IEC TS 63291-2

Edition 1.0 2023-09

TECHNICAL SPECIFICATION

colour inside

High voltage direct current (HVDC) grid systems and connected converter stations – Guideline and parameter lists for functional specifications – Part 2: Parameter lists



IEC TS 63291-2:2023-09(en)



THIS PUBLICATION IS COPYRIGHT PROTECTED

Copyright © 2023 IEC, Geneva, Switzerland

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either IEC or IEC's member National Committee in the country of the requester. If you have any questions about IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

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

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

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

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

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 It also gives information on projects, replaced and withdrawn publications.

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

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

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

Electropedia - www.electropedia.org
The world's leading online dictionary on electrotechnology, containing more than 22 300 terminological entries in English and French, with equivalent terms in 19 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC TS 63291-2

Edition 1.0 2023-09

TECHNICAL SPECIFICATION

colour inside

High voltage direct current (HVDC) grid systems and connected converter stations – Guideline and parameter lists for functional specifications – Part 2: Parameter lists

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 29.200; 29.240.01

ISBN 978-2-8322-7572-6

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

® Registered trademark of the International Electrotechnical Commission

CONTENTS

FOREWORD 9
INTRODUCTION 11
1 Scope 12
2 Normative references 12
3 Terms, definitions and abbreviated terms 13
3.1 Terms and definitions 13
3.2 Abbreviated terms 17
4 Coordination of HVDC grid and AC systems 18
4.1 About HVDC grids 18
4.2 HVDC grid structure 18
4.3 Purpose of the HVDC grid and power network diagram 18
4.4 AC/DC power flow optimisation 19
4.5 Converter operational functions 21
4.5.1 Basic operation functions – Converter normal operation state 21
4.5.2 Basic operation functions – Converter abnormal operation state 22
4.5.3 Ancillary services 24
5 HVDC grid characteristics 28
5.1 HVDC circuit topologies 28
5.1.1 Availability and reliability 28
5.1.2 Basic characteristics and nomenclature 28
5.1.3 Attributes of HVDC grids or HVDC grid subsystems 29
5.1.4 Attributes of an HVDC station 29
5.2 Connection modes 30
5.3 Grid operating states 30
5.3.1 General 30
5.3.2 Normal state 30
5.3.3 Alert state 30
5.3.4 Emergency state 30
5.3.5 Blackout state 30
5.3.6 Restoration 30
5.4 DC voltages 31
5.4.1 General 31
5.4.2 Nominal DC system voltage 32
5.4.3 Steady-state DC pole voltage 32
5.4.4 Temporary DC pole voltage 32
5.4.5 DC neutral bus voltage 33
5.5 Insulation coordination 35
5.6 Short-circuit characteristics 35
5.6.1 Calculation of short-circuit currents in HVDC grids 35
5.6.2 Short-circuit current design requirements 37
5.7 Steady-state voltage and current distortions 37
5.7.1 Emissions and impacts 37
5.7.2 Rights and obligations of a connectee 39
5.7.3 Similarities between HVDC grids and AC networks 39
5.7.4 Voltage and current distortion limits 39
5.7.5 Allocation of limits to individual connectees 39

5.7.6 Frequency-dependent DC system impedance 39
5.8 DC system restoration 39
5.8.1 General 39
5.8.2 Post-DC fault recovery 40
5.8.3 Restoration from blackout 40
6 HVDC grid control 40
6.1 Closed-loop control functions 40
6.1.1 General 40
6.1.2 Core control functions 40
6.1.3 Coordinating control functions 40
6.2 Controller hierarchy 40
6.2.1 General 40
6.2.2 Internal converter control 40
6.2.3 DC node voltage control 40
6.2.4 Coordinated HVDC grid control 41
6.2.5 AC/DC grid control 44
6.3 Propagation of information 44
6.4 Open-loop controls 48
6.4.1 Coordination of connection modes between HVDC stations and their PoC-DC 48
6.4.2 Operating sequences for HVDC grid installations 48
6.4.3 Post-DC fault recovery 49
7 HVDC grid protection 49
7.1 General 49
7.2 DC fault separation 49
7.3 Protection system related installations and equipment 50
7.3.1 AC/DC converter station 50
7.3.2 HVDC grid topology and equipment 50
7.4 HVDC grid protection zones 50
7.4.1 General 50
7.4.2 Permanent stop P 53
7.4.3 Permanent stop PQ 54
7.4.4 Temporary stop P 54
7.4.5 Temporary stop PQ 54
7.4.6 Continued operation 54
7.4.7 Example of a protection zone matrix 54
7.5 DC protection 55
7.5.1 General 55
7.5.2 DC converter protections 55
7.5.3 HVDC grid protections 55
7.5.4 HVDC grid protection communication 55
8 AC/DC converter stations 55
8.1 Purpose 55
8.2 AC/DC converter station types 55
8.3 Overall requirements 55
8.3.1 Robustness of AC/DC converter stations 55
8.3.2 Availability and reliability 56
8.3.3 Active power reversal 56

