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TECHNICAL REPORT

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)

colour inside

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

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IEC/TR 62543, which is a technical report, 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 present technical report cancels and replaces IEC/PAS 62543:2008 (Ed.1) which was published by IEC and CIGRÉ jointly, and combined with engineering experience.

The present IEC/TR 62543 bears the edition number 1.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
22F/230/DTR	22F/239A/RVC

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

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication 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

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- withdrawn,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

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

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

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

1 Scope

This technical report gives general guidance on the subject of voltage-sourced converters 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 d.c. 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, 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 the report, 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 report.

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 60633, *Terminology for high-voltage direct-current (HVDC) transmission*

IEC 61975, *High-voltage direct current (HVDC) installations – System tests*

3 Terms and definitions

For the purpose of this document, the following definitions apply.

3.1 General

NOTE This report uses the terminology established by IEC 60633 and IEC 61803 for line-commutated HVDC. Only terms which are specific to HVDC transmission using voltage sourced converters are defined in this clause. Those terms that are either identical to or obvious extensions of IEC 60633 or IEC 61803 terminology have not been defined.

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.

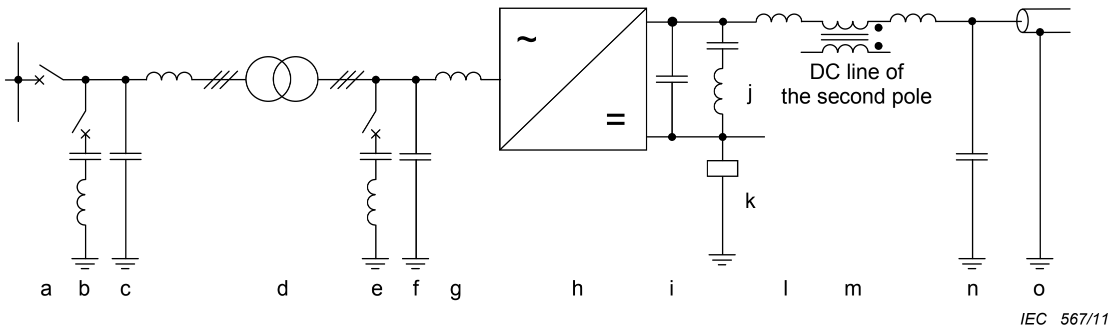

Figure 1 – Major components that may be found in a VSC substation

a	circuit breaker	i	VSC d.c. capacitor [b]
b	line side harmonic filter	j	d.c. harmonic filter
c	line side high frequency filter	k	neutral point grounding branch [c]
d	interface transformer	l	d.c. reactor [d]
e	converter side harmonic filter	m	common mode blocking reactor [d]
f + g	converter side high frequency filter [a]	n	d.c. side high frequency filter [d]
g	phase reactor [a]	o	d.c. cable or overhead transmission line [b]
h	VSC unit		

[a] In some designs of VSC, the phase reactor may fulfil part of the function of the converter-side high frequency filter. In addition, in some designs of VSC, part of or all of the phase reactor may be built into the three “Phase units” of the VSC unit, as “Valve reactors”.

[b] 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.

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

[d] Not normally required for back-to-back systems.

3.2 Letter symbols

U_{conv} line-to-line a.c. voltage of the converter unit(s), r.m.s. value, including harmonics;

I_{conv} alternating current of the converter unit(s), r.m.s. value, including harmonics;

U_L line-to-line a.c. voltage of the a.c. system, r.m.s. value, including harmonics;

I_L alternating current of the a.c. system, r.m.s. value, including harmonics;

U_d d.c. line-to-line voltage of the d.c. bus of the VSC transmission system;

I_d d.c. current of the d.c. bus of the VSC transmission system.

3.3 Power semiconductor terms

NOTE There are several types of switched valve devices which can be used in voltage sourced converters (VSC) for HVDC and currently the IGBT is the major device used in such converters. The term IGBT is used throughout this technical report to refer to the switched valve device. However, the technical report is equally applicable to other types of devices with turn-off capability in most of the parts.

3.3.1
switched valve devices
a controllable valve device which may be turned on and off by a control signal, for example IGBT

3.3.2
insulated gate bipolar transistor
IGBT
a controllable switch with the capability to turn-on and turn-off a load current. An IGBT has three terminals: a gate terminal (G) and two load terminals emitter (E) and collector (C).

By applying appropriate gate to emitter voltages, current in one direction can be controlled, i.e. turned on and turned off.

3.3.3
free-wheeling diode
FWD
power semiconductor device with diode characteristic. A FWD has two terminals: an anode (A) and a cathode (K). The current through FWDs is in opposite direction to the IGBT current.

FWDs are characterized by the capability to cope with high rates of decrease of current caused by the switching behaviour of the IGBT.

3.3.4
IGBT-diode pair
arrangement of IGBT and FWD connected in inverse parallel

3.4 VSC topologies

3.4.1
symmetrical monopole
a single VSC converter with symmetrical d.c. voltage output on the two terminals

3.4.2
asymmetrical monopole
a single VSC converter with asymmetrical d.c. voltage output on the two terminals, normally with one terminal earthed

3.4.3
bipole
two or more VSC asymmetrical monopoles forming a bipolar d.c. circuit

3.4.4
two-level converter
a converter in which the voltage at the a.c. terminals of the VSC unit is switched between two discrete d.c. voltage levels

3.4.5
three-level converter
a converter in which the voltage at the a.c. terminals of the VSC unit is switched between three discrete d.c. voltage levels

3.4.6
multi-level converter
a converter in which the voltage at the a.c. terminals of the VSC unit is switched between more than three discrete d.c. voltage levels

3.4.7
modular multi-level converter
MMC
multi-level converter in which each VSC valve consists of a number of self-contained, single-phase voltage sourced converters connected in series

3.4.8
VSC unit
three VSC phase units, together with VSC unit control equipment, essential protective and switching devices, d.c. storage capacitors, valve reactor and auxiliaries, if any, used for conversion

3.4.9
VSC phase unit
the equipment used to connect the two d.c. busbars to one a.c. terminal

NOTE In the simplest implementation, the VSC phase unit consists of two VSC valves. In some case, it consists of two VSC valves and valve reactors. The VSC phase unit may also include control and protection equipment, and other components.

