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INTERNATIONAL STANDARD

Determination of power losses in high-voltage direct current (HVDC) converter stations

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

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

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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Determination of power losses in high-voltage direct current (HVDC) converter stations

FOREWORD

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IEC 61803 has been prepared by subcommittee 22F: Power electronics for electrical transmission and distribution systems, of IEC technical committee 22: Power electronic systems and equipment. It is an International Standard.

This third edition cancels and replaces the second edition published in 2020. This edition constitutes a technical revision.

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

a) HVDC stations with voltage-sourced converters (VSC) technology have been included;
b) to facilitate the application of this document and to ensure its quality remains consistent, 5.1.8 and 5.8 have been reviewed, taking into consideration that the present thyristor production technology provides considerably less thyristor parameters dispersion comparing with the situation in 1999 when the first edition of IEC 61803 was developed; therefore, the production records of thyristors can be used for the power losses calculation;

c) the calculation of the total station load losses (cases D1 and D2 in Annex C) has been corrected.

The text of this International Standard is based on the following documents:

Draft	Report on voting
22F/860/FDIS	22F/868/RVD

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 International Standard is English.

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, or
– revised.

1 Scope

This document applies to all high-voltage direct current (HVDC) converter stations with line-commutated converters (LCC) as well with voltage-sourced converters (VSC) used for power exchange (power transmission or back-to-back installation) in utility systems. For line-commutated converters (LCC), this document presumes the use of 12-pulse thyristor converters but can, with due care, also be used for 6-pulse thyristor converters.

Where VSC is referred to in this document, it is assumed to be of the MMC-type or similar, with very low harmonic generation. It is important to treat other types of VSC as appropriate.

In some applications, synchronous compensators, static var compensators (SVC), or static synchronous compensator (STATCOM) are connected to the AC bus of the HVDC converter station. The loss determination procedures for such equipment are not included in this document.

This document presents a set of standard procedures for determining the total losses of an HVDC converter station, except for VSC valves which are covered by the IEC 62751 series. The procedures cover all parts, except as noted above, and address no-load operation and operating losses together with their methods of calculation which use, wherever possible, measured parameters.

Converter station designs employing novel components or circuit configurations compared to the typical design assumed in this document, or designs equipped with unusual auxiliary circuits that can affect the losses, are assessed on their own merits.

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 60076-1, *Power transformers - Part 1: General*

IEC 60076-6, *Power transformers - Part 6: Reactors*

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

IEC 60700-1:2015, *Thyristor valves for high voltage direct current (HVDC) power transmission - Part 1: Electrical testing*
IEC 60700-1:2015/AMD1:2021

IEC 60871-1, *Shunt capacitors for a.c. power systems having a rated voltage above 1 000 V - Part 1: General*

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

3 Terms, definitions and symbols

For the purposes of this document, the terms and definition given in IEC 60633, IEC 62747 and the following 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 Terms and definitions

3.1.1
auxiliary losses
electric power required to feed the converter station auxiliary loads

Note 1 to entry: The auxiliary losses depend on the number of converter units used and whether the station is in no-load operation or carrying load, in which case the auxiliary losses depend on the load level.

3.1.2
equipment no-load operation losses
losses produced in an item of equipment with the converter station energised but with the converters blocked and all station service loads and auxiliary equipment connected as required for immediate pick-up of load to specified minimum power

3.1.3
load level
set of AC system and converter operating conditions at which the converter station is operating

Note 1 to entry: For LCC schemes, the load level is defined by the direct current, direct voltage, firing angle, AC system voltage and converter transformer tap-changer position.

Note 2 to entry: For VSC schemes, the load level is defined by the direct current, direct voltage, AC system voltage, interface transformer tap-changer position (where appropriate), converter AC voltage, converter AC current and the phase angle between converter AC voltage and current.

3.1.4
equipment operating losses
losses produced in an item of equipment at a given load level with the converter station energised and the converters operating

3.1.5
rated load
load corresponding to operation at nominal values of the operating conditions defined in 3.1.3

Note 1 to entry: The AC system shall be assumed to be at nominal frequency, and its 3-phase voltages are nominal and balanced. The position of the tap-changer of the converter/interface transformer and the number of AC filters and shunt reactive elements, if any connected, shall be consistent with operation at rated load, coincident with nominal conditions.

