# TECHNICAL REPORT

# IEC TR 60919-1

Second edition
2005-03

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

## Part 1: Steady-state conditions



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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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# PERFORMANCE OF HIGH-VOLTAGE DIRECT CURRENT (HVDC) SYSTEMS WITH LINE-COMMUTATED CONVERTERS –

## Part 1: Steady-state conditions

## FOREWORD

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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 second edition cancels and replaces the first edition, published in 1988, and constitutes a technical revision.

This edition includes the following main changes with respect to the previous edition:

a) this report concerns only line-commutated converters;
b) significant changes have been made to the control system technology;

c) some environmental constraints, for example audible noise limits, have been added;

d) the capacitor coupled converters (CCC) and controlled series capacitor converters (CSCC) have been included.

The text of this technical report is based on the following documents:

| Enquiry Draft | Report on voting |
|---|---|
| 22F/95A/DTR | 22F/104/RVC |

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

IEC 60919 consists of the following parts, under the general title: *Performance of high-voltage direct current (HVDC) systems with line-commutated converters*:

Part 1: Steady-state conditions

Part 2: Faults and switching

Part 3: Dynamic conditions



The committee has decided that the contents of this publication will remain unchanged until the maintenance result date[1] 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.

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

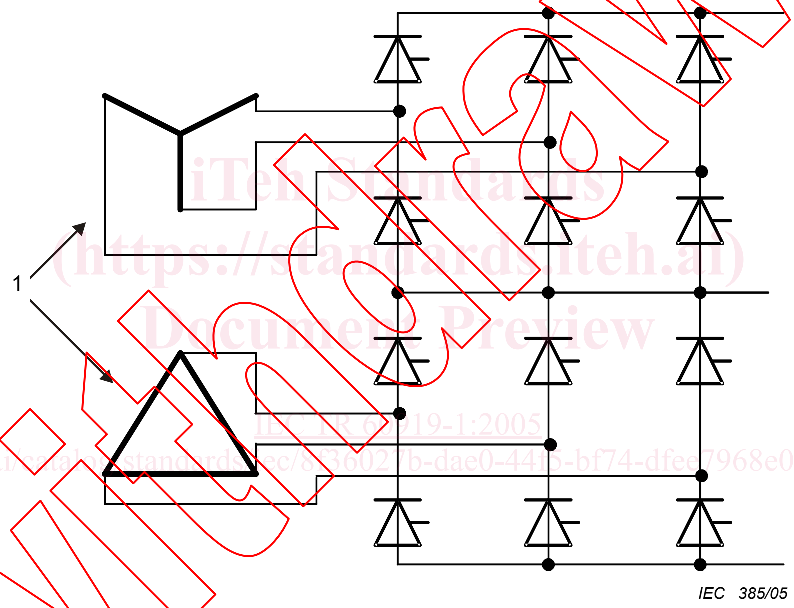
[1] The National Committees are requested to note that for this publication the maintenance result date is 2010.

# PERFORMANCE OF HIGH-VOLTAGE DIRECT CURRENT (HVDC) SYSTEMS WITH LINE-COMMUTATED CONVERTERS –

## Part 1: Steady-state conditions

## 1 Scope

This technical report provides general guidance on the steady-state performance requirements of 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 60146-1-2 and IEC 60146-1-3. Voltage-sourced converters are not considered.

This technical report, which covers steady-state performance, will be 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 performance requirements. In addition, because there are many variations between different possible HVDC systems, this report does not consider these in detail;

consequently, it should not be used directly as a specification for a particular project, but rather to provide the basis for an appropriate specification tailored to fit actual system requirements.

Frequently, performance specifications are prepared as a single package for the two HVDC substations in a particular system. Alternatively, some parts of the HVDC system can be separately specified and purchased. In such cases, due consideration should be given to co-ordination of each part with the overall HVDC system performance objectives and the interface of each with the system should be clearly defined. Typical of such parts, listed in the appropriate order of relative ease for separate treatment and interface definition, are:

a) d.c. line, electrode line and earth electrode;
b) telecommunication system;
c) converter building, foundations and other civil engineering work;
d) reactive power supply including a.c. shunt capacitor banks, shunt reactors, synchronous and static VAR compensators;
e) a.c. switchgear;
f) d.c. switchgear;
g) auxiliary systems;
h) a.c. filters;
i) d.c. filters;
j) d.c. reactors;
k) converter transformers;
l) surge arresters;
m) series commutation capacitors;
n) valves and their ancillaries;
o) control and protection systems.

NOTE The last four items are the most difficult to separate, and, in fact, separation of these four may be inadvisable.



A complete steady-state performance specification for a HVDC system should consider Clauses 3 to 21 of this report.

Terms and definitions for high-voltage direct current (HVDC) transmission used in this report are given in IEC 60633.

Since the equipment items are usually separately specified and purchased, the HVDC transmission line, earth electrode line and earth electrode (see Clause 10) are included only because of their influence on the HVDC system performance.

