

# TECHNICAL REPORT

**Guideline for the system design of HVDC converter stations with line-commutated converters**



## THIS PUBLICATION IS COPYRIGHT PROTECTED

Copyright © 2019 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 Central Office  
3, rue de Varembe  
CH-1211 Geneva 20  
Switzerland

Tel.: +41 22 919 02 11  
[info@iec.ch](mailto:info@iec.ch)  
[www.iec.ch](http://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](http://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 It also gives information on projects, replaced and withdrawn publications.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](http://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](http://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](mailto:sales@iec.ch).

#### Electropedia - [www.electropedia.org](http://www.electropedia.org)

The world's leading online dictionary on electrotechnology, containing more than 22 000 terminological entries in English and French, with equivalent terms in 16 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

#### IEC Glossary - [std.iec.ch/glossary](http://std.iec.ch/glossary)

67 000 electrotechnical terminology entries in English and French extracted from the Terms and Definitions clause of IEC publications issued since 2002. Some entries have been collected from earlier publications of IEC TC 37, 77, 86 and CISPR.

Preview generated by EVS

# TECHNICAL REPORT

---

**Guideline for the system design of HVDC converter stations with line-commutated converters**

INTERNATIONAL  
ELECTROTECHNICAL  
COMMISSION

ICS 29.240.01; 29.240.10

ISBN 978-2-8322-7068-4

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

## CONTENTS

FOREWORD.....	6
INTRODUCTION.....	8
1 Scope.....	9
2 Normative references .....	9
3 Terms and definitions .....	9
4 Symbols .....	10
4.1 Letter symbols for variables .....	10
4.2 Subscripts.....	11
5 Overview of HVDC system design .....	11
5.1 General.....	11
5.2 Formulation of system design .....	13
5.2.1 HVDC system ratings.....	13
5.2.2 HVDC system configuration .....	13
5.2.3 Reactive power compensation and control .....	13
5.2.4 AC/DC interaction and control.....	13
5.2.5 Insulation coordination.....	14
5.2.6 AC/DC harmonic filtering .....	14
5.2.7 Environmental considerations .....	14
5.3 System studies and simulations .....	14
6 Determination of design conditions and requirements .....	16
6.1 Environmental conditions and requirements .....	16
6.2 DC transmission line (cable) and earth electrode .....	17
6.2.1 Parameters of DC overhead transmission line .....	17
6.2.2 Parameters of DC cable.....	18
6.2.3 Parameters of electrode line and ground electrode .....	18
6.3 AC system conditions.....	18
6.3.1 Operating scenarios of AC/DC system .....	18
6.3.2 AC system modelling .....	18
6.3.3 Relevant AC system protection .....	19
6.3.4 Reactive power supply and absorption.....	19
6.3.5 Short-circuit current or capacity .....	20
6.3.6 AC bus voltage .....	20
6.3.7 AC system frequency.....	21
6.3.8 Pre-existing harmonic and negative sequence voltage .....	21
6.4 Requirements for HVDC systems arising from AC/DC interaction .....	22
6.5 AC system equivalents.....	23
6.5.1 General .....	23
6.5.2 Equivalent for AC/DC system dynamic or transient simulation .....	23
6.5.3 Impedance equivalent for AC filter design.....	24
6.5.4 System equivalent for low order harmonic resonance study .....	25
7 Main circuit design.....	26
7.1 Ratings .....	26
7.1.1 Rated power .....	26
7.1.2 Rated voltage .....	27
7.1.3 Rated current.....	28
7.2 Configurations .....	28