3.1.6
total station no-load operation losses
sum of all equipment no-load operation losses (3.1.2) and corresponding auxiliary losses (3.1.1)

3.1.7
total station operating losses
sum of all equipment operating losses (3.1.4) and corresponding auxiliary losses (3.1.1) at a particular load level

Note 1 to entry: An illustrative example using total station operating losses and corresponding loss evaluation is given in Annex C, case D1.

3.1.8
total station load losses
difference between total station operating losses (3.1.7) and total station no-load operation losses (3.1.6)

Note 1 to entry: Such calculated total station load losses are considered as being quantitatively equivalent to load losses as in conventional AC substation practice.

Note 2 to entry: It is recognized that some purchasers evaluate total station no-load operation losses (3.1.6) and total station load losses individually instead of the evaluating total station operating losses (3.1.7).

Note 3 to entry: An illustrative example to derive load losses, equivalent load losses and corresponding loss evaluation is given in Annex C, case D2.

3.1.9
station essential auxiliary load
load whose failure affects the conversion capability of the HVDC converter station (e.g. valve cooling), as well as load that remains working in case of complete loss of AC power supply (e.g. battery chargers, operating mechanisms)

3.2 Symbols

3.2.1 Common

f AC system frequency, in hertz (Hz)

I_d direct current, in amperes (A)

I_n harmonic RMS current of order n, in amperes (A)

n harmonic order

P power loss in an item of equipment, in watts (W)

Q_n quality factor of a reactor at harmonic order n

R resistance value, in ohms (Ω)

U_d direct voltage, in volts (V)

U_n harmonic RMS voltage of order n, in volts (V)

X_n inductive reactance at harmonic order n, in ohms (Ω)

3.2.2 Line-commutated converters

α (trigger/firing) delay angle, in radians (rad)

γ extinction angle, in radians (rad)

μ overlap angle, in radians (rad)

L_1 inductance, in henrys (H), referred to the valve winding, between the commutating voltage source and the point of common coupling between star- and delta-connected windings; L_1 shall include any external inductance between the transformer line-winding terminals and the point of connection of the AC harmonic filters

L_2 inductance, in henrys (H), referred to the valve winding, between the point of common coupling between star- and delta-connected windings; the valve L_2 shall include the saturated inductance of the valve reactors

m electromagnetic notch coupling factor, $m = L_1/(L_1 + L_2)$

N_t number of series-connected thyristors per valve

U_{vo} RMS value of the phase-to-phase no-load voltage on the valve side of the converter transformer excluding harmonics, in volts (V)

