IEC TR 62543

Edition 1.0 2017-05

TECHNICAL REPORT

colour inside

AMENDMENT 2

High-voltage direct current (HVDC) power transmission using voltage sourced converters (VSC)

IEC TR 62543:2013-07/AMD2:2017-05(en)

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 29.200; 29.240.99

ISBN 978-2-8322-4350-3

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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:

DTR	Report on voting
22F/440/DTR	22F/450/RVDTR

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

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- withdrawn,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

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

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2 Normative references

Replace the existing reference "IEC 60633, Terminology for high-voltage direct-current (HVDC) transmission" *by the following new reference:* "IEC 62747, Terminology for voltage-sourced converters (VSC) for high-voltage direct current (HVDC) systems".

Add the following new references:

IEC 62501, *Voltage sourced converter (VSC) valves for high-voltage direct current (HVDC) power transmission – Electrical testing*

IEC 62751 (all parts), *Power losses in voltage sourced converter (VSC) valves for high voltage direct current (HVDC) systems*

3 Terms and definitions

Replace the existing sentence by the following new sentence:

For the purposes of this document, the terms and definitions given in IEC 62747, IEC 62501 and the following apply.

3.1 General

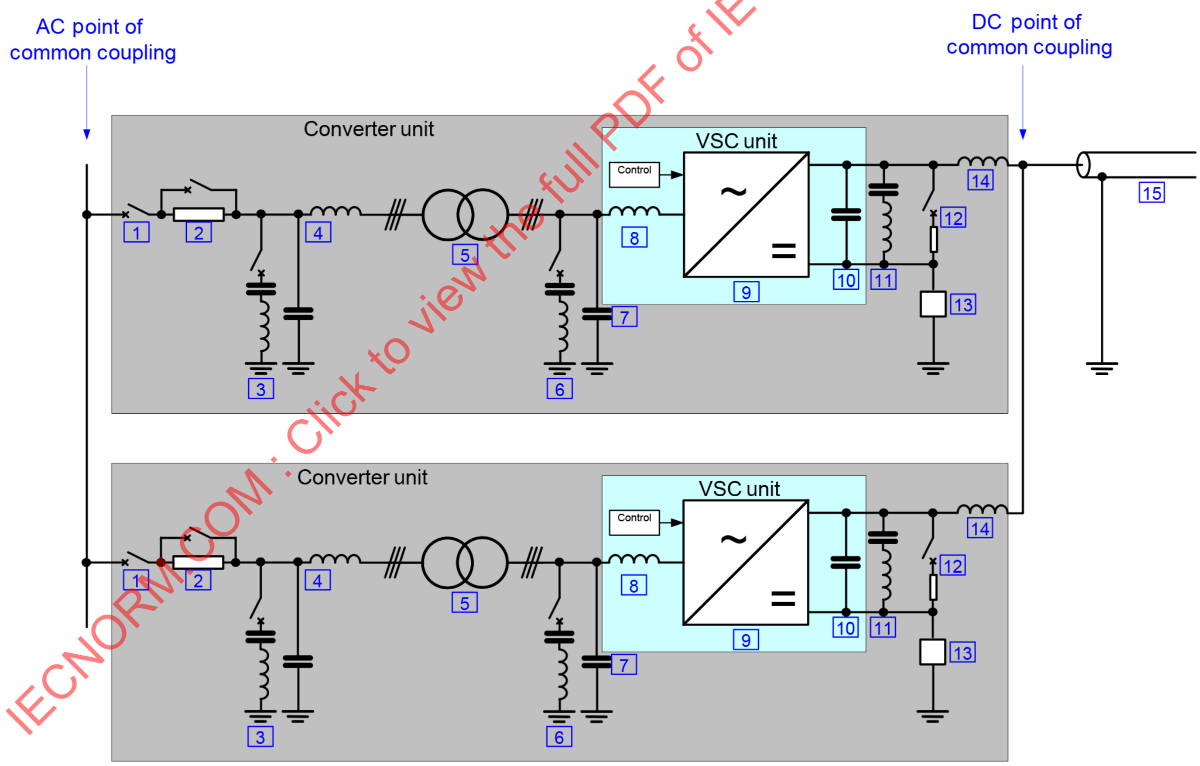
Insert the following text just after the title of 3.1:

Basic terms and definitions for voltage sourced converters used for HVDC transmission are given in IEC 62747. Terminology on electrical testing of VSC valves for HVDC transmission is given in IEC 62501.

