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TECHNICAL REPORT

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Control and protection systems for high-voltage direct current (HVDC) power transmission systems – Off-site real-time simulation testing

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CONTROL AND PROTECTION SYSTEMS FOR HIGH-VOLTAGE DIRECT CURRENT (HVDC) POWER TRANSMISSION SYSTEMS – OFF-SITE REAL-TIME SIMULATION TESTING

FOREWORD

IEC TR 63368 has been prepared by subcommittee 22F: Power electronics for electrical transmission and distribution systems, of IEC technical committee 22: Power electronic systems and equipment. It is a Technical Report.

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

Draft	Report on voting
22F/763/DTR	22F/787/RVDTR

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

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

- reconfirmed,
- withdrawn, or
- revised.

IMPORTANT – The "colour inside" logo on the cover page of this document indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

It has been the mainstream practice of HVDC transmission system engineering to build a real-time simulation test system with actual control and protection (C&P) devices to test the functionality of various functions of the HVDC C&P system.

In order to provide practical guidance for the functional tests of HVDC transmission systems, this document covers the real-time test environment, functional performance tests, and the test report.

In order to construct the test system in the test preparation phase, Clause 4 introduces the off-site real-time simulation test environment of the functional performance tests (FPT), including the real-time simulator, the C&P system for test purposes, the interface devices and their connection relationships, and the simulation models.

Clause 5 introduces the test practices and test methods of HVDC steady state control functions.

Clause 6 introduces the test practices and test methods of HVDC dynamic control functions, whose main concerns are dynamic responses of DC voltage, DC current and DC power.

Clause 7 introduces the test practices and test methods of DC protection, whose main concerns are DC protection logic and threshold values.

Clause 8 introduces the reliability tests of C&P systems, including redundancy tests and related system switching tests, with the test practices and test methods described in detail.

Clause 9 introduces the special test practices and test methods for VSC-HVDC. In order to thoroughly test the unique functions of VSC-HVDC, it can be necessary to add some specific tests to be decided case by case.

Clause 10 introduces test reports. It includes mainly the contents of a test report.

The above clauses introduce various possible functionalities which do not apply to every HVDC project mandatorily as a whole. It is the purchaser's task to select the appropriate project-specific combination of functionalities. This document describes various possibilities; however, it is important that project-specific needs be clearly defined by the purchaser. The relationship between clauses and test phases is shown in Figure 1.

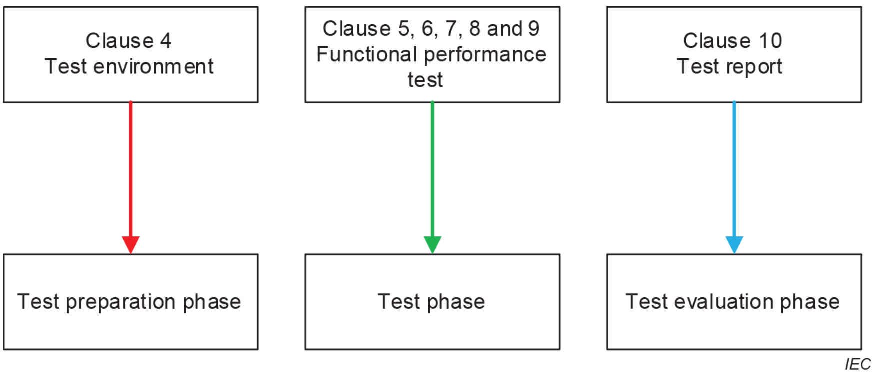

Figure 1 – Relationship between clauses and test phases

CONTROL AND PROTECTION SYSTEMS FOR HIGH-VOLTAGE DIRECT CURRENT (HVDC) POWER TRANSMISSION SYSTEMS – OFF-SITE REAL-TIME SIMULATION TESTING

1 Scope

This document provides guidance on off-site real-time simulation tests of control and protection (C&P) systems for HVDC power transmission systems. The off-site real-time simulation tests are carried out after the testing of C&P devices and prior to on-site system tests.

This document covers point-to-point, back-to-back, and multi-terminal HVDC systems of line commutated converters (LCC), voltage-sourced converters (VSC) and hybrid HVDC technologies.