3.4.10
VSC valve
complete controllable device assembly, which represents a functional unit as part of a VSC phase unit and characterized by switching actions of the power electronic devices upon control signals of the converter base electronics

NOTE Dependent on the converter topology, a valve can either have the function to act like a controllable switch or to act like a controllable voltage source.

3.4.11
diode valve
a semiconductor valve containing diodes but no switched semiconductor devices, which might be used in some VSC topologies

3.4.12
valve
refers to VSC valve or diode valve according to the context

3.4.13
VSC valve level
part of a VSC valve comprising a controllable switch and an associated diode, or controllable switches and diodes connected in parallel, or controllable switches and diodes connected to a half bridge or full bridge arrangement, together with their immediate auxiliaries, storage capacitor, if any

NOTE In the context of modular multi-level converters, the term “submodule” is also used to refer to a VSC valve level.

3.4.14
diode valve level
part of a diode valve composed of a diode and associated circuits and components, if any

3.4.15
redundant levels
the maximum number of VSC valve levels or diode valve levels in a valve that may be short-circuited externally or internally during service without affecting the safe operation of the valve as demonstrated by type tests, and which if and when exceeded, would require shutdown of the valve to replace the failed levels or acceptance of increased risk of failures

3.4.16
valve protective blocking
means of protecting the valve or converter from excessive electrical stress by the emergency turn-off of all IGBTs in one or more valves

3.4.17
submodule d.c. capacitor
a capacitor (if any) used as part of a certain VSC valve level, which is used as energy storage d.c. source

3.4.18
valve reactor
a reactor (if any) which is connected in series to the VSC valve. One or more valve reactors can be associated to one VSC valve and might be connected at different positions within the valve. According to the definition, valve reactors are not part of the VSC valve. However, it is also possible to integrate the valve reactors in the structural design of the VSC valve, e.g. into each valve level.

NOTE At present valve reactors are used in converter topologies with valves acting like a controllable voltage source only.

3.4.19
valve structure
physical structure holding the levels of a valve which is insulated to the appropriate voltage above earth potential

3.4.20
valve support
that part of the valve which mechanically supports and electrically insulates the active part of the valve from earth

NOTE A part of a valve which is clearly identifiable in a discrete form to be a valve support may not exist in all designs of valves.

3.4.21
multiple valve unit
MVU
mechanical arrangement of 2 or more valves or 1 or more VSC phase units sharing a common valve support

NOTE A MVU might not exist in all topologies and physical arrangement of converters.

3.4.22
valve section
electrical assembly, composing a number of VSC or diode valve levels and other components, which exhibits pro-rated electrical properties of a complete valve

3.4.23
valve base electronics
VBE
electronic unit, at earth potential, which is the interface between the converter control system and the VSC valves

3.5 VSC transmission

3.5.1
VSC substation
part of a VSC transmission scheme, consisting of one or more VSC unit(s) installed in a single location together with buildings, VSC d.c. capacitors, reactors, transformers, filters, control, monitoring, protective, measuring and auxiliary equipment, as applicable

3.5.2
interface transformer
transformer (if any) through which power is transmitted between the a.c. system connection point and one or more VSC units

3.5.3
phase reactor
a reactor connected directly to the a.c. terminal of the VSC phase unit, and combined with interface transformer leakage reactance (if any), in order to provide the commutating reactance

3.5.4
VSC d.c. capacitor
capacitor bank (s) (if any) connected between two d.c. terminals of the VSC, used as energy storage and / or filtering purposes

3.5.5
a.c. system side harmonic filter
a filter (if any) used to prevent harmonics generated by the VSC from penetrating into the a.c. system. The filter can be located at the point of common coupling (outside the interface transformer) or/ and on the valve side (inside the interface transformer)

3.5.6
a.c. side radio frequency interference filter (RFI filter)
filters (if any) used to reduce penetration of radio frequency interference (RFI) into the a.c. system to an acceptable level

3.5.7
HF-blocking filter
filters (if any) used to reduce penetration of high frequency (HF) harmonics into the a.c. system to an acceptable level

3.5.8
valve side harmonic filter
filters (if any) used to mitigate the HF stresses of the interface transformer

3.5.9
common mode blocking reactor
a reactor (if any) used to reduce common mode harmonic currents flowing into a d.c. overhead line or cable of a bipolar long distance transmission scheme

3.5.10
d.c. harmonic filter
d.c. filters (if any) used to prevent harmonics generated by VSC valve from penetrating into the d.c. system. The filter can consist of a tuned shunt branch, smoothing reactor or common mode blocking reactor or combinations thereof.

3.5.11
d.c. reactor
a reactor (if any) connected in series to a d.c. overhead transmission line or cable used to reduce harmonic currents flowing in the d.c. line or cable and to detune critical resonances within the d.c. circuit. A d.c. reactor might also be used for protection purposes.

3.5.12
d.c. side radio frequency interference filter
filters (if any) used to reduce penetration of radio frequency (RF) into the d.c. system to acceptable limits