Delete the first paragraph of the note. Change the second paragraph of the note into normal paragraph text.

Figure 1 – Major components that may be found in a VSC substation

Replace the existing figure and its footnotes modified by IEC TR 62543:2011/AMD1:2013 by the following new figure and footnotes:



IEC

1	circuit breaker	9	VSC unit [3)]
2	pre-Insertion Resistor	10	VSC d.c. capacitor [4)]
3	line side harmonic filter[1)]	11	d.c. harmonic filter[1)]
4	line side high frequency filter[6)]	12	dynamic braking system[7)]
5	interface transformer	13	neutral point grounding branch [5)]
6	converter side harmonic filter[1)]	14	d.c. reactor[8)]
7 + 8	converter side high frequency filter[2)]	15	d.c. cable or overhead transmission line
8	phase reactor [2)]		

[1] In some designs of VSC based on "controllable voltage source" valves, the harmonic filters may not be required.

[2] In some designs of VSC, the phase reactor may fulfill part of the function of the converter-side high frequency filter.

[3] In some VSC topologies, each valve of the VSC unit may include a "valve reactor", which may be built into the valve or provided as a separate component.

[4] In some designs of VSC, the VSC d.c. capacitor may be partly or entirely distributed amongst the three phase units of the VSC Unit, where it is referred to as the d.c. submodule capacitors.

[5] The philosophy and location of the neutral point grounding branch may be different depending on the design of the VSC unit.

[6] In some designs of VSC, the interface transformer may fulfill part of the function of the line-side high frequency filter.

[7] Optional.

[8] Optional, if phase reactors are located on the d.c. side of the converter.

3.3 Power semiconductor terms

Delete the existing sub-clause, modified by IEC TR 62543:2011/AMD1:2013, including its title.

3.4 VSC topologies

Delete the existing sub-clause, modified by IEC TR 62543:2011/AMD1:2013, including its title.

3.5 VSC transmission

Delete items 3.5.1 to 3.5.3, 3.5.5, 3.5.7 and 3.5.9 modified by IEC TR 62543:2011/AMD1:2013.

3.6 Operating states

Delete the existing sub-clause, modified by IEC TR 62543:2011/AMD1:2013, including its title.

3.10 Insulation co-ordination terms

Delete the existing sub-clause, including its title.

4.1.2.1 General

Replace, in the last paragraph, the first sentence by the following new sentence:

The active and reactive power are related to the AC voltages U_{L} and U_{conv} of the AC system and converter respectively, the reactance X between these voltages and the phase angle δ between them, according to the following:

$$P = \frac{U_L \times U_{\mathrm{conv}} \times \sin\delta}{X}$$

$$Q = \frac{U_L \times (U_L - U_{\mathrm{conv}} \times \cos\delta}{X}$$

Move the second and third sentences of the last paragraph on a new line to become a fourth paragraph.

4.1.3 Operating principles of a VSC transmission scheme

Add, at the beginning of the first sentence of the last paragraph, the words "For example,".

4.1.4 Applications of VSC transmission

Add, at the beginning of the first sentence of the third bullet point of the subclause, the words "In most cases,".