For the purpose of this report, an HVDC substation is assumed to consist of one or more converter units installed in a single location together with buildings, reactors, filters, reactive power supply, control, monitoring, protective, measuring and auxiliary equipment. While there is no discussion of a.c. switching substations in this report, a.c. filters and reactive power sources are included, although they may be connected to an a.c. bus separate from the HVDC substation, as discussed in Clause 16.

## 2 Normative references

The following referenced documents are indispensable for the application 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 60146-1-1:1991, *Semiconductor converters – General requirements and line commutated converters – Part 1-1: Specifications of basic requirements*
Amendment 1 (1996)

IEC 60146-1-2:1991, *Semiconductor converters – General requirements and line commutated converters – Part 1-2: Application guide*

IEC 60146-1-3:1991, *Semiconductor converters – General requirements and line commutated converters – Part 1-3: Transformers and reactors*

IEC 60633:1998, *Terminology for high-voltage direct current (HVDC) transmission*

IEC 61803:1999, *Determination of power losses in high-voltage direct current (HVDC) converter stations*

CISPR 16 (all parts), *Specification for radio disturbance and immunity measuring apparatus and methods*

ISO 1996-1: 2003, *Acoustics – Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment procedures*

CIGRE Brochure No. 139: *Guide to the specification and design evaluation of AC filters for HVDC systems*

CIGRE Report 14-97: *Protocol for reporting the operational performance of HVDC transmission systems*



## 3 Types of HVDC systems

### 3.1 General

This part of the specification should include the following basic data:

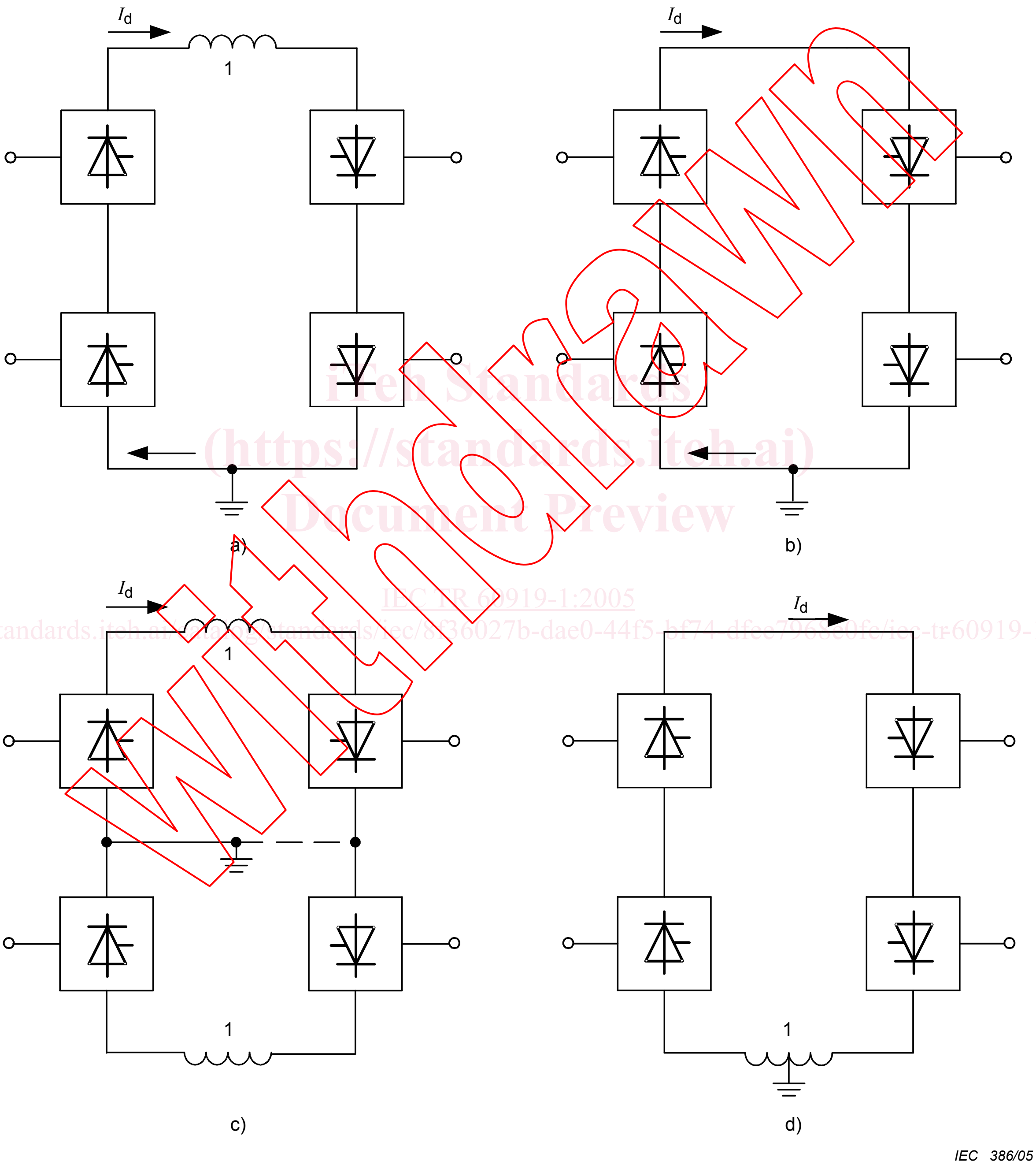
a) general information on the location of the HVDC substations and the purpose of the project;
b) type of system needed, including a simple one-line diagram;
c) the number of 12-pulse converter units;
d) pertinent information derived from the discussion in this section.

