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TECHNICAL REPORT

colour inside

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

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HIGH-VOLTAGE DIRECT CURRENT (HVDC) POWER TRANSMISSION USING VOLTAGE SOURCED CONVERTERS (VSC)

FOREWORD

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IEC TR 62543 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 a Technical Report.

This second edition cancels and replaces the first edition published in 2011, Amendment 1:2013 and Amendment 2:2017. This edition constitutes a technical revision.

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

a) in Clause 3, some redundant definitions which were identical to those listed in IEC 62747 have been deleted;

b) in 4.3.4, description and diagrams have been added for the cases of a bipole with dedicated metallic return and a rigid bipole;

c) in 4.4, mention is made of the bi-mode insulated gate transistor (BiGT) and injection enhanced gate transistor (IEGT) as possible alternatives to the IGBT;

d) in 5.6, the reference to common-mode blocking reactors has been deleted since these are very rarely used nowadays.

The text of this Technical Report is based on the following documents:

Draft	Report on voting
22F/649/DTR	22F/669/RVDTR

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- withdrawn,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

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HIGH-VOLTAGE DIRECT CURRENT (HVDC) POWER TRANSMISSION USING VOLTAGE SOURCED CONVERTERS (VSC)

1 Scope

This document gives general guidance on the subject of voltage sourced converters (VSC) used for transmission of power by high voltage direct current (HVDC). It describes converters that are not only voltage sourced (containing a capacitive energy storage medium and where the polarity of DC voltage remains fixed) but also self-commutated, using semiconductor devices which can both be turned on and turned off by control action. The scope includes 2-level and 3-level converters with pulse-width modulation (PWM), along with multi-level converters, modular multi-level converters and cascaded two-level converters, but excludes 2-level and 3-level converters operated without PWM, in square-wave output mode.

HVDC power transmission using voltage sourced converters is known as "VSC transmission".

The various types of circuit that can be used for VSC transmission are described in this document, along with their principal operational characteristics and typical applications. The overall aim is to provide a guide for purchasers to assist with the task of specifying a VSC transmission scheme.

Line-commutated and current-sourced converters are specifically excluded from this document.

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

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

3 Terms and definitions

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

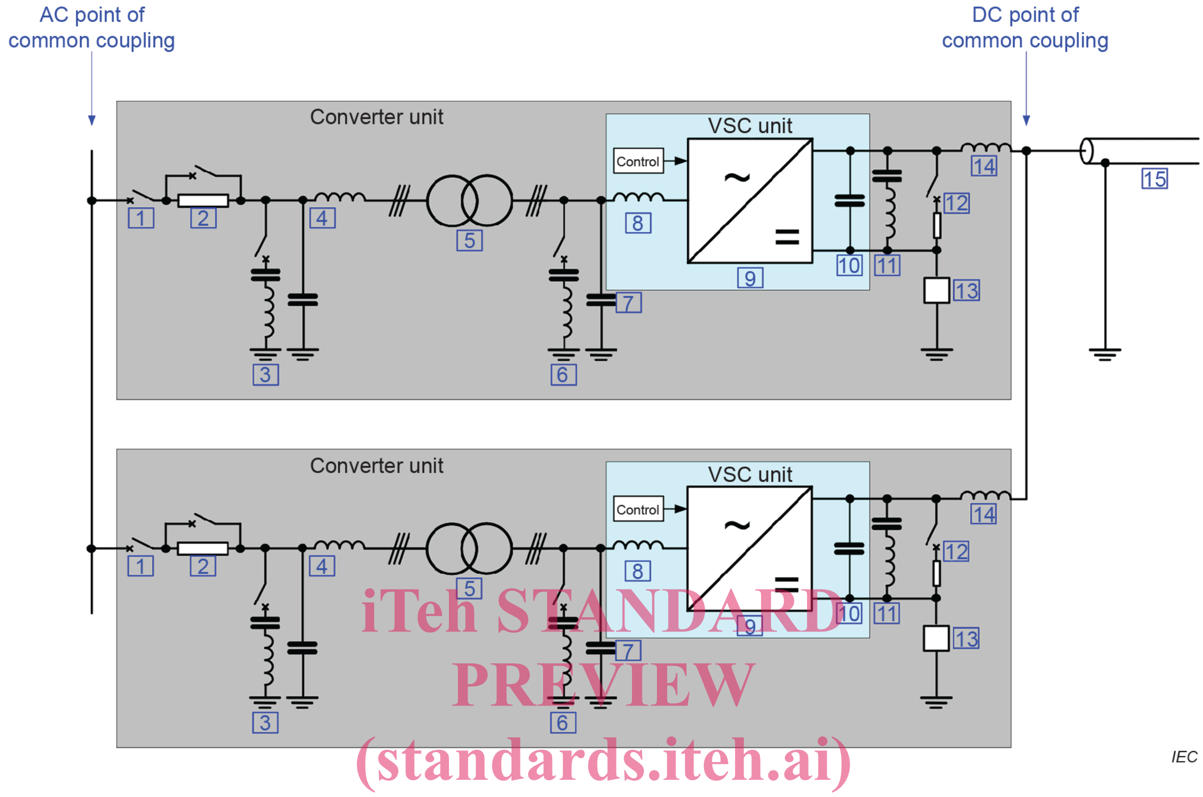
ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1 General

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.

