise

With the station in operation, noise measurements should be made on a contour around the station that has been defined in the specification. The results should meet the specified requirements and be in compliance with government regulations that may apply.

11.2.5 Loss performance

The increasing cost of energy has made it prudent to consider the cost of energy losses in the design and operation of dc systems. Guaranteed loss values may be included as part of the contract and it is not uncommon to also include provisions for bonus or penalty payments based on final loss evaluation. Direct measurement of total station loss is difficult since losses typically represent less than 1% of the station rating, a number that is comparable in magnitude to the accuracy limits of the measurement equipment provided. Usually loss evaluation is a total of individual equipment losses determined from a combination of measured and calculated values. The loss evaluation method and system parameters used for evaluation should be identified by the specification or contract. Losses are usually evaluated at no-load and at full-load operation (see IEEE Std 1158-1991 and IEEE PC57.129/D10).

Losses that are typically measured are station service loads, transformer and smoothing reactor cooling fans and pumps, valve cooling equipment, and station service transformer losses. Some calculated losses may be based upon measurements that are made at the time of equipment factory testing.

For the following equipment, the losses are usually evaluated through calculations, based on factory test results:

- Transformers
- Thyristor valves
- Smoothing reactors
- AC filters and shunt compensation banks

11.2.6 Earth electrode interference tests

Siting of the earth electrode may require coordination with owners of underground facilities such as pipelines and communications cables. A test may be required to operate the electrode at rated current with a distinguishable on-off pattern. Simultaneous measurements should be made on various underground facilities to verify that mitigation measures function properly.

11.3 Disturbance tests

Disturbance tests should be performed to verify that the dc system responds according to specified requirements to ac faults, dc line faults, loss of one pole (if applicable), and other specific dynamic response criteria. Disturbance testing may be performed off-site during dynamic performance testing (see 5.3) and on-site as part of transmission testing (see Clause 9.).

During the transmission testing period, it is important to expose the operating dc system to various disturbances to verify performance. Examples of disturbance tests include tripping reactive power compensation elements, energizing nearby transformers or shunt reactors, tripping poles, tripping generators, and forcing mode shifts with transformer tap changers or in combination with filter tripping. Disturbances can also be made by power order, current order, or voltage reference step changes to exercise different control loops.

Transfer functions could be measured by noise injection through control functions provided proper precautions are used. Other types of noise injection could involve simulations of communication noise or failures during steady-state operation or ramping.

11.3.1 Dynamic performance tests

Many dynamic performance tests can be tested more completely and without risk to the ac system by using an off-site simulator. Examples of these tests includes:

- Control mode transfers
- AC system interaction
- Commutation failures and valve misfires
- Transient behavior of ac filters
- Transformer and reactive element switching
- AC and dc system faults
- Islanding

11.3.2 Staged-fault performance tests

Staged-fault performance testing may be used to verify the overall transient performance of the dc system and verify benchmark tests performed off-site during dynamic performance testing. The application of faults results in stress to the ac network, which may be unacceptable in some situations. The tests demonstrate protection operation, fault recovery characteristics of the HVDC system, ac/dc system interactions, and electromagnetic interference performance within the station.

11.3.2.1 AC-system fault tests

Staged ac network faults can be applied near the converter station and at a remote ac line location designed to produce a known percentage voltage reduction. Faults should be performed in both rectifier and inverter operation. For faults within the converter station, the faulted pole would not be expected to recover operation. Because of the severity of the impact on the ac system, the number of faults allowed may be limited and phase-to-phase faults may not be allowed. Fault testing checks the coordination of ac and dc protection, possible misoperation of protection equipment, and transient recovery of the HVDC system.

11.3.2.2 1 DC-line fault tests

DC-line fault testing is used to verify the correct performance of the dc line protection. Since fault current is limited by the HVDC control system, dc faults have much less impact on the ac network than ac faults. DC-line fault testing may be needed to correctly adjust the dc line protection and line fault location equipment, if provided. Factory off-site tests of the dc line protection are often limited by the frequency response of the simulated transmission line. The dc line protection should correctly operate for faults at each end of the line, and should not misoperate in the unfaulted pole. The dc line protection should not operate for inverter commutation failures or for faults on the ac system.

