IEC TR 62543

Edition 2.0 2022-03

TECHNICAL REPORT

colour inside

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

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 29.200; 29.240.99

ISBN 978-2-8322-1090-6

Warning! Make sure that you obtained this publication from an authorized distributor.

® Registered trademark of the International Electrotechnical Commission

CONTENTS

FOREWORD 6
1 Scope 8
2 Normative references 8
3 Terms and definitions 8
3.1 General 8
3.2 Letter symbols 10
3.3 VSC transmission 10
3.4 Power losses 11
4 VSC transmission overview 11
4.1 Basic operating principles of VSC transmission 11
4.1.1 Voltage sourced converter as a black box 11
4.1.2 Principles of active and reactive power control 12
4.1.3 Operating principles of a VSC transmission scheme 14
4.1.4 Applications of VSC transmission 15
4.2 Design life 15
4.3 VSC transmission configurations 15
4.3.1 General 15
4.3.2 DC circuit configurations 16
4.3.3 Monopole configuration 16
4.3.4 Bipolar configuration 17
4.3.5 Parallel connection of two converters 18
4.3.6 Series connection of two converters 19
4.3.7 Parallel and series connection of more than two converters 19
4.4 Semiconductors for VSC transmission 19
5 VSC transmission converter topologies 21
5.1 General 21
5.2 Converter topologies with VSC valves of switch type 21
5.2.1 General 21
5.2.2 Operating principle 22
5.2.3 Topologies 22
5.3 Converter topologies with VSC valves of the controllable voltage source type 25
5.3.1 General 25
5.3.2 MMC topology with VSC levels in half-bridge topology 26
5.3.3 MMC topology with VSC levels in full-bridge topology 28
5.3.4 CTL topology with VSC cells in half-bridge topology 28
5.3.5 CTL topology with VSC cells in full-bridge topology 28
5.4 VSC valve design considerations 29
5.4.1 Reliability and failure mode 29
5.4.2 Current rating 29
5.4.3 Transient current and voltage requirements 29
5.4.4 Diode requirements 30
5.4.5 Additional design details 30
5.5 Other converter topologies 31
5.6 Other equipment for VSC transmission schemes 31
5.6.1 General 31
5.6.2 Power components of a VSC transmission scheme 31

5.6.3 VSC substation circuit breaker 32
5.6.4 AC system side harmonic filters 32
5.6.5 Radio frequency interference filters 32
5.6.6 Interface transformers and phase reactors 32
5.6.7 Valve reactor 33
5.6.8 DC capacitors 33
5.6.9 DC reactor 35
5.6.10 DC filter 36
5.6.11 Dynamic braking system 36
6 Overview of VSC controls 36
6.1 General 36
6.2 Operational modes and operational options 37
6.3 Power transfer 38
6.3.1 General 38
6.3.2 Telecommunication between converter stations 38
6.4 Reactive power and AC voltage control 38
6.4.1 AC voltage control 38
6.4.2 Reactive power control 39
6.5 Black start capability 39
6.6 Supply from a wind farm 39
7 Steady-state operation 40
7.1 Steady-state capability 40
7.2 Converter power losses 41
8 Dynamic performance 42
8.1 AC system disturbances 42
8.2 DC system disturbances 42
8.2.1 DC cable fault 42
8.2.2 DC overhead line fault 43
8.3 Internal faults 43
9 HVDC performance requirements 44
9.1 Harmonic performance 44
9.2 Wave distortion 45
9.3 Fundamental and harmonics 45
9.3.1 Three-phase 2-level VSC 45
9.3.2 Multi-pulse and multi-level converters 45
9.4 Harmonic voltages on power systems due to VSC operation 46
9.5 Design considerations for harmonic filters (AC side) 46
9.6 DC side filtering 46
10 Environmental impact 47
10.1 General 47
10.2 Audible noise 47
10.3 Electric and magnetic fields (EMF) 47
10.4 Electromagnetic compatibility (EMC) 47
11 Testing and commissioning 48
11.1 General 48
11.2 Factory tests 49
11.2.1 Component tests 49
11.2.2 Control system tests 49

11.3 Commissioning tests/system tests 49
11.3.1 General 49
11.3.2 Precommissioning tests 50
11.3.3 Subsystem tests 50
11.3.4 System tests 50
Annex A (informative) Functional specification requirements for VSC transmission systems 55
A.1 General 55
A.2 Purchaser and manufacturer information requirements 55
A.2.1 General 55
A.2.2 General requirements 56
A.2.3 Detailed descriptions 57
Annex B (informative) Modulation strategies for 2-level converters 61
B.1 Carrier wave PWM 61
B.2 Selective harmonic elimination modulation 62
Bibliography 64

Figure 1 – Major components that can be found in a VSC substation 9
Figure 2 – Diagram of a generic voltage source converter 12
Figure 3 – Principle of active power control 13
Figure 4 – Principle of reactive power control 14
Figure 5 – A point-to-point VSC transmission scheme 14
Figure 6 – VSC transmission with a symmetrical monopole 16
Figure 7 – VSC transmission with an asymmetrical monopole with metallic return 17
Figure 8 – VSC transmission with an asymmetrical monopole with earth return 17
Figure 9 – VSC transmission in bipolar configuration with earth return 17
Figure 10 – VSC transmission in bipolar configuration with dedicated metallic return 18
Figure 11 – VSC transmission in rigid bipolar configuration 18
Figure 12 – Parallel connection of two converter units 19
Figure 13 – Symbol of a turn-off semiconductor device and associated free-wheeling diode 20
Figure 14 – Symbol of an IGBT and associated free-wheeling diode 20
Figure 15 – Diagram of a three-phase 2-level converter and associated AC waveform for one phase 23
Figure 16 – Single-phase AC output for 2-level converter with PWM switching at 21 times fundamental frequency 23
Figure 17 – Diagram of a three-phase 3-level NPC converter and associated AC waveform for one phase 24
Figure 18 – Single-phase AC output for 3-level NPC converter with PWM switching at 21 times fundamental frequency 25
Figure 19 – Electrical equivalent for a converter with VSC valves acting like a controllable voltage source 26
Figure 20 – VSC valve level arrangement and equivalent circuit in MMC topology in half-bridge topology 27
Figure 21 – Converter block arrangement with MMC topology in half-bridge topology 27
Figure 22 – VSC valve level arrangement and equivalent circuit in MMC topology with full-bridge topology 28

Figure 23 – Typical SSOA for the IGBT 29
Figure 24 – A 2-level VSC bridge with the IGBTs turned off 30
Figure 25 – Representing a VSC unit as an AC voltage of magnitude U and phase angle δ behind reactance 36
Figure 26 – Concept of vector control 37
Figure 27 – VSC power controller 38
Figure 28 – AC voltage controller 39
Figure 29 – A typical simplified PQ diagram 41
Figure 30 – Protection concept of a VSC substation 43
Figure 31 – Waveforms for three-phase 2-level VSC 45
Figure 32 – Equivalent circuit at the PCC of the VSC 46
Figure B.1 – Voltage harmonics spectra of a 2-level VSC with carrier frequency at 21st harmonic 62
Figure B.2 – Phase output voltage for selective harmonic elimination modulation (SHEM) 63

INTERNATIONAL ELECTROTECHNICAL COMMISSION

_____

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

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

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.

IMPORTANT – The "colour inside" logo on the cover page of this document 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.

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*