Generally, in studies of projects of the types discussed in this report, economic considerations should take into account the capital costs, the cost of losses, cost of outages and other expected annual expenses.

In terms of the type of system, the relatively new development of “capacitor-commuted converter (CCC)” and “controlled series capacitor converter (CSCC)” technology may be suitable alternatives to a conventional HVDC scheme. These are described in 3.10.

### 3.2 HVDC back-to-back system

In this arrangement there is no d.c. transmission line and both converters are located at one site. The valves for both converters may be located in one valve hall, or even in one integrated structure or separately as outdoor valves. Similarly, many other items for the two converters, such as the control system, cooling equipment, auxiliary system, etc., may be located in one area or even integrated in layout into configurations common to the two converters. Circuit configurations may vary. Examples are given in Figure 2. The performance and economics of these configurations differ and must be evaluated. DC filters are not needed.






**Key**

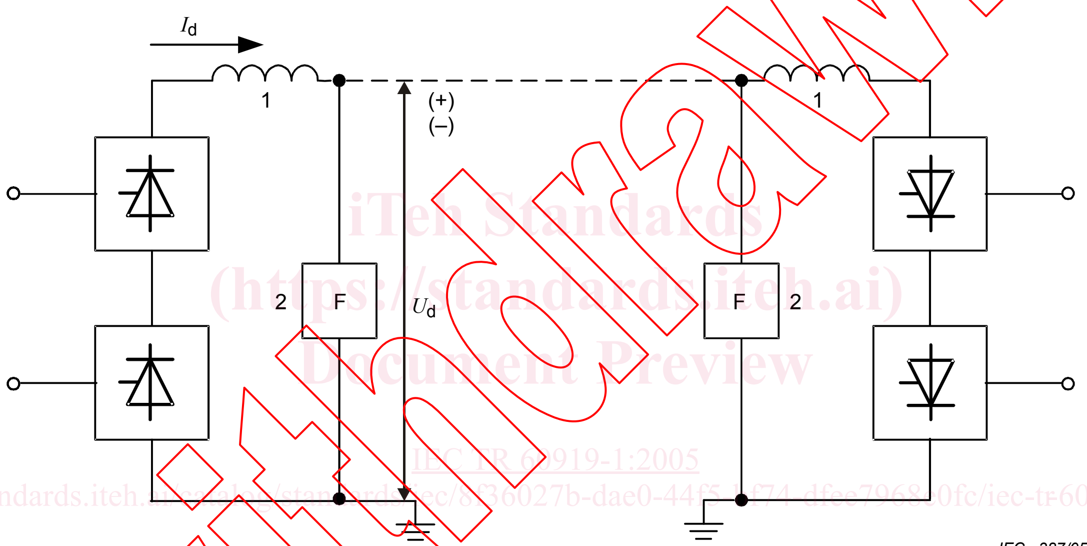
1 DC reactor

**Figure 2 – Examples of back-to-back HVDC systems**

The voltage and current ratings for a given power rating should be optimized to achieve the lowest system cost, including the evaluated cost of losses. Ordinarily, the user does not need to specify the direct voltage and current ratings, unless there are specific reasons to do so, for example, for compatibility with an already existing station, to provide for a future extension of for some other reason. Economics dictate that each converter will usually be a 12-pulse converter unit. Where operating criteria require that the loss of one converter unit will not cause loss of full power capability, large HVDC substations could be comprised of two or more back-to-back systems. For this, some of the equipment of the back-to-back systems can, for economic reasons, be located in the same area or even physically integrated, but events which could cause a failure of equipment required by all back-to-back systems need to be carefully considered and preventive measures taken where appropriate.

## 3.3 Monopolar earth return HVDC system

Cost considerations often lead to the adoption of a monopolar earth return system (Figure 3), particularly for cable transmission which may be expensive.




**Key**

1 DC reactor

2 DC filters

**Figure 3 – Monopolar earth return system**



The monopolar earth return configuration might also be the first stage in the development of a bipolar scheme. Monopolar arrangements may include one or more 12-pulse units in series or in parallel at the ends of the HVDC transmission (Figures 4 and 5). More than one 12-pulse unit might be used

a) to ensure partial transmission capacity during converter unit outages;

b) to complete the project in stages;

c) because of the physical limitations of transformer transport.