Figure 7 – VSC transmission with an asymmetrical monopole with metallic return

Replace the existing figure by the following new figure:

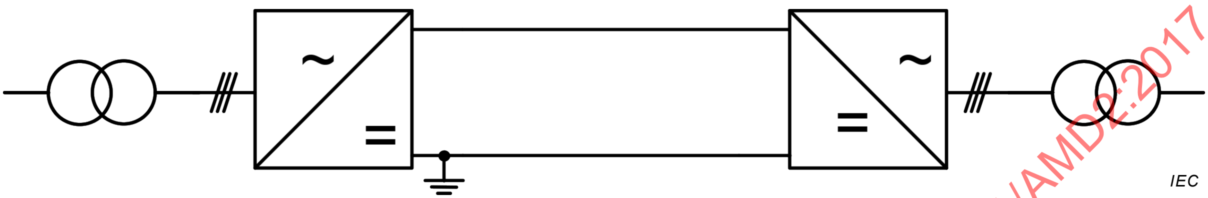


Figure 8 – VSC transmission with an asymmetrical monopole with earth return

Replace the existing figure by the following new figure:

Figure 9 – VSC transmission in bipolar configuration

Replace the existing figure by the following new figure:

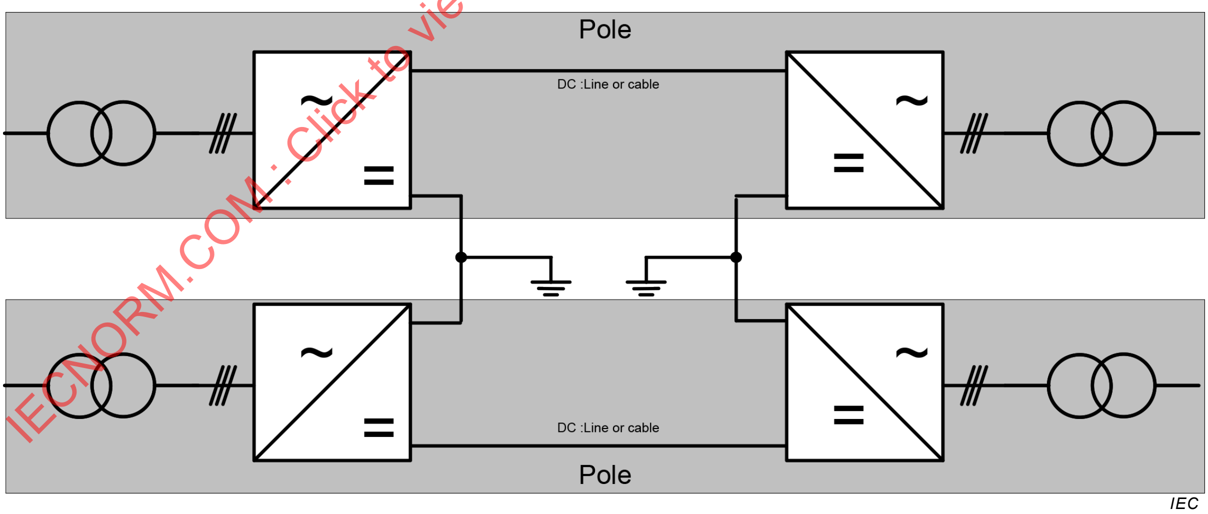
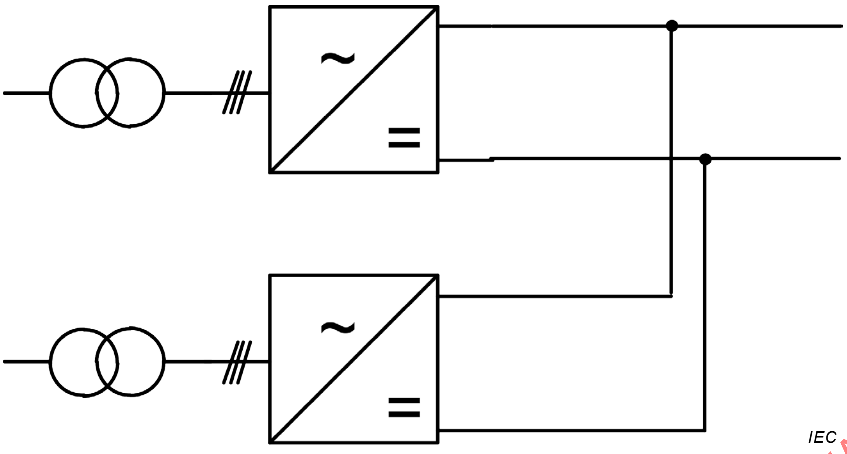


Figure 10 – Parallel connection of two converter units

Replace the existing figure by the following new figure:



5.3.2 MMC topology with VSC levels in half-bridge topology

Replace, in the first paragraph, the three occurrences of the word "module" *by* "submodule".

