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INTERNATIONAL STANDARD

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AMENDMENT 1
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Power losses in voltage sourced converter (VSC) valves for high-voltage direct current (HVDC) systems – Part 2: Modular multilevel converters

Pertes de puissance dans les valves à convertisseur de source de tension (VSC) des systèmes en courant continu à haute tension (CCHT) – Partie 2: Convertisseurs multiniveaux modulaires

IEC 62751-2:2014-08/AMD1:2019-08(en-fr)

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FOREWORD

This amendment has been prepared by subcommittee 22F: Power electronics for electrical transmission and distribution systems, of IEC technical committee 22: Power electronic systems and equipment.

The text of this amendment is based on the following documents:

CDV	Report on voting
22F/479/CDV	22F/488B/RVC

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

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

- reconfirmed,
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2 Normative references

Add the following new reference:

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

3.1.11
no-load operating state

Add, after the existing definition, the following new note:

Note 1 to entry: In the no-load state, in principle no switching should occur as the valve is blocked. However, in some designs, it may be necessary to make occasional switching operations to balance voltages between different parts of the converter. Here, some losses may occur and need to be accounted for.

4 General conditions

4.1 General

Replace, in the third sentence of the existing paragraph, the abbreviated term "CTLC" by "CTL".

4.2 Principles for loss determination

Add, to the end of the first existing paragraph, the following new sentence:

The manufacturer shall justify, in the loss calculation report, how the uncertainties have been considered.

Replace the last two sentences of the third existing paragraph by the following new sentences:

In practice, this measurement would require the use of state-of-the-art measurement equipment that rivals the best equipment available at national metrology institutes. To date, although some industry/academic partnership projects have demonstrated prototypes of measurement equipment claiming sufficient accuracy, there is little industry experience with using such equipment on site. The feasibility of using laboratory measurements on VSC valves to support a more accurate determination of valve losses is now under study in CIGRÉ WG B4-75.

4.4 Loss calculation method

Replace the first sentence of the existing second paragraph by the following new sentence:

An important requirement for such simulations is an accurate modelling of the system under investigation.

4.5.2 Input data for numerical simulations

Replace the last item of the existing dash list by the following new items:

– For calculating converter valve currents and MMC building block capacitor currents, which are the basis for the calculation of corresponding losses, it is sufficient to use a simplified model in which the on-state and switching characteristics of the IGBTs and diodes are represented by worst-case characteristics applicable to their maximum rated junction temperature.
– For the detailed calculation of losses, the simulation shall also consider the junction temperature dependent semiconductor properties, such as on-state voltages, switching and recovery losses. These properties are based on the characterisation testing as described in IEC 62751-1:2014, 4.4.2. The steady-state junction temperatures of the semiconductors are calculated iteratively for the relevant operating point to derive the semiconductor losses.

4.5.3 Input data coming from numerical simulations

Add, to the last existing paragraph, the following new sentence:

The mean and rms currents in IGBTs and diodes are not required if conduction losses in IGBTs and diodes are calculated using polynomials as discussed in 5.1.

4.5.4 Converter station data

Add, to the sixth dash of the existing list, the words "(for CTL designs)".

Add, after the existing 4.5.5, the following new subclause:

4.6 Contents and structure of valve loss determination report

The manufacturer or bidder shall prepare and submit to the purchaser a detailed report explaining how the losses in the VSC valves have been determined and including a breakdown of the valve losses into the constituent parts P_{V1} to P_{V9} for each operating condition at which losses are required to be guaranteed.

At the bid stage, and (where requested in the contract) after contract award but before the manufacturing of valve components, the report shall document the assumptions used in arriving at the calculated value of losses. After manufacturing, the report shall document the actual values of test data derived from characterisation tests and routine tests on components.

Although a breakdown of the valve losses into the constituent parts P_{V1} to P_{V9} is requested, only the total valve losses P_{Vt} shall be subject to financial evaluation.

A recommended list of data to be included in the report is presented in Annex B.