To support the explanations, Figure 1 presents the basic diagram of a VSC system. Dependent on the converter topology and the requirements in the project, some components can be omitted or can differ.



Key

1	circuit breaker	9	VSC unit 3)
2	pre-insertion resistor	10	VSC DC capacitor 4)
3	line side harmonic filter 1)	11	DC 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	DC reactor 8)
7 + 8	converter side high frequency filter 2)	15	DC cable or overhead transmission line
8	phase reactor 2)		

1) In some designs of VSC based on controllable voltage source valves, it is possible the harmonic filter is not required.

2) In some designs of VSC, the phase reactor can fulfil part of the function of the converter-side high frequency filter.

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

4) In some designs of VSC, the VSC DC capacitor can be partly or entirely distributed amongst the three-phase units of the VSC unit, where it is referred to as the DC submodule capacitors.

5) The philosophy and location of the neutral point grounding branch can be different depending on the design of the VSC unit.

6) In some designs of VSC, the interface transformer can fulfil part of the function of the line-side high frequency filter.

7) Optional.

8) Optional.

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

3.2 Letter symbols

U_{conv}	line-to-line AC voltage of the converter unit(s), RMS value, including harmonics
I_{conv}	alternating current of the converter unit(s), RMS value, including harmonics
U_{L}	line-to-line AC voltage of the AC system, RMS value, including harmonics
I_{L}	alternating current of the AC system, RMS value, including harmonic
U_{dc}	DC terminal-to-terminal voltage of one converter unit
I_{d}	DC current of the DC bus of the VSC transmission system

3.3 VSC transmission

3.3.1
VSC DC capacitor
capacitor bank(s) (if any) connected between two DC terminals of the VSC, used for energy storage and/or filtering purposes

3.3.2
AC side radio frequency interference filter
RFI filter
filters (if any) used to reduce penetration of radio frequency interference (RFI) into the AC system to an acceptable level

3.3.3
converter side high frequency filter
filters (if any) used to mitigate the HF stresses of the interface transformer

3.3.4
DC side radio frequency interference filter
filters (if any) used to reduce penetration of radio frequency (RF) into the DC system to acceptable limits

3.3.5
type tests
tests carried out to verify that the components of VSC transmission system design will meet the requirements specified

Note 1 to entry: In this document, type tests are classified under two major categories: dielectric tests and operational tests.

3.3.6
dielectric tests
tests carried out to verify the high voltage withstanding capability of the components of VSC transmission system

3.3.7
operational tests
tests carried out to verify the turn-on (if applicable), turn-off (if applicable), and current related capabilities of the components of VSC transmission system

3.3.8
production tests
tests carried out to verify proper manufacture, so that the properties of the certain component of VSC transmission system correspond to those specified

3.3.9

sample tests

production tests which are carried out on a small number of certain VSC transmission components, for example valve sections or special components taken at random from a batch

3.4 Power losses

3.4.1

auxiliary losses

electric power required to feed the VSC substation auxiliary loads

Note 1 to entry: The auxiliary losses depend on whether the substation is in no-load or carrying load, in which case the auxiliary losses depend on the load level.

3.4.2

no-load operating losses

losses produced in an item of equipment with the VSC substation energized but with the VSCs blocked and all substation service loads and auxiliary equipment connected as required for immediate pick-up of load

3.4.3

idling operating losses

losses produced in an item of equipment with the VSC substation energized and with the VSCs de-blocked but with no real or reactive power output

3.4.4

operating losses

losses produced in an item of equipment at a given load level with the VSC substation energized and the converters operating

3.4.5

total system losses

sum of all operating losses, including the corresponding auxiliary losses

3.4.6

station essential auxiliary load

loads whose failure will affect the conversion capability of the HVDC converter station (e.g. valve cooling), as well as the loads that need to remain working in case of complete loss of AC power supply (e.g. battery chargers, operating mechanisms)

Note 1 to entry: Total "operating losses" minus "no-load operating losses" can be considered as being quantitatively equivalent to "load losses" as in conventional AC substation practice.