5.4.4 Diode requirements

Replace, in the first sentence of the first paragraph, the words "the MMC with half-topology" *by* "the MMC with half-bridge topology".

5.4.5 Additional design details

Replace the last existing paragraph by the following new paragraph:

Converter topologies with VSC valves of the "controllable voltage source" type only require synchronized switching of individual valve levels when multiple IGBTs are connected in series in each switch position (as in the cascaded two level converter). Where no direct series connection of IGBTs is used, a coordination of IGBTs switching properties of individual valve levels is not required.

5.6.3 VSC substation circuit breaker

Add, at the end of the first sentence of the second paragraph, the words ", or a separate resistor, with either a circuit breaker or disconnector in parallel with it, may be provided in series with the main circuit breaker".

5.6.6 Interface transformers and phase reactors

Add, at the beginning of the bullet point list of the fourth paragraph, the following new bullet point:

- DC voltage stress on converter winding insulation to ground, for the cases of asymmetrical monopole or bipole;

5.6.7 Valve reactor

Add, to the existing list, a fourth new bullet point:

- in some designs, the valve reactors may be combined with tuning capacitors and play a role in limiting circulating harmonic currents between phases.

Add a note to the existing subclause:

NOTE The valve reactors can be placed in several locations, for example at the DC terminals, at the AC terminals, distributed amongst the valve submodules or integrated into the same tank as the interface transformer.

5.6.8.2.5 Control aspects

Replace the first existing bullet point by the following new bullet point:

- MMCs have many submodule capacitors, whose voltages may tend to become unbalanced. Therefore, a balancing control is required in order to ensure that any unbalance does not become excessive and result in equipment ratings being exceeded.

6.6 Supply from a wind farm

Replace, in the last bullet point of the last paragraph, the words "chopper circuit" *by* "dynamic braking system".

7.2 Converter power losses

Replace the existing fourth paragraph by the following new paragraph:

For most equipment, the overall principles are the same as described in IEC 61803 for LCC HVDC, although adjustments need to be made to reflect, for example, differences of harmonic spectra. For converter valve losses, the IEC 62751 series shall be used instead of IEC 61803 (see also [31], [32]).

9.1 Harmonic performance

Replace the existing second paragraph by the following new paragraph:

In common with LCC converters, the interaction of VSC converters with the network is quite complex and, for an accurate calculation, the pre-existing (background) harmonics on the AC network need to be taken into account and the network impedance at harmonic frequencies is very important. Pre-existing harmonics may be damped or amplified due to operation of the VSC. In order to perform these calculations, accurate information about background harmonic distortion and network impedances for the frequency range of interest is necessary. More guidance on these topics can be found in the IEC 62001 series.

9.3.1 Three-phase 2-level VSC

Add, at the end of the second paragraph, the following new sentence:

Some typical modulation strategies used with 2-level VSC are discussed in Annex B.

Delete all text, equations and figures after the second paragraph, except Figure 29.

Figure 29 – Waveforms for three-phase 2-level VSC

Replace the subfigure's title "a) Phase a output voltage (V_{am})" *by* "b) Phase a output voltage (V_{am})", *and subfigure's title* "b) Control signals for a PWM VSC" *by* "a) Control signals for a PWM VSC".

9.3.2 Selective harmonic elimination modulation

Delete the existing sub-clause, including its title.

11.3.4.3 Converter operational tests

Replace the subclause's existing title by "Converter operating tests".