12. Documentation

Documentation typically required to begin commissioning an HVDC system can be subdivided into the three categories shown in Figure 4 as commissioning plan, design documentation, and safety considerations [B1][6].

[6]The numbers in brackets correspond to those of the bibliography in Annex A.

Likewise, documentation resulting from the commissioning process can be subdivided into the categories identified as performance documentation, as-built drawings, and nonconformity reports.

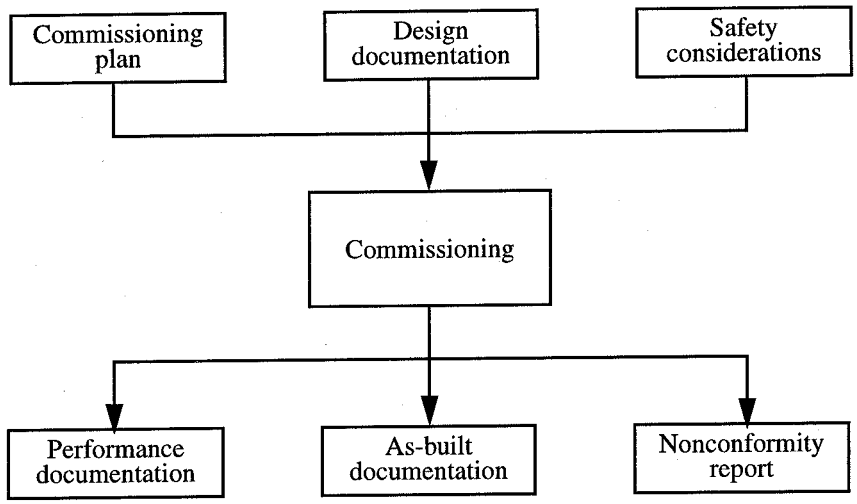

Figure 4— Documentation before and after commissioning

12.1 Commissioning plan

The commissioning plan typically consists of a master test program, disturbance test schedule, commissioning test flow diagram, and testing procedures.

12.1.1 Master test program

The master test program should provide a summary and overview of all commissioning tests required for the HVDC converter stations and associated transmission systems. The master test program should avoid unnecessary duplication of testing and identify the commissioning test team and locations where individual tests are to be performed and coordinated (converter station, load dispatch center, affected substations, etc.). Test durations should be planned with adequate time margin to allow for contingencies.

12.1.2 Disturbance test schedule

A disturbance test schedule should indicate all off-site and on-site tests planned to verify that the HVDC system responds according to specified requirements (see 11.3). Some on-site disturbance tests may require coordination with other utilities and require scheduling of tests during off-peak hours to reduce the potential impact of disturbances on connected ac systems.

12.1.3 Commissioning test flow diagram

HVDC commissioning programs involve an interrelated set of off-site and on-site tests (precommissioning, subsystem, converter station, and transmission). Figure 5 illustrates a typical commissioning test flow diagram.