4 Overview

4.1 General

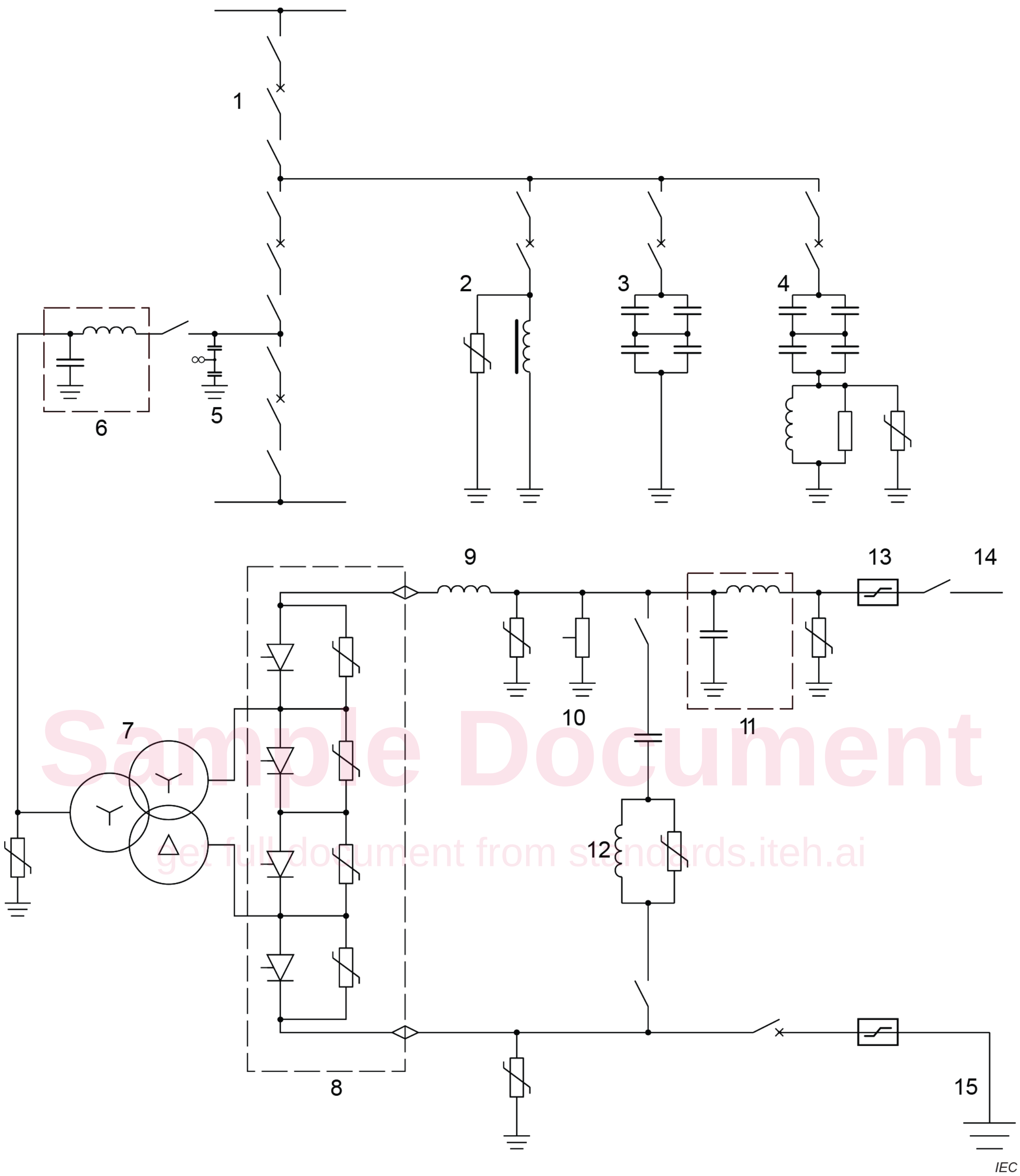
It is important for suppliers to know in detail how and where losses are generated, since this affects component and equipment ratings. Purchasers are interested in a verifiable loss figure which allows equitable bid comparison and in a procedure which can objectively verify the guaranteed performance requirements of the supplier after delivery. The main purpose of this document is to serve the purchasers this specific interest.

As a general principle, it would be desirable to determine the efficiency of an HVDC converter station by a direct measurement of its energy losses. However, attempts to determine the station losses by subtracting the measured output power from the measured input power should recognize that such measurements have an inherent inaccuracy, especially if performed at high voltage. The losses of an HVDC converter station at full load are generally less than 1 % of the transmitted power. Therefore, the loss measured as a small difference between two large quantities is not likely to be a sufficiently accurate indication of the actual losses.

In some special circumstances, it can be possible, for example, to arrange a temporary test connection in which two converters are operated from the same AC source and also connected together via their DC terminals. In this connection, the power drawn from the AC source equals the losses in the circuit though in most cases this does not represent a normal operating design mode. However, the AC source shall also provide var support and commutating voltage to the two converters. Once again, there are practical measurement difficulties, and it is still important that the losses are recalculated/corrected for nominal parameters and ambient/operating conditions.

In order to avoid the problems described above since these practical measurements are unreliable and also will depend on the type of HVDC solution, it is recommended to use this document which standardizes a method of calculating the HVDC converter station losses by summing the losses calculated for each item of equipment. The standardized calculation method will help the purchaser to meaningfully compare the competing bids. It will also allow an easy generation of performance curves for the wide range of operating conditions in which the performance has to be known. In the absence of an inexpensive experimental method which could be employed for an objective verification of losses during type tests, the calculation method is the next best alternative as it uses, wherever possible, experimental data obtained from measurements on individual equipment and components under conditions equivalent to those encountered in real operation.

Typical high-voltage direct current (HVDC) equipment for one pole of an LCC HVDC substation is shown in Figure 1 and for one pole of a VSC HVDC substation in Figure 2. The calculation of harmonic currents and voltages in HVDC equipment for line-commutated converter stations is described in Annex A.



Key

1	AC switchyard	9	DC smoothing reactor
2	shunt reactor bank	10	voltage divider
3	shunt capacitor bank	11	PLC filter
4	AC filter bank	12	DC filter
5	capacitor voltage transformer	13	DC current measuring device
6	PLC filter	14	pole line
7	converter transformer	15	ground electrode
8	valve hall		

Figure 1 – Typical high-voltage direct current (HVDC) equipment for one pole of an LCC scheme