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INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

Determination of power losses in high-voltage direct current (HVDC) converter stations with line commutated converters

Détermination des pertes en puissance dans les postes de conversion en courant continu à haute tension (CCHT) munis de convertisseurs commutés par le réseau

IEC 61803:1999-02+AMD1:2010-11+AMD2:2016-05 CSV(en-fr)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

DETERMINATION OF POWER LOSSES IN HIGH-VOLTAGE DIRECT CURRENT (HVDC) CONVERTER STATIONS WITH LINE-COMMUTATED CONVERTERS

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IEC 61803 edition 1.2 contains the first edition (1999-02) [documents 22F/51/FDIS and 22F/56/RVD] and its corrigendum 1 (1999-10), its amendment 1 (2010-11) [documents 22F/214/CDV and 22F/224/RVC] and its amendment 2 (2016-05) [documents 22F/374/CDV and 22F/393A/RVC].

In this Redline version, a vertical line in the margin shows where the technical content is modified by amendments 1 and 2. Additions are in green text, deletions are in strikethrough red text. A separate Final version with all changes accepted is available in this publication.

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

Annex A forms an integral part of this standard.

Annexes B and C are for information only.

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

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DETERMINATION OF POWER LOSSES IN HIGH-VOLTAGE DIRECT CURRENT (HVDC) CONVERTER STATIONS WITH LINE-COMMUTATED CONVERTERS

1 Scope

This International Standard applies to all line-commutated high-voltage direct current (HVDC) converter stations used for power exchange in utility systems. This standard presumes the use of 12-pulse thyristor converters but can, with due care, also be used for 6-pulse thyristor converters.

In some applications, synchronous compensators or static var compensators (SVC) may be connected to the a.c. bus of the HVDC converter station. The loss determination procedures for such equipment are not included in this standard.

This standard presents a set of standard procedures for determining the total losses of an HVDC converter station. Typical HVDC equipment is shown in figure 1. 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 standard, or designs equipped with unusual auxiliary circuits that could affect the losses, shall be assessed on their own merits.

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 60076-1~~:1993~~, *Power transformers – Part 1: General*

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

~~IEC 60289:1988, *Reactors*~~

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

IEC 60700-1~~:1998~~, *Thyristor valves for high voltage direct current (HVDC) power transmission – Part 1: Electrical testing*

IEC 60747-6~~:1983~~, *Semiconductor devices ~~– Discrete devices~~ – Part 6: Thyristors*

IEC 60871-1~~:1997~~, *Shunt capacitors for a.c. power systems having a rated voltage above 1 000 V – Part 1: General ~~performance, testing and rating – Safety requirements – Guide for installation and operation~~*

3 Definitions and symbols

For the purpose of this International Standard, the following definitions apply:

3.1 Definitions

3.1.1
auxiliary losses
~~the~~ 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
~~the~~ 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
this term specifies the direct current, direct voltage, firing angle, a.c. voltage, and converter transformer tap-changer position at which the converter station is operating

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

3.1.5
rated load
~~this~~ load ~~is~~ related to operation at nominal values of d.c. current, d.c. voltage, a.c. voltage and converter firing angle

Note 1 to entry: The a.c. 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 transformer and the number of a.c. filters and shunt reactive elements connected shall be consistent with operation at rated load, coincident with nominal conditions.

3.1.8
total station no-load operation losses
sum of all equipment no-load operation losses (3.1.2) and corresponding auxiliary losses (3.1.1)

3.1.6
total station operating losses
~~the total station loss is the~~ sum of all equipment operating ~~or no-load operation~~ losses (3.1.4) and ~~the~~ corresponding auxiliary losses (3.1.1) at a particular load level

Note 1 to entry: It is recognised that some purchasers evaluate “total station no-load operation losses” (definition 3.1.8) and total station load losses individually instead of the evaluating “total station operating losses” (definition 3.1.6).

Note 2 to entry: "Operating losses” minus “no-load operation losses” may be considered as being quantitatively equivalent to “load losses” as in conventional a.c. substation practice.

Note 3 to entry: An illustrative example to derive “load losses”, “equivalent load losses” and corresponding “loss evaluation” is given in Annex D.

3.1.7
station essential auxiliary load
load whose failure will affect the conversion capability of the HVDC converter station (e.g. valve cooling), as well as load that must remain working in case of complete loss of a.c. power supply (e.g. battery chargers, operating mechanisms)

3.2 Letter symbols

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

μ ~~commutation~~ overlap angle, in radians (rad)

f a.c. system frequency, in hertz (Hz)

I_d direct current~~, in the bridge d.c. connection~~, in amperes (A)

I_n harmonic r.m.s. current of order n, in amperes (A)

L_1 the 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 a.c. harmonic filters

L_2 the inductance, in henrys (H), referred to the valve winding, between the point of common coupling between star- and delta-connected windings, and 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 harmonic order

N_t the number of series-connected thyristors per valve

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

Q_n quality factor at harmonic order n

R resistance value, in ohms ~~(W)~~ (Ω)

U_d direct voltage, in volts (V)

U_n harmonic r.m.s. voltage of order n, in volts (V)

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

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

4 General

4.1 Introduction

Suppliers need 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 after delivery which can objectively verify the guaranteed performance requirements of the supplier.

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 may be possible, for example, to arrange a temporary test connection in which two converters are operated from the same a.c. source and also connected together via their d.c. terminals. In this connection, the power drawn from the a.c. source equals the losses in the circuit. However, the a.c. source must also provide var support and commutating voltage to the two converters. Once again, there are practical measurement difficulties.