5.1 General

Add, after the existing Figure 2, the following new paragraphs:

To simplify the process of mathematically analysing conduction losses, the on-state voltage of IGBTs and diodes is usually represented as a piecewise-linear approximation with a threshold voltage V_0 and a slope resistance R_0, as shown in Figure 2 of IEC 62751-1:2014.

It is possible to obtain greater accuracy by using a more exact model of the device on-state voltage (for example, using a polynomial function to represent the on-state voltage) rather than the piecewise-linear approximation, and then performing a direct numerical integration. However, the piecewise-linear approximation is preferred because it simplifies the calculation process, allows greater transparency and still permits good accuracy to be obtained, provided the measurements used to derive the piecewise-linear approximation are made at appropriate values of current. Therefore, it is recommended that V_0 and R_0 are determined by measuring on-state voltage at 100 % and 33 % of the device rated current and performing a linear extrapolation.

In the event that the purchaser prefers to use the more accurate method using a polynomial function, then this shall be clearly stated in the purchasing specification, and all bidders are expected to calculate power losses in a comparable way.

5.2 IGBT conduction loss

Replace the existing second paragraph, starting with "By means of…" *and including Equations (2) to (5) and their key, as well as the existing third paragraph, by the following new text:*

By means of numerical simulation, the currents shall be calculated for the IGBTs T1 and T2 for each MMC building block, respectively:

$$I_{\mathrm{T1av}} = \frac{1}{t_i} \cdot \int_0^{t_i} i_{\mathrm{T1}}(t) \cdot dt \qquad (2)$$

$$I_{\mathrm{T2av}} = \frac{1}{t_i} \cdot \int_0^{t_i} i_{\mathrm{T2}}(t) \cdot dt \qquad (3)$$

$$I_{\mathrm{T1rms}} = \sqrt{\frac{1}{t_i} \cdot \int_0^{t_i} i_{\mathrm{T1}}(t)^2 \cdot dt} \tag{4}$$

$$I_{\mathrm{T2rms}} = \sqrt{\frac{1}{t_i} \cdot \int_0^{t_i} i_{\mathrm{T2}}(t)^2 \cdot dt} \tag{5}$$

where

t_i is the integration time used in the simulation;

t_i shall not be less than 1 s.

If different IGBT types are used for T1 and T2, corresponding values for threshold voltages and slope resistances shall be used accordingly.

5.3 Diode conduction losses

Replace the existing second paragraph, starting with "By means of…"*, including Equations (7) to (10), the key to these equations and the note, by the following new text:*

By means of numerical simulation, the currents shall be calculated for the diodes D1 and D2 for each MMC building block, respectively:

$$I_{\mathrm{D1av}} = \frac{1}{t_{\mathrm{i}}} \cdot \int_0^{t_{\mathrm{i}}} i_{\mathrm{D1}}(t) \cdot dt \tag{7}$$

$$I_{\mathrm{D2av}} = \frac{1}{t_{\mathrm{i}}} \cdot \int_0^{t_{\mathrm{i}}} i_{\mathrm{D2}}(t) \cdot dt \tag{8}$$

$$I_{\mathrm{D1rms}} = \sqrt{\frac{1}{t_{\mathrm{i}}} \cdot \int_0^{t_{\mathrm{i}}} i_{\mathrm{D1}}(t)^2 \cdot dt} \tag{9}$$

$$I_{\mathrm{D2rms}} = \sqrt{\frac{1}{t_{\mathrm{i}}} \cdot \int_0^{t_{\mathrm{i}}} i_{\mathrm{D2}}(t)^2 \cdot dt} \tag{10}$$

where

t_i is the integration time used in the simulation;

t_i shall not be less than 1 s.

If different diode types are used for D1 and D2, corresponding values for threshold voltages and slope resistances shall be used accordingly.

5.4 Other conduction losses

Replace the second sentence of the first existing paragraph by the following new sentences:

For modular multi-level converters, this mainly consists of interconnecting busbars. Losses in valve reactors shall be considered separately from valve losses and calculated using the principles defined for AC filter reactors in IEC 61803.