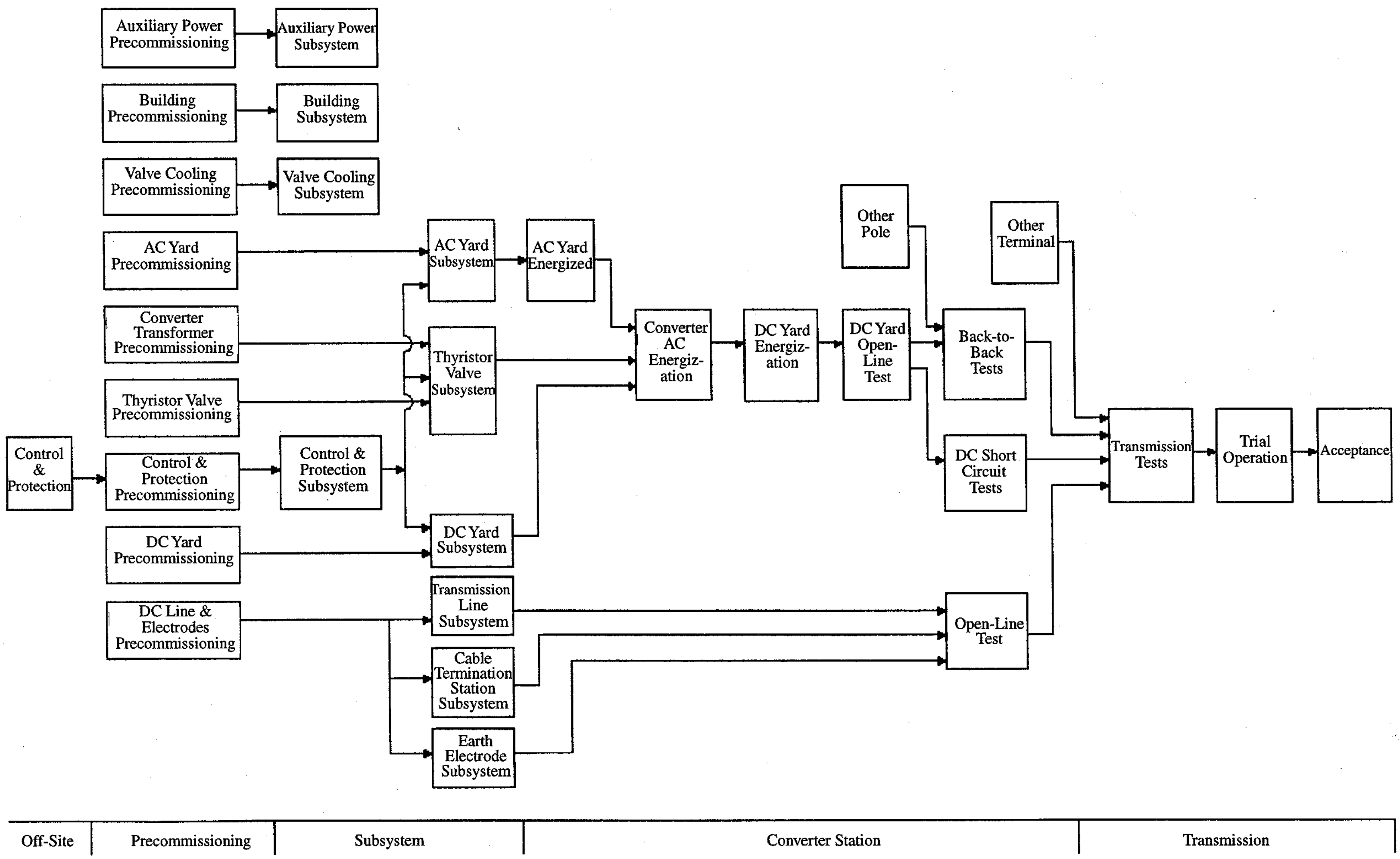

Figure 5— Commissioning test flow diagram

Precommissioning tests are local, device oriented, and independent of other equipment. These tests verify proper installation, adjustment, and local manual operation of an individual piece of equipment or apparatus. Precommissioning tests are often referred to as installation tests and can be performed by the user or supplier. Testing of transducers, capacitors, reactors, resistors, disconnects, circuit breakers, pumps, fans, grounding switches, switchgear, motor control centers, transformers, valves, and control panels is included. Devices requiring ac or dc auxiliary power can be supplied from the actual auxiliary power distribution system (if available) or from a temporary source.

If the HVDC system is to be developed in stages or involves expansion or modernization of equipment, the commissioning test program may be split into different stages. If there is an existing HVDC system already in commercial operation, the commissioning program may be compressed into a short, intensive, integrated period or broken up and spread out over a longer period during off-peak hours.

Transmission testing involves power transfer from one point to another and may require restricted use of ground electrodes and dc line. Full power testing may be limited due to operating restrictions either for network security or for economics.