In order to avoid the problems described above, this standard 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.

It is important to note that the power loss in each item of equipment will depend on the ambient conditions under which it operates, as well as on the operating conditions or duty cycles to which it is subjected. Therefore, the ambient and operating conditions shall be defined for each item of equipment, based on the ambient and operating conditions of the entire HVDC converter station.

4.2 Ambient conditions

A set of standard reference ambient conditions shall be used for determining the power losses in HVDC converter stations.

4.2.1 Outdoor standard reference temperature

An outdoor ambient dry bulb temperature of 20 °C shall be used as the standard reference temperature for determining the total converter station losses. Corresponding valve hall temperature may be defined by the supplier if necessary. The equivalent wet-bulb temperature (where necessary) shall be defined by the purchaser.

NOTE If not defined, the wet-bulb temperature is recommended to be 14 °C which corresponds to approximately 50 % RH at 20 °C dry bulb temperature.

4.2.2 Coolant standard reference temperature

Where forced cooling is used for equipment, the flow rate and temperature of the coolant can influence the temperature rise and associated losses of that equipment. Therefore, the coolant temperatures and flow rates established by the purchaser and the supplier shall be used as a basis for determining the losses.

4.2.3 Standard reference air pressure

The reference air pressure to be used for the evaluation of total converter station power losses shall be the standard atmospheric pressure (101,3 kPa) corrected to the altitude of the installation in question.

4.3 Operating parameters

The losses of an HVDC converter station depend on its operating parameters.

The losses of HVDC converter stations are classified into ~~three~~ two categories, ~~termed the no-load operation losses, operating losses and auxiliary losses~~ referred to as operating losses (3.1.4 and 3.1.6) and no-load operation losses (3.1.2 and 3.1.8).

The operating losses and auxiliary losses are affected by the load level of the station because the numbers of certain types of energized equipment (for example harmonic filters and cooling equipment) may depend upon the load level and because losses in individual items of equipment themselves vary with the load level.

HVDC converter station losses shall be determined for nominal (balanced) a.c. system voltage and frequency, symmetrical impedances of the converter transformer and symmetrical firing angles. The transformer tap-changer shall be assumed to be in the position corresponding to nominal a.c. system voltage or as decided by the control system for the defined operating condition.

The operating losses shall be determined for the load levels specified by the purchaser, or at rated load if no such conditions are specified. For each load level, the valve-winding a.c. voltage, d.c. current, converter firing angle, shunt compensation and harmonic filtering equipment shall be consistent with the respective load level and other specified performance requirements, relating, for example, to harmonic distortion and reactive power. Cooling and other auxiliary equipment, as appropriate to the standard reference temperature (see 4.2.1 and 4.2.2), shall be assumed to be connected to support the respective load level.

For the no-load operation mode, converter transformers shall be energized and the converters blocked. All filters and reactive power compensation equipment shall be assumed to be disconnected except for those which are required to sustain operation at zero load in order, for example, to meet the specified reactive power requirements. Station service loads and auxiliary equipment (e.g. cooling-water pumps) shall be assumed to be connected as required for immediate pick-up of load for the converter station (without waiting for tap changer movement) to specified minimum power.

5 Determination of equipment losses

5.1 Thyristor valve losses

The loss production mechanisms applicable when the valves are blocked (no-load operation losses) are different from those applicable in normal operation (operating losses). Operating losses are dealt with in subclauses 5.1.1 to 5.1.10, and no-load operation losses are dealt with in 5.1.11. Auxiliary losses are dealt with in 5.8.

A simplified three-phase diagram of an HVDC 12-pulse converter is shown in figure 2. Individual valves are marked in the order of their conduction sequence.

A simplified equivalent circuit of a typical valve is shown in figure 3. Symbol *th* combines together the effects of N_t thyristors connected in series in the valve. C_{AC} and R_{AC} are the corresponding combined values of R-C damping circuits used for voltage sharing and overvoltage suppression. R_{DC} represents d.c. grading resistors and other resistive components which incur loss when the valve blocks voltage. It also includes the effects of the thyristor leakage current (see 5.1.4 and 5.1.11). C_s includes both stray capacitances and surge distribution capacitors (if used). L_s represents saturable reactors used to limit the d*i*/d*t* stresses to safe values and to improve the distribution of fast rising voltages. R_s represents the resistances of the current conducting components of the valve such as the busbars, contact resistances, resistance of the windings of the saturable reactors etc. Power losses in the valve surge arrester (not shown) shall be neglected.

Figure 4 shows, as an example, current and voltage waveforms of valve 1 (according to figure 2) operating in rectifier and inverter modes. In the example shown, the firing instants of the valves of the upper bridge are delayed by 30° with respect to the valves of the lower bridge due to the phase shift between the two secondaries. For each valve, the length of the conduction intervals is 130° ($2\pi/3 + \mu$). During commutations the valve current is assumed, for this standard, to be changing linearly whereas in reality the valve currents follow portions of sine waves. This simplification has negligible effect on the resulting losses, while the trapezoidal waveform significantly simplifies the calculations. The voltage blocked by the valve shows notches caused by commutations between individual valves.

5.1.1 Thyristor conduction loss per valve

This loss component is the product of the conduction current $i(t)$ and the corresponding ideal on-state voltage as shown in figures 5 and 6. Formula P_{V1a} shall be used provided that the d.c. bridge current is well smoothed. In the event that the root sum square value of the d.c. side harmonic currents, determined in accordance with clause A.4 (annex A), exceeds 5 % of the d.c. component, formula P_{V1b} shall be used instead.