In order to provide practical guidance for the functional performance tests of HVDC power transmission systems, this document covers the test environment, the contents and methods of functional performance tests, and the test report.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

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

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

3.1 Terms and definitions

3.1.1
control system delay
total time delay of the control link, including sampling delays, transmission delays and signal processing time of all control devices

3.2 Abbreviated terms

C&P	Control and protection
EHV	Extra high voltage
EMT	Electromagnetic transient
FPGA	Field-programmable gate array
FPT	Functional performance test
GRTS	Ground return transfer switch
HIL	Hardware in loop
HMI	Human machine interface
HVDC	High-voltage direct current

IGBT	Insulated-gate bipolar transistor
I/O	Input / output
LCC	Line-commutated converter
MMC	Modular multilevel converter
MRTB	Metallic return transfer breaker
MTDC	Multi-terminal HVDC transmission system
RTS	Real-time simulator/simulation
SCADA	Supervisory control and data acquisition
SER	Sequence of event recording / Sequence of event recorder
SM	Sub-module
STATCOM	Static synchronous compensator
SVC	Static var compensator
TCSC	Thyristor controlled series compensation
VDCOL	Voltage dependent current order limitation
VSC	Voltage-sourced converter

4 Test environment

4.1 General

The test environment is used for providing various power system conditions. The system conditions are based on real-time simulation for testing the functionality including dynamic behavior of an HVDC C&P system. It commonly includes RTS with models and delivered C&P devices of a specific HVDC project.

4.2 Real-time simulator

4.2.1 General

RTS refers to real-time digital simulators based on electro-magnetic transient (EMT) algorithm. RTS is used to model HVDC main circuits, adjacent AC system(s), and adjacent HVDC system(s) as required by the purpose of the test, to connect actual C&P devices with simulation interfaces. It runs models with sufficient simulation cycle time, stably and continuously, strictly in real-time in every simulation time step.

4.2.2 Simulation interface devices

4.2.2.1 General

Simulation interface devices are used to connect C&P devices, with RTS for establishing closed-loop HIL simulation systems. The protocols used for the communication among RTS, the C&P devices and the simulation interface devices are dependent on the actual project and type of simulator in use.

4.2.2.2 I/O interface devices

Simulation interface devices are used for establishing the I/O communications with RTS. Generally, there are two types of interface techniques used for commercial RTS nowadays: analog interface and digital interface.

1) Analog interface: the interface connections are performed through wires connected to the I/O interface cards of RTS.
2) Digital interface: the interface connections are performed through digital system buses, and in most of the applications, physically established via optical fibers.

4.2.2.3 Other special interfaces for RTS tests

1) Power amplifiers can be used to amplify RTS analog output signals to ensure the interface adaptation to the C&P devices designed for the actual interfaces on site. It is optional and dependent on the measurement input design of the C&P devices.
2) Disconnectors and earthing switches with slow operating time are usually not represented in RTS. Instead, they are simulated in other suitable ways such as by AC and DC switch simulator in the form of relay or digital system.

4.2.2.4 Valve interfaces for MMC-HVDC

In order to test the functions of the MMC valve base control device, appropriate interface devices could be provided for RTS. These devices are optional, and if needed, used for translating the packets of MMC sub-module on/off commands from the MMC valve base control device into a specific form adapting to the MMC models in RTS.

4.2.3 Simulation model

4.2.3.1 General

The simulator model must be adapted for the specific project and for the planned testing. Generally, the detailed characteristics of equipment in the model match the testing purposes. The simulation model is generally composed of one or more of the following in 4.2.3.2.

4.2.3.2 Model of HVDC main circuit

4.2.3.2.1 LCC converter and transformer

The LCC converter and transformer are generally integrated with one component or two individual models according to the test requirement.

The component simulates the key characteristics of the converter and transformer, including compensation algorithm, firing angle, and extinction angle measurement.

4.2.3.2.2 MMC converter and transformer

The large number of sub-modules creates an excessive computational burden for the EMT simulation of MMC-HVDC systems, especially in real-time environments. For the HIL test, the exchange of large numbers of capacitor voltages and individual firing pulses presents a communication challenge for the simulation model and the external physical control devices. In order to meet the requirements of MMC-HVDC simulation and testing, various types of models based on both processors and FPGAs have been developed using vast parallel computation techniques, which can model the MMC converter with up to thousands of sub-modules.

The time step of the MMC converter model on FPGA is usually less than 10 µs. In this case, the transformer can be modelled as an interface model for decoupling the MMC converter in small time step from the main network in large time step.

If the MMC converter model and the main network use the same time step, a traditional transformer model can be used to connect the MMC converter model and the main network.

4.2.3.2.3 HVDC transmission line and electrode line or metallic return conductor

Generally, the distributed parameter frequency-dependent model is used in RTS for HVDC overhead lines, HVDC cables, and the electrode line or metallic return conductor. The model parameters are in accordance with the actual project. For stability and accuracy purposes, the phase domain frequency dependent line model can be utilized to model DC lines and cables.