7.2.1	Pole and return path .....	28
7.2.2	Converter topology .....	29
7.2.3	DC switchyard configuration .....	30
7.2.4	Reactive power equipment.....	38
7.3	Determination of main circuit parameters .....	38
7.3.1	General .....	38
7.3.2	Control strategy .....	39
7.3.3	Tolerances and errors.....	40
7.3.4	Determination of converter transformer impedance .....	40
7.3.5	Relative inductive voltage drop ( $d_{xN}$ ) and relative resistive voltage drop ( $d_{rN}$ ) .....	40
7.3.6	Ideal no-load DC voltage .....	41
7.3.7	DC voltage and DC current .....	41
7.3.8	Rated capacity of converter transformer .....	42
7.3.9	Converter transformer taps .....	43
7.3.10	Inductance of smoothing reactor .....	44
8	Insulation coordination.....	44
9	Filter design .....	45
9.1	General.....	45
9.2	AC filter design .....	45
9.3	DC filter design .....	45
9.4	Power line carrier (PLC) filters .....	46
9.5	Radio frequency interference (RFI) .....	46
10	Reactive power compensation and control.....	47
10.1	General.....	47
10.2	Reactive power consumption .....	47
10.2.1	Reactive power consumption calculation.....	47
10.2.2	Maximum reactive power consumption.....	48
10.2.3	Minimum reactive power consumption .....	48
10.3	Determination of reactive power equipment capacity .....	48
10.3.1	General .....	48
10.3.2	Capacity of reactive power supply equipment .....	48
10.3.3	Capacity of reactive power absorption equipment .....	48
10.3.4	Sizing of reactive power sub-bank .....	49
10.3.5	Sizing of reactive power bank .....	49
10.4	Reactive power control .....	49
10.4.1	General .....	49
10.4.2	Reactive power exchange control/voltage control .....	50
10.4.3	Voltage limitation .....	50
10.5	Temporary overvoltage control.....	51
11	Basic parameters of main equipment .....	51
11.1	General.....	51
11.2	Converter valves .....	51
11.2.1	General .....	51
11.2.2	Valve hall environment .....	51
11.2.3	Current rating .....	52
11.2.4	Voltage rating .....	52
11.2.5	Losses of converter valves .....	53
11.2.6	Testing requirements .....	53

11.3	Converter transformers .....	53
11.3.1	General .....	53
11.3.2	Current rating .....	54
11.3.3	Voltage rating .....	54
11.3.4	Other rating .....	54
11.3.5	Rated loss .....	54
11.3.6	Test requirements.....	55
11.4	Smoothing reactor.....	55
11.4.1	General .....	55
11.4.2	Current ratings.....	55
11.4.3	Voltage rating .....	56
11.4.4	Other ratings .....	56
11.4.5	Losses.....	56
11.4.6	Test requirements.....	56
11.5	Wall bushings .....	56
11.5.1	General .....	56
11.5.2	Current rating .....	56
11.5.3	Voltage rating .....	56
11.5.4	Testing requirement.....	56
11.6	AC and DC filter equipment.....	57
11.7	PLC filter equipment .....	57
11.8	Other equipment in DC yard.....	57
Annex A (informative) Typical control, measurement and equipment manufacturing tolerance in HVDC systems .....		58
Annex B (informative) Technical parameters for equipment specification .....		59
B.1	Converter valve.....	59
B.2	Converter transformer.....	61
B.3	Smoothing reactor.....	62
Bibliography.....		63
Figure 1 – System design in an HVDC project.....		12
Figure 2 – Example of schematic diagram of AC system frequency variation range.....		21
Figure 3 – Sector diagram of system harmonic impedance.....		24
Figure 4 – Circle diagram of system harmonic impedance.....		25
Figure 5 – Structure of equivalent network for low order harmonic resonance study.....		26
Figure 6 – Converter transformer connection topology .....		30
Figure 7 – Sketch maps of the DC yard switches of HVDC system .....		33
Figure 8 – Schematic diagram of converter parallel connection .....		33
Figure 9 – Schematic diagram of pole line parallel connection .....		34
Figure 10 – Procedure of NBS disconnecting DC fault .....		34
Figure 11 – Current transfer path of the MRTS.....		35
Figure 12 – Current transfer path of ERTS.....		35
Figure 13 – Connection and function of the NBES.....		36
Figure 14 – Commutating process of NBES in case of DMR.....		36
Figure 15 – High speed bypass switch .....		37
Figure 16 – Converter paralleling switches.....		37

