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HVDC Grid Systems and connected Converter Stations - Guideline and Parameter Lists for Functional Specifications - Part 1: Guidelines

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HVDC Grid Systems and connected Converter Stations - Guideline and Parameter Lists for Functional Specifications - Part 1: Guidelines

Réseaux CCHT et stations de conversion connectées - Lignes directrices et listes de paramètres pour les spécifications fonctionnelles - Partie 1: Lignes directrices

Hochspannungsgleichstrom-Netzsysteme - Leitfaden und Parameter-Listen für funktionale Spezifikationen - Teil 1: Leitfaden

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CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
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CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

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European foreword

This document (CLC/TS 50654-1:2018) has been prepared by CLC/TC8X/WG 06 “System Aspects of HVDC Grid”.

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Introduction

HVDC Grid Systems are a new field of technology. There are very few systems with a small number of converter stations in operation; some more are in execution or in detailed planning.

The Guidelines and Parameter Lists to Functional Specifications are presented featuring planning, specification and execution of multi-vendor HVDC Grid Systems in Europe. Being elaborated by a team of experts from leading manufacturers of HVDC technology, Transmission System Operators (TSO's), Academia and Institutions in Europe, the present document provides a commonly agreed basis for an open market of compatible equipment and solutions for HVDC Grid Systems. Executing such systems and gaining operational experience is seen an important prerequisite for developing corresponding technical standards in the future.

By elaborating this document, special care has been taken to as far as possible describe the requirements in a technologically independent way. In order to achieve that, a function of interest is described by a comprehensive set of parameters. The parameters are selected based on a systematic analysis of physical phenomena relevant to achieve the requested functionality. The physical phenomena are categorized in order to show the mutual dependence of the individual parameters and ensure completeness of the physical aspects to be considered. Based on a clearly defined common language describing the functionalities requested, existing technologies can be applied or new dedicated technical solutions can be developed.

Reflecting the early stage of technology, these Guidelines and Parameter Lists to Functional Specifications need comprehensive explanations and background information for the technical parameters. This dual character of the content will be represented by two corresponding parts:

- Part I “Guidelines” containing the explanations and the background information in context with the Parameter Lists.

- Part II “Parameter Lists” containing the essential lists of parameters and values describing properties of the a.c. respectively d.c. system (operating conditions) and parameters describing the performance of the newly installed component (performance requirements).

1 Scope

1.1 General

These Guidelines and Parameter Lists to Functional Specifications describe specific functional requirements for HVDC Grid Systems. The terminology “HVDC Grid Systems” is used here describing HVDC systems for power transmission having more than two converter stations connected to a common d.c. circuit.

While this document focuses on requirements, that are specific for HVDC Grid Systems, some requirements are considered applicable to all HVDC systems in general, i.e. including point-to-point HVDC systems. Existing IEC, Cigré or other documents relevant have been used for reference as far as possible.

Corresponding to electric power transmission applications, this document is applicable to high voltage systems, i.e. .only nominal d.c. voltages equal or higher than 50 kV with respect to earth are considered in this document.

NOTE While the physical principles of d.c. networks are basically voltage independent, the technical options for designing equipment get much wider with lower d.c. voltage levels, e.g. in case of converters or switchgear.

Both parts have the same outline and headlines to aid the reader.

1.2 About the Present Release

The present release of the Guidelines and Parameter Lists for Functional Specifications describes technical guidelines and specifications for HVDC Grid Systems which are characterized by having exactly one single connection between two converter stations, often referred to as radial systems. When developing the requirements for radial systems, care is taken not to build up potential show-stoppers for meshed systems. Meshed HVDC Grid Systems can be included into this specification at a later point in time.

The Guidelines and Parameter List to the Functional Specification of HVDC Grid Systems cover technical aspects of

- Coordination of HVDC Grid and a.c. Systems
- HVDC Grid System Characteristics
- HVDC Grid System Control
- HVDC Grid System Protection
- Models and Validation
- Beyond the present scope, the following aspects are proposed for future work:
- AC/DC converter stations
- HVDC Grid System Equipment
- HVDC Grid System Integration Tests

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

EN 60909 (all parts), *Short-circuit currents in three-phase A.C. systems*

EN 61660-1:1997, *Short-circuit currents in d.c. auxiliary installations in power plants and substations — Part 1: Calculation of short-circuit currents (IEC 61660-1:1997)*

3 Terms, definitions and abbreviations

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply. ISO and IEC maintain terminological databases for use in standardization at the following addresses:

• IEC Electropedia: available at http://www.electropedia.org/

• ISO Online browsing platform: available at http://www.iso.org/obp

3.1.1
AC/DC converter unit
indivisible operative unit comprising all equipment between the point of connection on the a.c. side and the point of connection on the d.c. side, essentially one or more converters, together with converter transformers, control equipment, essential protective and switching devices and auxiliaries, if any, used for conversion

[SOURCE: EN 62747:2014, modified – The definition was neutralised with respect to technology (not only VSC converters) and uses the terms PoC as defined in the present document]

3.1.2
AC/DC converter station
part of an HVDC system which consists of one or more AC/DC converter units including d.c. switchgear, d.c. fault current controlling devices, if any, installed in a single location together with buildings, reactors, filters, reactive power supply, control, monitoring, protective, measuring and auxiliary equipment

[SOURCE: EN 62747:2014, modified – The definition was made specific with respect to AC/DC converter units, differentiating from DC/DC converter units. Furthermore, only the term AC/DC converter station is used in the present document]

3.1.3
point of connection-DC (PoC-DC)
electrical interface point at d.c. voltage

3.1.4
point of connection-AC (PoC-AC)
electrical interface point at a.c. voltage

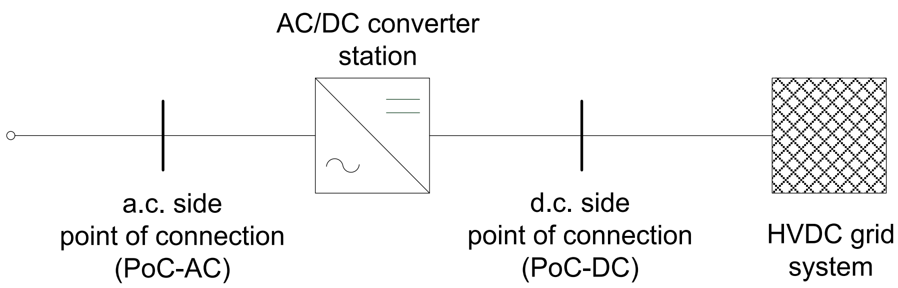

Figure 1 — Definition of the Point Of Connection-AC and the Point Of Connection-DC at an AC/DC converter station

3.1.5
DC/DC converter unit
indivisible operative unit comprising all equipment between the points of connection to the HVDC Grid System, essentially one or more converters, together with converter transformers, if any, control equipment, essential protective and switching devices and auxiliaries, if any, used for conversion

3.1.6
DC/DC converter station
part of an HVDC Grid System which consists of one or more DC/DC converter units including d.c. switchgear, d.c. fault current controlling devices, if any, installed in a single location together with buildings, reactors, filters, control, monitoring, protective, measuring and auxiliary equipment

3.1.7
HVDC Grid System
high voltage direct current transmission network connecting more than two AC/DC converter stations transferring energy in the form of high-voltage direct current including related transmission lines, switching stations, DC/DC converter stations, if any, as well as other equipment and sub-systems needed for operation

3.1.8
meshed HVDC Grid System
HVDC Grid System having more than one direct current connection between at least two converter stations

3.1.9
DC protection zone
physical part of a HVDC Grid System with a common response to d.c. faults

3.1.10
radial HVDC Grid System
HVDC Grid System having exactly one direct current connection between two arbitrary converter stations

3.1.11
rigid bipolar (HVDC) system
bipolar (HVDC) system without Dedicated Return Path or electrodes as illustrated in Figure 2

Note 1 to entry: Monopolar operation is possible by means of bypass switches during a converter pole outage, but not during an HVDC conductor outage. A short bipolar outage will follow a converter pole outage before bypass operation can be established.

(SOURCE: IEEE P1899 [1])

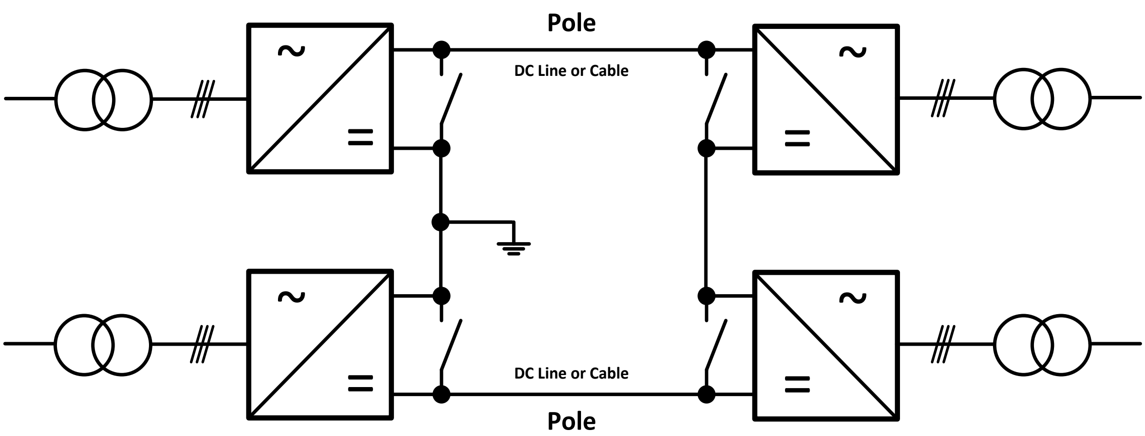

Figure 2 — Rigid Bipolar HVDC system

3.2 Abbreviations

AC/DC	alternating current / direct current (conversion)
DC/DC	direct current / direct current (conversion)
DPT	dynamic performance tests
ENTSO-E	European Network of Transmission System Operators for Electricity
FAT	factory acceptance tests
FCR	frequency containment reserve
FRR	frequency restoration reserve
GOOSE	generic object-oriented substation events
HSS	high-speed switches
HV	high voltage
HVDC	high-voltage direct current
IEEE	Institute of Electrical and Electronics Engineers
LAT	laboratory acceptance test
LVRT	low-voltage ride through
MMC	modular multilevel converter
NC	Network Code
OHL	overhead line
OP	operating point
OPF	optimum power flow
OVRT	over-voltage ride through
PoC-AC	point of connection on a.c. side
PoC-DC	point of connection on d.c. side
POD	power oscillation damping
STATCOM	static synchronous compensator
THD	total harmonic distortion
TSO	transmission system operator
UVRT	under-voltage ride through
VSC	voltage-sourced converter

4 Coordination of HVDC Grid System and AC Systems

4.1 Purpose of the HVDC Grid System and Power Network Diagram

To provide an overall understanding of the HVDC Grid System, the purposes and basic functions of the HVDC Grid System including all AC/DC converter stations shall be explained.

To explain the a.c. and HVDC Grid System structure, a Power Network Diagram shall be specified. This diagram shall contain the following information as a minimum:

- a.c. networks showing the connection of each AC/DC converter station to the synchronous zones

- HVDC Grid System showing in detail, how the AC/DC converter stations are interconnected on the d.c. side, including, if any, lines, reactors, switches, DC Breakers, DC/DC converters, energy storages, braking choppers, pre-insertion resistors

The main electrical parameters of all installations listed above shall be specified.

4.2 Hybrid AC/DC Power Flow Optimization

The behaviour of an HVDC Grid System and its AC/DC converter stations within their a.c. system environment is typically described in corresponding network codes for the respective a.c. systems. This chapter describes typical requirements from the a.c. system perspective with respect to their implications on the design of HVDC Grid Systems.

An HVDC Grid System with more than two AC/DC converter stations in operation requires superordinate coordination of the power flow between the individual converter stations. The requirements for such coordination are described in chapter HVDC Grid System Control.

The steady-state active and reactive power capabilities of an AC/DC converter station are described by the maximum and minimum reactive power exchange capability charts (inductive and capacitive) depending on active power and voltage (P_{AC},U_{AC}) at the PoC-AC of each station as shown in Figure 3. This diagram can be specified for different a.c. voltage levels. There can be similar diagrams describing the boundaries under temporary conditions, e.g. overload operation.

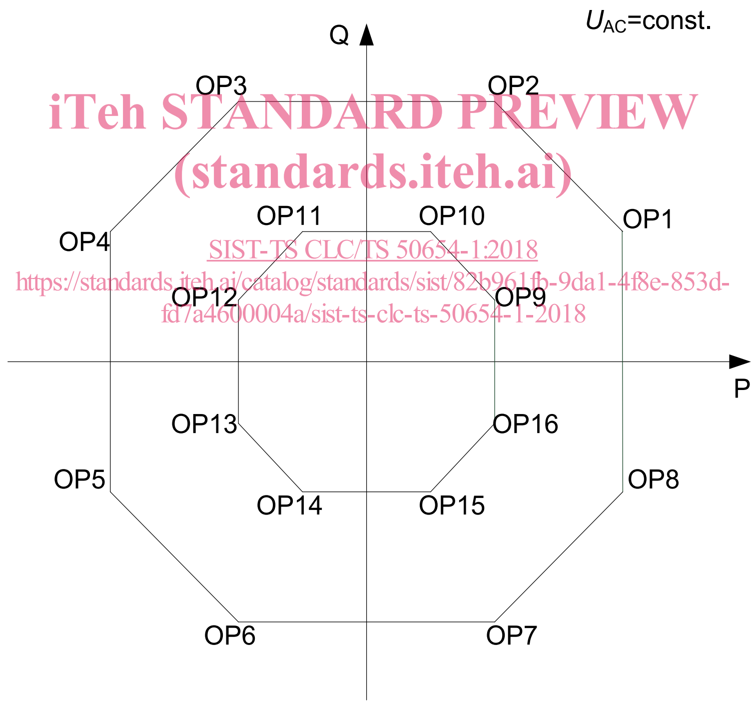

Figure 3 — Example of a PQ-diagram showing maximum and minimum reactive power (inductive and capacitive) exchange capability of an AC/DC converter station

Compared to a.c. infrastructures, AC/DC converter stations provide the capability to set and control active power flow going through them. The active power set points as well as the control droop parameters have an impact on the global grid power flows (a.c. and d.c.). Optimizing the static power flow, can aim at different objectives, e.g. minimizing the overall losses, while remaining below the limits of individual equipment (converters, ampacity of lines, breakers, etc.) and minimizing the consequences of contingencies such as loss of transmissible power.

In this chapter a general categorization of converter operational functions into basic operation functions during normal operation states, basic operation functions during abnormal operation states and functions for ancillary service provision is provided. Basic operation functions both during normal and abnormal operating state are functions which need to be parameterized since they are basic to the coordination of an HVDC grid with a.c. systems. The consecutive chapters will further outline these functions.

4.3 Basic Operation Functions – Converter Normal Operation State

4.3.1 General

The converter station control has two fundamental degrees of freedom on the a.c. side:

- active power injection
- reactive power injection

In general for active current exchange, reference values can be given for the following control objectives:

- active power control
- a.c. frequency control
- d.c. voltage control

The corresponding control objectives for active current exchange cannot be reached independently from one another.

For reactive current exchange, reference values can be given for the following control objectives

- reactive power control
- a.c. voltage magnitude control

These functions are described under subchapter Ancillary Services.

The corresponding control objectives for reactive current exchange cannot be reached independently from one another.

The two fundamental degrees of freedom are reflected in the following three basic operation functions of a converter station:

- maintaining the a.c. system frequency
- maintaining the d.c. voltage
- transmitting scheduled power at a defined power factor

The basic operating functions are specified by as follows:

- a.c. system frequency by a frequency / power droop (s_{PF})
- d.c. voltage by a d.c. voltage / d.c. power droop (s_{P_UDC}) or a d.c. voltage / d.c. current droop s_{IDC_UDC})

The capabilities and requirements of all converter stations connected to an HVDC Grid System have to be coordinated with the a.c. system needs.

4.3.2 AC System Frequency by a Frequency / Power Droop

The a.c. system frequency by frequency power droop describes the change of active power in response to a deviation of the a.c. system frequency from its reference value. It is defined by

$$s_{PF} = (\Delta f / f_{nom}) / (\Delta P / P_{nom})$$

where:

Δf is the frequency change

f_{nom} is the nominal a.c. system frequency

ΔP is the change of the active power output of the converter station

P_{nom} is the nominal active power of an AC/DC converter station

There are two extreme cases:

a) scheduled power, $|s_{PF}| \rightarrow \infty$

In this case, the converter station will operate at a power reference value and does not contribute to a.c. system frequency control

b) constant a.c. system frequency $s_{PF} = 0$

In this case, the converter station will exchange the power needed to keep the a.c. system frequency constant.

Case b) as well as all other cases with $|s_{PF}| \neq \infty$ require at least one independent source of active power connected to the HVDC Grid System, such as an asynchronous a.c. system.

4.3.3 DC Voltage / DC Power Droop

The d.c. voltage by a d.c. voltage / d.c. power droop (s_{P_UDC}) describes the change of active power in response to a deviation of the d.c. voltage from its reference value.

$$s_{P\_UDC} = (\Delta U_{DC} / U_{DCnom}) / (\Delta P / P_n)$$

Similarly, the d.c. voltage by a d.c. voltage / d.c. current droop (s_{IDC_UDC}) describes the change of d.c. current in response to a deviation of the d.c. voltage from its reference value. It is defined by

$$s_{IDC\_UDC} = (\Delta U_{DC} / U_{DCnom}) / (\Delta I_{DC} / I_{DCnom})$$

There are two extreme cases:

a) scheduled power, $s_{P\_UDC} = \infty$, $s_{IDC\_UDC} = \infty$

In this case, the converter station will operate at a power reference value and does not contribute to d.c. voltage control.

b) constant d.c. voltage, $s_{P\_UDC} = 0$, $s_{IDC\_UDC} = 0$

In this case, the converter station will exchange the power needed to keep the d.c. voltage at its terminals constant.

In all other cases, the contributions of a converter station to the d.c. voltage control is specified by corresponding droop values s_{P_UDC}, s_{IDC_UDC} between these two extremes.

The above droop characteristics are the most common, but there could be others along with all other control modes as defined in chapter Converter Control Modes where it is explained that droop constants could be a function of active power, d.c. voltage, etc. Several droop constants $s(P)$ could be used to model dead bands etc.