Annex B – Determination of VSC valve power losses

Replace the existing annex, including its title, by the following new annex and title:

Annex B
(informative)

Modulation strategies for 2-level converters

B.1 Carrier wave PWM

Figure B.1 a) shows the control signals (the carriers and the voltage references as sine wave) for a PWM VSC. Figure B.1 b) shows the resulting voltage V_{am} at the a.c. terminal a, with respect to a hypothetical midpoint m of the d.c. capacitor. In this example, the frequency of the carrier (triangular wave signal) is nine times the fundamental frequency.

The general harmonic form of the switched waveform of Figure 29 b) can be written as:

$$v_{\mathrm{am}}(t)=\frac{U_{\mathrm{d}}}{2}M\cos(\omega_1 t+\theta_1)+\sum_{m=1}^{\infty}\sum_{n=-\infty}^{\infty}C_{mn}\cos[m(\omega_{\mathrm{c}}t+\theta_{\mathrm{c}})+n(\omega_1 t+\theta_1)]$$

where

M is the modulation index;

ω_1 is the fundamental frequency;

ω_c is the carrier frequency;

m is a multiple of the carrier frequency;

n is a multiple of the fundamental frequency;

θ_1 is an arbitrary phase offset of the fundamental waveform;

θ_c is an arbitrary phase offset of the carrier waveform.

The most effective approach to determine the harmonic coefficients C_{mn} is using double integral Fourier form as:

$$C_{mn}=\frac{1}{2\pi^2}\int_{-\pi}^{\pi}\int_{-\pi}^{\pi}F(x,y)e^{j(mx+ny)}dxdy$$

where

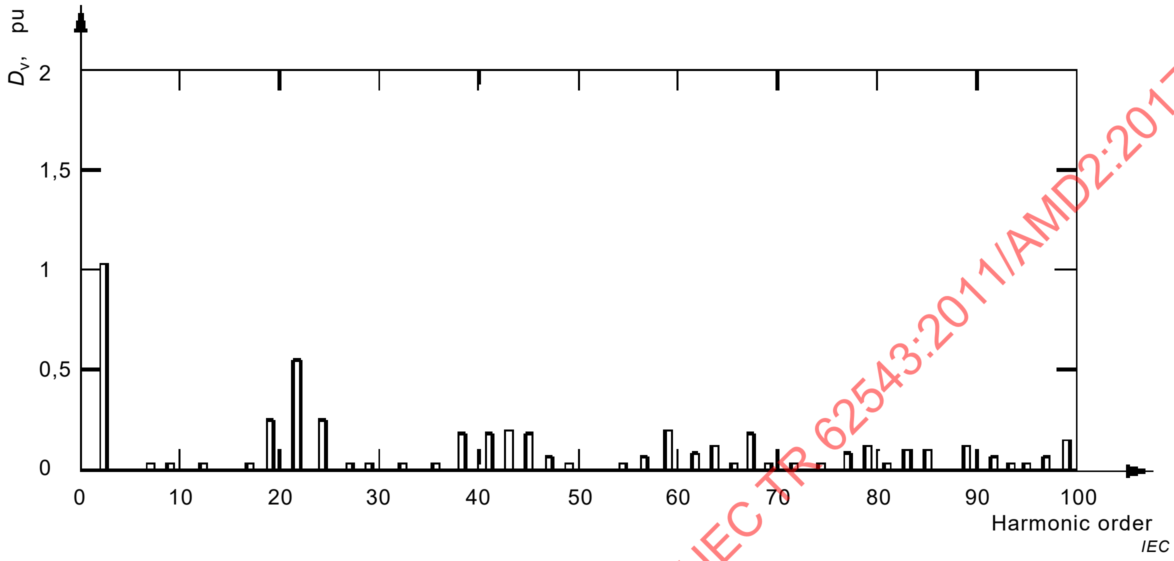
$F(x,y)$ is the switched waveform for one fundamental cycle;

x = $\omega_c t$;