9.1 Snubber circuit losses

Replace the existing note by the following new paragraph:

Including a snubber parallel to a VSC valve level influences the turn-on/turn-off behaviour of the IGBT/diode, which means that the snubber circuits shall be correctly represented during the characterisation tests on the semiconductor devices.

9.2.1 General

Replace the first existing sentence of the fourth paragraph by the following new sentences:

The power consumption of each valve electronics unit should be determined by direct measurement on a sample of real valve electronics units under representative switching conditions (voltage, current, switching frequency etc). Tests shall be performed on a minimum quantity of valve electronics units equivalent to five submodules or 10 VSC valve levels (for the CTL design).

Annex A – Description of power loss mechanisms in MMC valves

Figure A.2 – Phase unit of the cascaded two-level converter (CTL) in half-bridge form

Replace "VSC valve leve" *by* "VSC valve level".

Figure A.3 – Basic operation of the MMC converters

Replace the three occurrences of "I_L" by "I_C", where I_C is an AC phase current on the converter side of the transformer.

Figure A.4 – MMC converters showing composition of valve current

Replace the four occurrences of "I_L" by "I_C".

Figure A.6 – Effect of 3rd harmonic injection on converter voltage and current

Replace the two occurrences of "I_L" by "I_C".

Figure A.9 – Typical patterns of conduction for inverter operation (left) and rectifier operation (right)

Replace the existing title of Figure A.9 by the following new title:

Figure A.9 – Typical patterns of conduction for inverter operation (left) and rectifier operation (right), based on the submodule configuration of Figure A.7 a)

Figure A.10 – Example of converter with only one MMC building block per valve to illustrate switching behaviour

Replace "I_L" by "I_C".

A.3.2.1 Approximate analytical solution

Equation (A.3)

Replace "i_v" by "i_{vtt}".

Add, immediately after the existing Equation (A.3), the following new text:

where

$i_{vtt}(\omega t)$ is the instantaneous current between the terminals of the valve.

Equation (A.4)

Replace "i_v" *by* "i_{vtt}".

Figure A.13 – Valve current and mean rectified valve current

Replace the existing Figure A.13 by the following new figure:

