



BSI Standards Publication

Performance of high-voltage direct current (HVDC) systems with line-commutated converters

Part 1: Steady-state conditions

National foreword

This Published Document is the UK implementation of IEC/TR 60919-1:2010+A2:2017. It supersedes PD IEC/TR 60919-1:2010+A1:2013, which is withdrawn.

The start and finish of text introduced or altered by amendment is indicated in the text by tags. Tags indicating changes to IEC text carry the number of the IEC amendment. For example, text altered by IEC amendment 1 is indicated by A1 A1.

The UK participation in its preparation was entrusted to Technical Committee PEL/22, Power electronics.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

© The British Standards Institution 2018
Published by BSI Standards Limited 2018

ISBN 978 0 580 92721 8

ICS 29.200; 29.240.99

Compliance with a British Standard cannot confer immunity from legal obligations.

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 31 July 2010.

Amendments/corrigenda issued since publication

Date	Text affected
30 June 2013	Implementation of IEC amendment 1:2013
31 May 2018	Implementation of IEC amendment 2:2017

TECHNICAL REPORT



**Performance of high-voltage direct current (HVDC) systems with line-commutated converters –
Part 1: Steady-state conditions**

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION








PRICE CODE **XC**

ICS 29.200; 29.240.99

ISBN 978-2-88910-968-5

Contents

Page

FOREWORD	ix
1 Scope	1
2 Normative references	3
3 Types of HVDC systems	3
3.1 General	3
3.2 HVDC back-to-back system	3
3.3  Monopolar HVDC system with earth return 	5
3.4  Monopolar HVDC system with metallic return 	7
3.5 Bipolar earth return HVDC system	8
3.6  Bipolar HVDC system with metallic return 	12
3.7 Two 12-pulse groups per pole	14
3.8 Converter transformer arrangements	14
3.9 DC switching considerations	18
3.10 Series capacitor compensated HVDC systems	20
 3.11 LCC/VSC hybrid bipolar system	24
4 Environment information	25
5 Rated power, current and voltage	28
5.1 Rated power	28
5.1.1 General	28
5.1.2 Rated power of an HVDC system with transmission line	28
5.1.3 Rated power of an HVDC back-to-back system	28
5.1.4 Direction of power flow	29
5.2 Rated current	29
5.3 Rated voltage	29
6 Overload and equipment capability	29
6.1 Overload	29
6.2 Equipment capability	30
6.2.1 General	30
6.2.2 Converter valve capability	30
6.2.3 Capability of oil-cooled transformers and reactors	31
6.2.4 AC harmonic filter and reactive power compensation equipment capability	31
6.2.5 Switchgear and buswork capability	31
7 Minimum power transfer and no-load stand-by state	31
7.1 General	31
7.2 Minimum current	31
7.3 Reduced direct voltage operation	32
7.4 No-load stand-by state	32
7.4.1 General	32
7.4.2 Converter transformers – No-load stand-by	32
7.4.3 Converter valves – No-load stand-by	32
7.4.4 AC filters and reactive compensation – No-load stand-by	32
7.4.5 DC reactors and d.c. filters – No-load stand-by	33
7.4.6 Auxiliary power system – No-load stand-by	33
7.4.7 Control and protection – No-load stand-by	33
8 AC system	33
8.1 General	33
8.2 AC voltage	33
8.2.1 Rated a.c. voltage	33
8.2.2 Steady-state voltage range	33
8.2.2.3 Voltage variation during emergency	34
8.2.3 Negative sequence voltage	34
8.3 Frequency	34

8.3.1	Rated frequency.....	34
8.3.2	Steady-state frequency range	34
8.3.3	Short-term frequency variation.....	34
8.3.4	Frequency variation during emergency.....	34
8.4	System impedance at fundamental frequency.....	35
8.5	System impedance at harmonic frequencies	35
8.6	Positive and zero-sequence surge impedance.....	35
8.7	Other sources of harmonics.....	35
8.8	Subsynchronous torsional interaction (SSTI).....	35
9	Reactive power	35
9.1	General.....	35
9.2	Conventional HVDC systems.....	35
9.3	Series capacitor compensated HVDC schemes.....	37
9.4	Converter reactive power consumption.....	37
9.5	Reactive power balance with the a.c. system.....	37
9.6	Reactive power supply	38
9.7	Maximum size of switchable VAR banks.....	38
10	HVDC transmission line, earth electrode line and earth electrode.....	38
10.1	General.....	38
10.2	Overhead line(s).....	39
10.2.1	General.....	39
10.2.2	Electrical parameters.....	39
10.3	Cable line(s).....	39
10.3.1	General.....	39
10.3.2	Electrical parameters.....	40
10.4	Earth electrode line.....	40
10.5	Earth electrode	40
11	Reliability.....	40
11.1	General.....	40
11.2	Outage.....	41
11.2.1	General.....	41
11.2.2	Scheduled outage	41
11.2.3	Forced outage	41
11.3	Capacity.....	41
11.3.1	General.....	41
11.3.2	Maximum continuous capacity P_m	41
11.3.3	Outage capacity P_o	41
11.3.4	Outage derating factor (ODF)	41
11.4	Outage duration terms.....	42
11.4.1	Actual outage duration (AOD).....	42
11.4.2	Equivalent outage duration (EOD)	42
11.4.3	Period hours (PH).....	42
11.4.4	Actual outage hours (AOH).....	42
11.4.5	Equivalent outage hours (EOH)	42
11.5	Energy unavailability (EU).....	42
11.5.1	General.....	42
11.5.2	Forced energy unavailability (FEU).....	43
11.5.3	Scheduled energy unavailability (SEU)	43
11.6	Energy availability (EA)	43
11.7	Maximum permitted number of forced outages.....	43
11.8	Statistical probability of outages.....	44
11.8.1	Component faults	44
11.8.2	External faults.....	44
12	HVDC control	44
12.1	Control objectives.....	44
12.2	Control structure.....	44

	12.2.1	General	44
	12.2.2	Converter unit firing control	45
	12.2.3	Pole control	47
	12.2.4	HVDC substation control	49
	12.2.5	Master control	49
	12.3	Control order settings	49
	12.4	Current limits	50
	12.5	Control circuit redundancy	50
	12.6	Measurements	50
13		Telecommunication	51
	13.1	Types of telecommunication links	51
	13.2	Telephone	51
	13.3	Power line carrier (PLC)	52
	13.4	Microwave	52
	13.5	Radio link	52
	13.6	Optical fibre telecommunication	52
	13.7	Classification of data to be transmitted	53
	13.8	Fast response telecommunication	53
	13.9	Reliability	54
14		Auxiliary power supplies	54
	14.1	General	54
	14.2	Reliability and load classification	54
	14.3	AC auxiliary supplies	55
	14.4	Batteries and uninterruptible power supplies (UPS)	55
	14.5	Emergency supply	56
15		Audible noise	56
	15.1	General	56
	15.2	Public nuisance	57
	15.2.1	General	57
	15.2.2	Valves and valve coolers	57
	15.2.3	Converter transformers	57
	15.2.4	DC reactors	57
	15.2.5	AC filter reactors	58
	15.3	Noise in working areas	58
16		Harmonic interference – AC	58
	16.1	AC side harmonic generation	58
	16.2	Filters	58
	16.3	Interference disturbance criteria	62
	16.4	Levels for interference	63
	16.5	Filter performance	64
17		Harmonic interference – DC	64
	17.1	DC side interference	64
	17.1.1	Harmonic currents in HVDC transmission line	64
	17.1.2	Characteristic and non-characteristic harmonics	64
	17.1.3	Groups of harmonics	65
	17.1.4	Calculation of harmonic currents	65
	17.1.5	Calculation of induced voltages	65
	17.1.6	Personnel safety	65
	17.1.7	DC filters	66
	17.2	DC filter performance	66
	17.2.1	Requirements for voice communication circuits	66
	17.2.2	Levels of interference	66
	17.2.3	Safety	67
	17.3	Specification requirements	67
	17.3.1	Economic level of filtering	67
	17.3.2	General criteria	68

	17.3.3	Factors to be taken into account for calculations	68
	17.3.4	Calculation of currents	69
18		Power line carrier interference (PLC)	69
	18.1	General	69
	18.2	Performance specification	70
19		[A1] Radio frequency interference	71
	19.2	RFI from HVDC systems	72
	19.2.1	RFI sources	72
	19.2.2	RFI propagation	72
	19.2.3	RFI characteristics	73
	19.3	RFI performance specification	73
	19.3.1	RFI risk assessment	73
	19.3.2	Specification RFI limit and its verification	73
	19.3.3	Design aspects	74
20		Power losses	75
	20.1	General	75
	20.2	Main contributing sources	75
	20.2.1	General	75
	20.2.2	AC filters and reactive power compensation	75
	20.2.3	Converter bridges	75
	20.2.4	Converter transformer	75
	20.2.5	DC reactor	76
	20.2.6	DC filter	76
	20.2.7	Auxiliary equipment	76
	20.2.8	Other components	76
21		Provision for extensions to the HVDC systems	76
	21.1	General	76
	21.2	Specification for extensions	76
		[A1] Annex A (informative) Factors affecting reliability and availability of converter stations	79
		Bibliography	87

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 nongovernmental 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 60919-1, which is a technical report, has been prepared by subcommittee 22F: Power electronics for electrical transmission and distribution systems, of IEC technical committee 22: Power electronic systems and equipment.

This edition includes the following significant technical changes with respect to the previous edition:

- a) the changes have been made to the description of multi 12-pulse groups per pole, especially for a large scale ultra high-voltage direct current (UHVDC) converter arrangement;
- b) the different arrangements of d.c. smoothing reactors have been included;

c) the figures depicting two 12-pulse groups per pole arrangement have been added.

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

A list of all parts of the IEC 60919 series, published under the general title *Performance of high-voltage direct current (HVDC) systems with line-commutated converters*, can be found on the IEC website

The committee has decided that the contents of the base publication and its amendments will remain unchanged until the stability date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

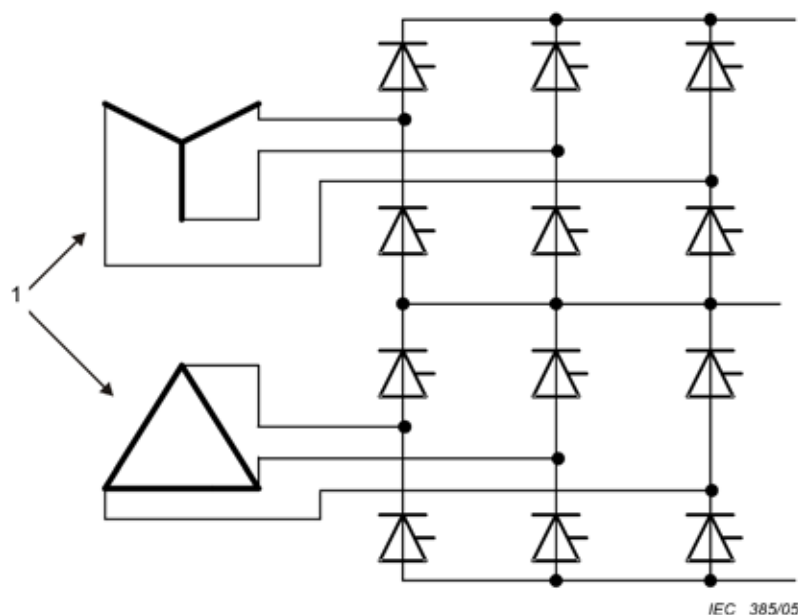
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

Performance of high-voltage direct current (HVDC) systems with line-commutated converters —

Part 1: Steady-state conditions

1 Scope

This part of the IEC 60919 provides general guidance on the steady-state performance requirements of high-voltage direct current (HVDC) systems. It concerns the steady-state performance of two-terminal HVDC systems utilizing 12-pulse converter units comprised of three-phase bridge (double-way) connections (see [Figure 1](#)), but it does not cover multi-terminal HVDC transmission systems. Both terminals are assumed to use thyristor valves as the main semiconductor valves and to have power flow capability in both directions. Diode valves are not considered in this report.



Key

1 Transformer valve windings

Figure 1 — Twelve-pulse converter unit

Only line-commutated converters are covered in this report, which includes capacitor commutated converter circuit configurations. General requirements for semiconductor line-commutated converters are given in IEC 60146-1-1, IEC/TR 60146-1-2 and IEC 60146-1-3. Voltage-sourced converters are not considered.

This technical report, which covers steady-state performance, is followed by additional documents on dynamic performance and transient performance. All three aspects should be considered when preparing two-terminal HVDC system specifications.

The difference between system performance specifications and equipment design specifications for individual components of a system should be realized. Equipment specifications and testing requirements are not defined in this report. Also excluded from this report are detailed seismic