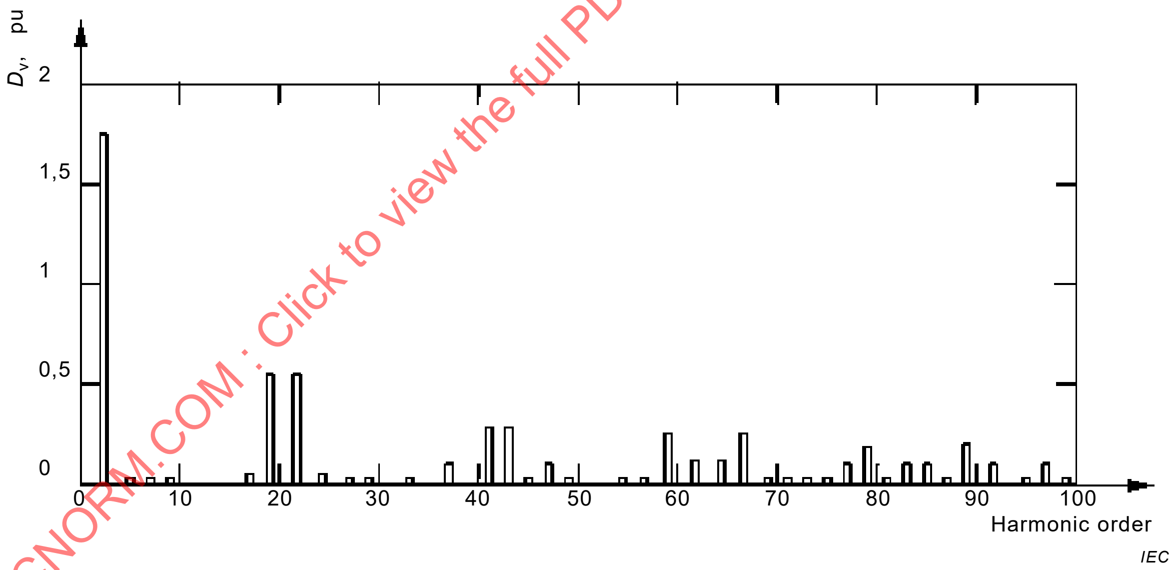
y = $\omega_1 t$.

The general harmonic form of the switched waveform defines carrier multiple harmonics (when $m \neq 0$ and $n = 0$) and sideband harmonics around the carrier multiples (when $m \neq 0$ and $n \neq 0$). Figure B.1 shows the typical harmonic spectra of the voltage waveforms for phase-to-floating neutral and phase-to-phase, respectively, for a 2-level VSC using PWM switched waveforms with a carrier-based control method using 21 times fundamental frequency and assuming infinite d.c. capacitance (i.e. no d.c. voltage ripple). These harmonic spectra would be changed under different specific operating conditions.

For a three-phase 2-level VSC, a balanced set of three-phase line-line output voltages is obtained if the phase leg references are displaced by 120°. In this case, the triplen sideband harmonics around each carrier multiple are cancelled in the line-line output voltages. It is important to note that the harmonic cancellation is a consequence of the triplen sideband harmonics. The carrier/fundamental ratio has no influence, and it can be odd, even or not integer.



B.1 a) Phase-to-floating neutral voltage amplitude versus harmonic order



B.1 b) Phase-to-phase voltage amplitude versus harmonic order

Figure B.1 – Voltage harmonics spectra of a 2-level VSC with carrier frequency at 21st harmonic

B.2 Selective harmonic elimination modulation

Selective harmonic elimination modulation (SHEM) is known as a modulation method to eliminate the undesirable low order harmonics. SHEM approach is an effective way to eliminate the selected most significant harmonics using lower switching frequency. Figure B.2 shows the waveform switched at predetermined angles. The switched waveform has odd half-wave symmetry and even quarter-wave symmetry. The K switching angles can be used to eliminate K-1 significant harmonic component and control the fundamental voltage.