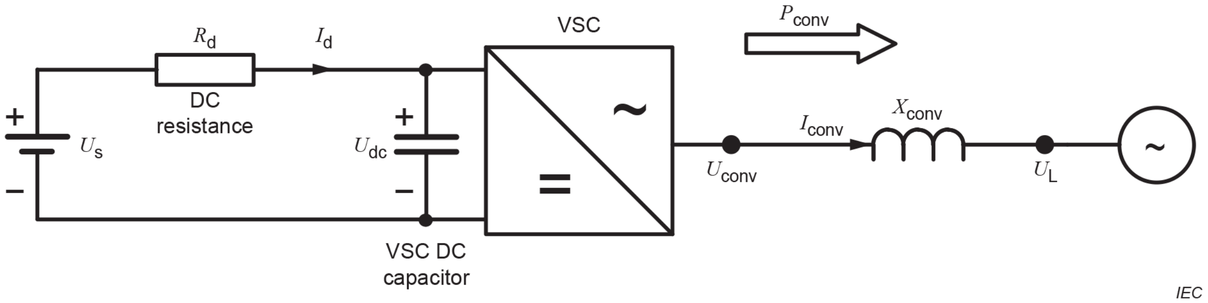
4 VSC transmission overview

4.1 Basic operating principles of VSC transmission

4.1.1 Voltage sourced converter as a black box

The operation of a voltage sourced converter is described in greater detail in Clause 5. In 4.1, the converter is treated as a black box that can convert from AC to DC and vice versa, and only steady-state operation is considered.

Figure 2 depicts a schematic diagram of a generic voltage sourced converter connected to a DC circuit on one side and to an AC circuit on the other.



NOTE AC filters are not shown.

Figure 2 – Diagram of a generic voltage source converter

The VSC can be operated as either an inverter, injecting real power into the AC network ($I_d \times U_{dc} > 0$), or as a rectifier absorbing power from the AC network ($I_d \times U_{dc} < 0$). Similarly, the VSC can be operated either capacitively, injecting reactive power into the AC network ($\mathrm{Im}(U_L \cdot I_L) > 0$) , or inductively, absorbing reactive power from the AC network ($\mathrm{Im}(U_L \cdot I_L) < 0$). The VSC can be operated capacitively or inductively in both the inverter and the rectifier mode.

The designation voltage sourced converter is used because the function of the VSC is predicated on the connection of a voltage source on the DC side.

To the left in Figure 2, a DC voltage source U_S is shown with a DC resistor R_d representing the DC circuit resistance, and a DC capacitor connected. The DC shunt capacitor serves the purpose of stabilizing the DC voltage U_d. Depending on the VSC converter topology, the DC storage capacitor is realized either as a central DC storage capacitor between both poles or as multiple storage capacitors distributed within the converter phase units. The conversion from DC to AC takes place in the VSC as explained in Clause 5.

On the AC side, an interface inductance X_{conv} is provided which serves two purposes: first, it stabilizes the AC current, and secondly, it controls active and reactive output power from the VSC, as explained in 4.1.2. The interface inductance can be implemented as reactors, as leakage inductances in transformers, or as a combination thereof. The DC capacitor on the input side and the AC interface inductance on the output side are important components for the proper functioning of a VSC.

A passive or active AC network can be connected on the AC side of the VSC. If the VSC is connected to a passive network on its AC side, the power flow can be only from the DC input side towards the passive load on the AC side. However, if the AC side is connected to an active AC network, the power flow can be in both directions by controlling the AC voltage output U_{conv} of the VSC.

By controlling the phase angle of U_{conv}, the active power through the VSC can be controlled as explained in 4.1.2.2. By controlling the voltage amplitude of U_{conv}, the reactive power through the VSC can be controlled as explained in 4.1.2.3.

4.1.2 Principles of active and reactive power control

4.1.2.1 General

The VSC can be considered as an equivalent of a synchronous generator without inertia, which has the capability of individually controlling active and reactive power.

The exchange of active and reactive power between a VSC and the AC grid is controlled by the phase angle and amplitude of the VSC output voltage in relation to the voltage of the AC grid.

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:

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

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

If U_conv is in phase with the line voltage U_L and its amplitude is equal to U_L, there is no AC current I_conv from the VSC. Under these conditions, the DC current I_d becomes zero and the DC capacitor voltage U_dc becomes equal to the DC source voltage U_s.

4.1.2.2 Principle of active power control

The principle of active power control is depicted in Figure 3, where the active power through the interface inductance is controlled by regulating the VSC voltage angle.

Figure 3 – Principle of active power control

If the angle of the VSC output voltage leads the AC grid voltage, the VSC will inject active power to the AC grid, i.e., it operates as an inverter. On the DC side, an equivalent current will be drawn from the DC source and the voltage U_dc will decrease in accordance with Ohm's law ($U_\mathrm{dc} = U_\mathrm{s} - R_\mathrm{d} \cdot I_\mathrm{d}$).

If, on the other hand, the VSC output voltage lags the voltage of the AC grid, the VSC will absorb active power from the AC grid, i.e., it operates as a rectifier. On the DC side, an equivalent current will be injected into the DC source and the voltage U_dc will increase in accordance with Ohm's law ($U_\mathrm{dc} = U_\mathrm{S} + R_\mathrm{d} \cdot I_\mathrm{d}$).

If the VSC is connected to a passive load, an AC output current will be drawn from the VSC determined by Ohm's law $I_\mathrm{conv} = U_\mathrm{conv}/Z$. Again, an equivalent DC current will be drawn from the source and the voltage U_dc on the DC capacitor will drop to a value determined by Ohm's law. No active power can be drawn from the AC side, because it is a passive AC circuit.