8.4 Main circuit design 56
8.4.1 General characteristics 56
8.4.2 DC side 57
8.4.3 AC side 62
8.5 HVDC grid control and protection interface 62
8.6 Controls 63
8.6.1 General 63
8.6.2 Automated vs manual operation 63
8.6.3 Control modes and support of coordination 63
8.6.4 Limitation strategies 64
8.6.5 Operating sequences for AC/DC converter station 65
8.6.6 Dynamic behaviour 65
8.7 Protection 66
8.7.1 General 66
8.7.2 Configuration requirements 66
8.7.3 Function requirements 66
8.7.4 Fault separation strategy for faults inside the AC/DC converter station 66
8.7.5 Coordination of the DC protection with the HVDC grid 66
8.7.6 Example for coordination of the DC protection with the HVDC grid 66
9 HVDC grid installations 66
9.1 General 66
9.2 DC switching station 66
9.2.1 Purpose 66
9.2.2 Overall requirements 67
9.2.3 Main circuit design 67
9.2.4 HVDC grid control and protection interface 74
9.2.5 Controls 75
9.2.6 Protection 78
9.3 HVDC transmission lines 79
9.3.1 Purpose 79
9.3.2 Overall requirements 79
9.3.3 Main circuit design 80
9.3.4 HVDC grid control and protection interface 82
9.3.5 Controls 83
9.3.6 Protection 83
9.4 DC/DC converter stations 83
10 Studies and associated models 84
10.1 General 84
10.2 Description of studies 84
10.2.1 General 84
10.2.2 HVDC grid planning studies 84
10.2.3 HVDC grid design studies 84
10.2.4 HVDC grid extension studies 84
10.2.5 Studies for HVDC grid installation refurbishments and other modifications 84
10.3 Models and interfaces 84
10.3.1 General 84
10.3.2 Model interfaces and integration compatibility 85
10.3.3 Model capability 85

10.3.4 Model format 85
10.3.5 Model maintenance and portability 86
10.3.6 Model aggregation 86
10.3.7 Model testing and validation 86
11 Testing 87
11.1 General 87
11.2 Off-site testing 88
11.2.1 General 88
11.2.2 Factory system tests 88
11.3 On-site testing 88
Bibliography 89

Figure 1 – Definition of the point of connection-AC and the point of connection-DC at an AC/DC converter station 14
Figure 2 – Rigid bipolar HVDC system 16
Figure 3 – Generic AC over- and undervoltage ride through profile of an AC/DC converter station: Different values can be specified for symmetrical and asymmetrical faults 24
Figure 4 – Temporary DC pole to earth voltage profiles at a PoC-DC 31
Figure 5 – Generic neutral bus voltage profile at a PoC-DC 34
Figure 6 – Standard approximation function 37
Figure 7 – Typical DC node voltage control modes (illustration in DC voltage/power plane) 41
Figure 8 – Generation of final converter schedules including converter control modes and its parameters 45
Figure 9 – Propagation of switching commands to individual HVDC stations 46
Figure 10 – Operating sequences as transitions between operating states 48
Figure 11 – Example voltage and current traces in the event of "permanent stop" 51
Figure 12 – Example voltage and current traces in the event of "temporary stop P" 52
Figure 13 – Example voltage and current traces in the event of "continued operation" 53

Table 1 – Nomenclature of HVDC circuit topologies 19
Table 2 – Active and reactive power characteristics for a given AC system voltage operating range of an AC/DC converter station 19
Table 3 – Parameters of an HVDC transmission line 21
Table 4 – Parameter list for AC system frequency following a frequency / power droop operation of an AC/DC converter station 21
Table 5 – Parameter list for DC voltage / DC power droop operation of an AC/DC converter station 22
Table 6 – Parameters describing the operation conditions of the AC network at an AC/DC converter station prior to and after a fault 22
Table 7 – Time requirements for power restoration in the event of temporary faults 23
Table 8 – AC undervoltage ride through requirements for an AC/DC converter station 23
Table 9 – AC overvoltage ride through requirements for an AC/DC converter station 24
Table 10 – Coordination of power associated with primary frequency control 25
Table 11 – FCR parameters for an AC/DC converter station, parameters for active power frequency response in FSM 26

Table 12 – Voltage range capability parameters for an AC/DC converter station 27
Table 13 – Reactive power capability parameters for an AC/DC converter station 27
Table 14 – Parameters describing electromechanical oscillations 27
Table 15 – Parameters describing post-fault active power recovery at an AC/DC converter station 28
Table 16 – Characteristics of the HVDC grid 28
Table 17 – DC circuit earthing parameters 29
Table 18 – Parameters for each return path 30
Table 19 – Nominal DC system voltage at a PoC-DC 32
Table 20 – DC pole voltage range parameters at a PoC-DC of an HVDC station – Steady-state 32
Table 21 – DC pole voltage range parameters at a PoC-DC of an HVDC station – Temporary undervoltages 32
Table 22 – DC pole voltage range parameters at a PoC-DC of an HVDC station – Temporary overvoltages 33
Table 23 – DC neutral bus voltage range parameters 34
Table 24 – Insulation levels at a PoC-DC 35
Table 25 – Maximum converter current of an HVDC station into the HVDC grid 35
Table 26 – Component data – Earthing branch 36
Table 27 – Component data – Standalone DC capacitors and DC filters of an HVDC station 36
Table 28 – Component data – DC line reactors of an HVDC station 36
Table 29 – Component data – DC lines (OHL, cable including electrode lines)[a] 36
Table 30 – Short-circuit current parameters at a PoC-DC 37
Table 31 – Equivalent impedances for calculating voltage and current distortions at a PoC-DC 38
Table 32 – Pre-existing DC voltage and current distortions at a PoC-DC 38
Table 33 – Planning levels and permissible DC voltage and current distortions at a PoC-DC 38
Table 34 – Coupling factors for calculating voltage distortions at a remote bus caused by emissions at a PoC-DC 39
Table 35 – Specification of DC system impedance 39
Table 36 – DC node voltage control parameters 41
Table 37 – System state variables and equipment status signals (interface list) 42
Table 38 – General interface (signal list) for autonomous adaption control rules 42
Table 39 – General interface (signal list) for defining an observation 43
Table 40 – General interface (signal list) for defining countermeasures of rules 43
Table 41 – Interface parameters required from the HVDC grid control layer 44
Table 42 – General interface (signal list) for orders from TSOs 44
Table 43 – General interface (signal list) defining a "converter schedule" 45
Table 44 – General interface (signal list) defining "switching commands" 46
Table 45 – General signal interface (physical quantities) of the "station information" 47
Table 46 – General signal interface (control parameters) of the "station information" 48
Table 47 – Unified description of operating sequences 49
Table 48 – Parameters for recovery sequences after DC line faults 49

Table 49 – Example of an HVDC grid protection zone matrix 50
Table 50 – DC protection parameter list 50
Table 51 – DC converter protection parameter list 55
Table 52 – Converter station topology 56
Table 53 – Energy dissipation/absorption capability at a PoC 57
Table 54 – DC connection modes of the AC/DC converter station 58
Table 55 – DC circuit re-configuration time requirements 58
Table 56 – Repetition of DC fault events and recovery attempts 59
Table 57 – DC circuit energisation 60
Table 58 – Connecting the AC/DC converter station 60
Table 59 – Disconnecting the AC/DC converter station 60
Table 60 – DC circuit de-energisation 61
Table 61 – Parameters for the automatic control interface of the AC/DC converter station according to standard protocols 63
Table 62 – Parameters for the automatic control interface of the AC/DC converter station according to proprietary protocols 63
Table 63 – Parameters for the available control modes of the AC/DC converter station 64
Table 64 – Limitation strategies 65
Table 65 – Operating states and transitions for the AC/DC converter station 65
Table 66 – Protection coordination of the AC/DC converter station and the HVDC grid (for main and backup concept including the separation concept and the FSD) 66
Table 67 – DC switching station topology 67
Table 68 – Temporary energy dissipation/absorption capability of the DC switching station 68
Table 69 – Power flow controlling capability of a DC SU 68
Table 70 – DC connection modes of a DC SU for PoC-DCx 69
Table 71 – DC circuit re-configuration time requirements 69
Table 72 – Repetition of DC fault events and recovery attempts 71
Table 73 – DC circuit energisation 72
Table 75 – Disconnecting the DC switching station 72
Table 76 – DC circuit de-energisation 73
Table 77 – Parameters for the automatic control interface of the DC switching station according to standard protocols 75
Table 78 – Parameters for the automatic control interface of the DC switching station according to proprietary protocols 75
Table 79 – Parameters for the available control modes of the DC switching station 76
Table 80 – Limitation strategies 77
Table 81 – Operating states and transitions for a SU of the DC switching station 78
Table 82 – Protection coordination of the DC switching station and the HVDC grid (for main and backup concept including the separation concept and the FSD) 79
Table 83 – DC line power transmission parameters for the transmission line including all different HVDC transmission line sections, if any 80
Table 84 – Frequency range for specification of DC system impedance 82
Table 85 – Parameters defining the model generalities 84