12.1.4 Testing procedures

Each test identified in the master test program should have an individual detailed test procedure. These procedures should identify the test and inspection plans to be performed and typically include the following (as appropriate):

- Test objectives
- Test sequence
- Preconditions and reference to specifications, system studies, and off-site test reports
- Initial and final HVDC system configuration including energy direction, duration, ramp rates, etc.
- Special conditions, including ac system configuration, power levels (real and reactive), and generation schedules
- Test acceptance criteria
- Test equipment, measurement points, and quality assurance

12.2 Design documentation

Design documentation that may be used during the commissioning process includes inventory lists, specifications, drawings, software, system study results, off-site test results, and manuals. Design documentation covers all necessary documents to explain the design features, calculations, studies, operating characteristics and limitations of the HVDC system.

Inventory lists should itemize all equipment items furnished for the particular project. The list should identify all deliverable equipment items with appropriate user’s and supplier’s designation and identification numbers. Included with the list should be the spare parts and test equipment delivered for the particular project.

The functions of individual equipment items and subsystems are typically described in a detailed manner using specifications, drawings, and software documentation. Specifications document the equipment and subsystem technical requirements while drawings typically show the functionality and design details. Software documentation indicates the interlocking sequences and operating conditions of the individual equipment or subsystem.

Off-site test documentation includes all tests performed off-site prior to installation of equipment items or subsystems at the site. These tests can be categorized as follows:

- Factory type and routine tests
- HVDC system control and protection steady-state, dynamic, and functional performance tests

Manuals typically used during the commissioning process include the following:

— Installation manuals
— Maintenance manuals
— Training manuals
— System information manuals
— User's manuals

Installation manuals describe the particulars for installation of the HVDC system and equipment items.

Maintenance manuals describe normal maintenance practices and procedures for the HVDC system and equipment items. Typically this would include detailed maintenance plans for individual equipment items and subsystems. Installation instructions and information to supplement installation drawings are normally provided. Preventive maintenance and repair instructions (removal, replacement, and adjustment) for all subsystems indicating manufacturer's recommended maintenance intervals as well as troubleshooting instructions and diagnostic tests of malfunctioning hardware and software can be useful during commissioning tests.

Training manuals provide material from training programs for the operation and maintenance of the HVDC system. In some cases, user's operating and maintenance personnel may participate in the commissioning process to become familiar with the equipment prior to commercial operation. The availability of training manuals during this process is a necessity.

System information manuals provide a brief overview of the HVDC system and describe major design features, characteristics, and limitations of operation.

User's manuals typically provide detailed information regarding HVDC system operations. These manuals provide instructions such as how a desired control action is to be performed, what response should be expected, when it should be performed, and where the control action has to be initiated.

12.3 Safety considerations

The relevant safety requirements form a part of the commissioning preconditions. Safety responsibilities for all activities in the project are defined in these documents. Safety manuals provide information identifying precautions needed to prevent damage to equipment or any danger to human life. Safety manuals may also include user-provided documentation.

12.4 Performance documentation

Documentation of the commissioning test results should include a report describing each test series together with all relevant tests data (SER printouts, TFR recordings, etc.). The report should also include detailed descriptions of unsuccessful tests, outages, or malfunctions and diagnostic tests leading to any modifications implemented for corrections. Final data showing results of any modifications should be documented with appropriate reference to the unsuccessful tests as well as other impacted converter station documentation changes.

12.5 As-built documentation

Changes and updates that result from the commissioning procedure will lead to drawings showing the final status of all the commissioned equipment and systems.

12.6 Nonconformity report

A nonconformity report can be used throughout the commissioning procedure from off-site factory, dynamic, and functional tests up to the on-site performance tests. Whenever a tests fails, the nonconformity report should be filled out so that a record of the faulty function or hardware is maintained. After completion of commissioning, no nonconformity report should be pending.

Annex A Bibliography

(Informative)

[B1] System Tests for HVDC Installations, CIGRÉ REF 97, GT/WG 14.12, Paris, France.