Table 1 – Studies and simulations in HVDC system design .....	15
Table 2 – Preferred rated voltages for overhead line HVDC power transmission .....	27
Table 3 – Preferred rated voltages for submarine HVDC power transmission .....	27
Table A.1 – Tolerance for main circuit calculation .....	58
Table A.2 – Control parameters for main circuit calculation .....	58

## INTERNATIONAL ELECTROTECHNICAL COMMISSION

# GUIDELINE FOR THE SYSTEM DESIGN OF HVDC CONVERTER STATIONS WITH LINE-COMMUTATED CONVERTERS

## 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.

The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a technical report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

IEC TR 63127, which is a Technical Report, has been prepared by IEC technical committee 115: High Voltage Direct Current (HVDC) transmission for DC voltages above 100 kV.

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

Enquiry draft	Report on voting
115/195/DTR	115/203/RVDTR

Full information on the voting for the approval of this Technical Report can be found in the report on voting indicated in the above table.



This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "<http://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.

A bilingual version of this publication may be issued at a later date.

## INTRODUCTION

HVDC is an established technology that has been in commercial use for more than 60 years. With the changes in demands due to evolving environmental needs, installation of HVDC systems has increased dramatically in the last 30 years and almost half of HVDC projects were commissioned after the year 2000. HVDC has become a common tool in the design of future global transmission systems.

HVDC systems transmit more electrical power over longer distances than a similar alternating current (AC) transmission system, which means fewer transmission lines are needed, saving both money and land and simplifying permissions. In addition to significantly lowering electrical losses over long distances, HVDC transmission is also very stable and easily controlled, and can stabilize and interconnect AC power networks that are otherwise incompatible. Typically HVDC systems provide unique or superior capabilities in the following aspects:

- long distance bulk power transmission;
- asynchronous interconnections;
- long distance cable;
- controllability;
- lower losses;
- environmental concerns;
- limitation of short-circuit currents.

Simply due to these technical merits, the market demand for HVDC transmission technology is spreading widely over the world. There are many HVDC power transmission systems with a DC voltage from 50 kV up to 660 kV in different countries. In addition, there are several  $\pm 800$  kV HVDC power transmission systems which have been built or operated or which are under construction in China, India and Brazil. In 2016, one  $\pm 1\,100$  kV HVDC power transmission system project was started in China.

The fast development of the HVDC power transmission and distribution industry has been accompanied by IEC standardization work. More than 40 IEC documents, from DC equipment to DC systems, have been published. Among these, the IEC TR 60919 series, IEC 60633, IEC 60071-5, the IEC TR 62001 series and the IEC 60700 series provide essential information for the design and operation of HVDC power transmission systems.

However, this document provides only a basic guide and refers to typical numbers and examples. Other points and values may also be valid in particular cases and should also be considered accordingly.

## **GUIDELINE FOR THE SYSTEM DESIGN OF HVDC CONVERTER STATIONS WITH LINE-COMMUTATED CONVERTERS**

### **1 Scope**

System design is the basis of construction and operation of HVDC systems. It defines the overall philosophy for the HVDC transmission system and enables the ratings and specifications for the equipment integrated in the project.

This document focuses on the system design of converter stations. It is applicable to point-to-point and back-to-back HVDC systems based on line-commutated converter (LCC) technology.

This document provides guidance and supporting information on the procedure for system design and the technical issues involved in the system design of HVDC transmission projects for both purchaser and potential suppliers. It can be used as the basis for drafting a procurement specification and as a guide during project implementation.

### **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 60633, *High-voltage direct current (HVDC) transmission – Vocabulary*

### **3 Terms and definitions**

For the purposes of this document, the terms and definitions given in IEC 60633 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>