Table 86 – Parameters to characterize the model capability 85
Table 87 – Parameters to define the model format 85
Table 88 – Parameters defining the model aggregation 86
Table 89 – Parameters defining the model validation 86
Table 90 – Parameters for testing 87
Table 91 – Minimum set of parameters to be defined for all test scenarios 87

INTERNATIONAL ELECTROTECHNICAL COMMISSION

_____

HIGH VOLTAGE DIRECT CURRENT (HVDC) GRID SYSTEMS AND CONNECTED CONVERTER STATIONS – GUIDELINE AND PARAMETER LISTS FOR FUNCTIONAL SPECIFICATIONS –

Part 2: Parameter lists

FOREWORD

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

IEC TS 63291-2 has been prepared by IEC technical committee TC 115: High Voltage Direct Current (HVDC) transmission for DC voltages above 100 kV. It is a Technical Specification.

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

Draft	Report on voting
115/320/DTS	115/329/RVDTS

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

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

This Technical Specification is to be used in conjunction with IEC TS 63291-1:2023.

A list of all parts in the IEC 63291 series, published under the general title *High voltage direct current (HVDC) grid systems and connected converter stations – Guideline and parameter lists for functional specifications*, can be found on the IEC website.

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,
- replaced by a revised edition, or
- amended.

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

In the preparation of 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.

Reflecting the early stage of technology, the technical parameters need comprehensive explanations and background information. This need is reflected in the dual character of the content, which is presented in the two corresponding parts:

- IEC TS 63291-1, Guideline containing the explanations and the background information in context with the parameter lists;
- IEC TS 63291-2, Parameter lists containing the essential lists of parameters and values describing properties of the AC as well as the DC system (operating conditions) and parameters describing the performance of the newly installed component (performance requirements).

IEC TS 63291-1 and IEC TS 63291-2 have the same structure to aid the reader.

At the time of writing there is no real-life multi-national, multi-vendor HVDC grid project to which the guideline and parameter lists can be applied. Practical experiences in the near future are expected to provide input for developing these guideline and parameter lists further.

HIGH VOLTAGE DIRECT CURRENT (HVDC) GRID SYSTEMS AND CONNECTED CONVERTER STATIONS – GUIDELINE AND PARAMETER LISTS FOR FUNCTIONAL SPECIFICATIONS –

Part 2: Parameter lists

1 Scope

This document defines aspects on planning, specification, and execution of multi-vendor HVDC grid systems also referred to as HVDC grids. The terms "HVDC grid systems" or "HVDC grids" are used in this document to describe HVDC systems for power transmission having more than two HVDC stations connected to a common DC circuit. The DC circuit can be of radial or meshed topology or a combination thereof. In this document, the term "HVDC grids" is used.

While this document focuses on requirements specific for HVDC grids, some requirements are considered applicable to all HVDC systems in general, i.e., including point-to-point HVDC systems. Existing IEC (e.g., IEC TR 63363-1 [1]), Cigre or other relevant documents 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., those having typically nominal DC voltages higher than 50 kV with respect to earth are considered in this document.

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

This document covers technical aspects of:

- coordination of HVDC grid and AC systems,
- HVDC grid characteristics,
- HVDC grid control,
- HVDC grid protection,
- AC/DC converter stations,
- HVDC grid installations, including DC switching stations and HVDC transmission lines,
- studies and associated models,
- testing.

Beyond the scope of this document, the following content is proposed for future work:

- DC/DC converter stations.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

IEC TS 63291-1:2023, *High voltage direct current (HVDC) grid systems and connected converter stations – Guideline and parameter lists for functional specifications – Part 1: Guideline*

3 Terms, definitions and abbreviated terms

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
AC/DC converter unit
indivisible operative unit comprising all equipment between the PoC-AC and the PoC-DC, essentially one or more converters, together with interface transformers, control and portection equipment, essential protective and switching devices and auxiliaries, if any, used for conversion

Note 1 to entry: The term "converter transformer" is also used instead of "interface transformer".

[SOURCE: IEC 62747:2014, 7.5, modified – The definition was neutralised with respect to technology (not only VSC converters) and uses the term PoC as defined in this document.]

3.1.2
AC/DC converter station
part of an HVDC system which consists of one or more AC/DC converter units including DC switchgear, if any, DC 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: IEC 62747:2014, 9.21, 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 this document.]

3.1.3
point of connection-DC
PoC-DC
electrical interface point at DC voltage as shown in Figure 1

3.1.4
point of connection-AC
PoC-AC
electrical interface point at AC voltage as shown in Figure 1