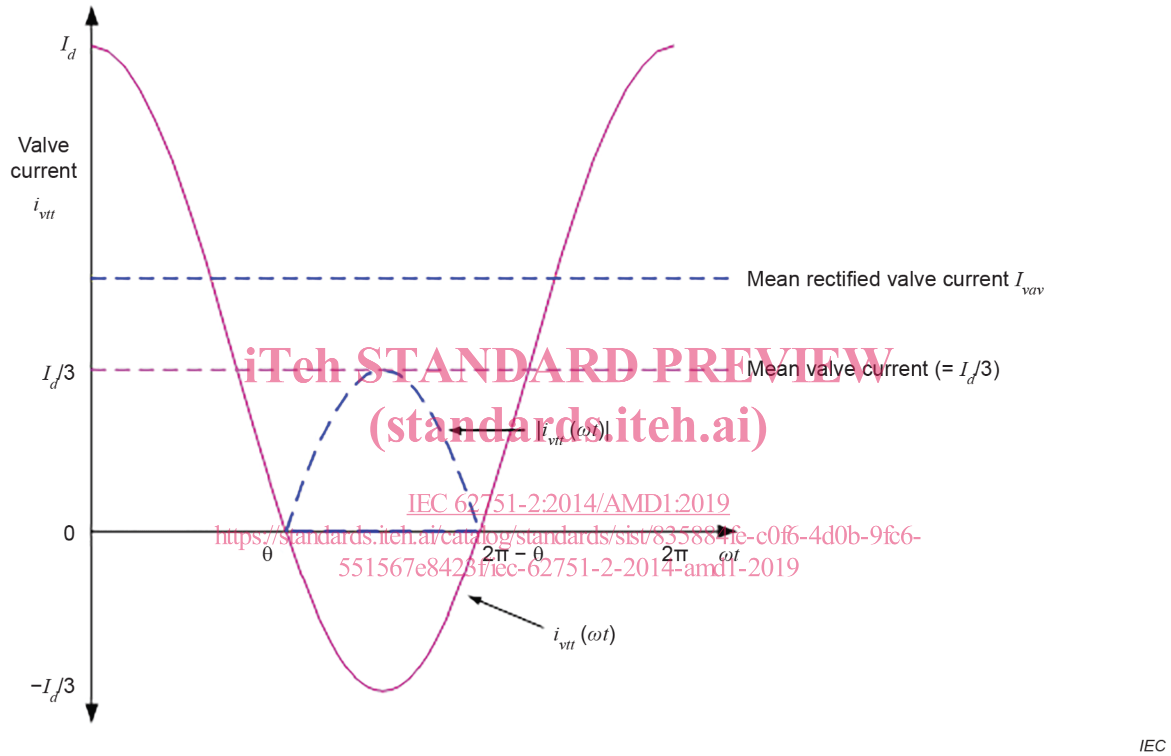

Figure A.13 – Valve current and mean rectified valve current

Equations (A.5)

Replace "I_L" *by* "I_C".

Equations (A.6)

Replace "I_L" *by* "I_C".

Equations (A.7)

Replace "I_L" *by* "I_C".

Equations (A.8)

Replace "I_L" *by* "I_C".

A.3.2.2 Exact analytical solution

Replace, in the existing title of this subclause, the word "Exact" *by* "Improved".

Equation (A.11)

Replace "u_v" *by* "u_{vtt}".

Replace, in the key to Equation (A.11), the existing symbol "$u_v(\omega t)$", including its definition, by the following new symbol and definition:

$u_{vtt}(\omega t)$ is the valve terminal-to-terminal voltage as a function of time;

Equation (A.12)

Replace "i_v" *by* "i_{vtt}".

Equation (A.13)

Replace "i_v" *by* "i_{vtt}"

Equation (A.14)

Replace "i_v" *by* "i_{vtt}"

Equation (A.15)

Replace "i_v" *by* "i_{vtt}".

Add, after the last paragraph of A.3.2.2, the following new paragraphs and new equation:

A further improvement to the analytical calculation of semiconductor conduction losses can be made by using a more sophisticated approximation for the device on-state voltage instead of the piecewise-linear model using V_0 and R_0. For example:

$$V_{ce(sat)}, V_f = A + B \cdot I + C \cdot \ln(I+1) + D \cdot \sqrt{I} \tag{A.1}$$

However, this improved model comes at the price of increased simulation complexity and reduced transparency and should only be used when specifically agreed by the purchaser.

A.3.3 MMC building block d.c. capacitor losses

Add a colon to the end of the first paragraph.

A.4.2 Analysis of state changes during cycle

Replace, in the first sentence of the second paragraph, the words "is very complex" by "can, depending on the modulation strategy chosen, be complex".

A.5.2.2 DC voltage-dependent losses with MMC building block – Analytical method

Replace, in the existing title of the subclause, the words "with MMC building block" by "in MMC building block".

*Replace, in items a) and b) of the last paragraph, the words "total losses" by "total d.c. voltage-dependent losses", and the words "*single MMC building block loss*" by "*single MMC building block d.c. voltage-dependant loss*".*

A.5.2.3 DC voltage-dependent losses with valve – Analytical method

Replace, in the existing title, the words "with valve" *by* "across complete valve".

A.5.3.2.2 Type A

Replace the two occurrences of "power circuit" *by* "power supply circuit".

A.5.3.2.3 Type B

Replace the three occurrences of "power circuit" *by* "power supply circuit".

A.6.2 Two-level full-bridge MMC building block

Add, in the first sentence of the penultimate paragraph, the word "(over-modulation)" *after* "d.c. pole-to-pole voltage".

Replace, in the penultimate paragraph, the last existing sentence by the following new sentence:

When such over-modulation is used, overall conduction losses of the full-bridge converter are therefore somewhat less than twice those of a half-bridge converter.

A.6.3 Multi-level MMC building blocks

*Delete, in the first sentence of the first existing paragraph, the words "*and used in the traditional "two-level" converter,*".*

Add, after the existing Annex A, the following new annex: