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TECHNICAL REPORT

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Performance of voltage sourced converter (VSC) based high-voltage direct current (HVDC) transmission – Part 1: Steady-state conditions

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Part 1: Steady-state conditions

FOREWORD

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IEC TR 63363-1 has been prepared by IEC technical committee 115: High Voltage Direct Current (HVDC) transmission for DC voltages above 100 kV and IEC subcommittee 22F: Power electronics for electrical transmission and distribution systems. It is a Technical Report.

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

Draft	Report on voting
115/281/DTR	115/298/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.

A list of all parts in the IEC 63363 series, published under the general title *Performance of voltage sourced converter (VSC) based high-voltage direct current (HVDC) transmission*, can be found on the IEC website.

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/standardsdev/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- withdrawn,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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INTRODUCTION

High-voltage direct current (HVDC) is an established technology that has been in commercial use for more than 60 years. With the changes in demands due to evolving environmental needs, installation of HVDC systems has increased dramatically in the last 30 years and almost half of the world's HVDC projects were commissioned after the year 2000. HVDC has become a common tool in the design of future global transmission systems.

An HVDC system transmits more electrical power over longer distances than a similar alternating current (AC) transmission system, which means fewer transmission lines are needed, saving both money and land and simplifying approvals. In addition to significantly lowering electrical losses over long distances, HVDC transmission is also very stable and easily controlled, and can stabilize and interconnect AC power networks that are otherwise incompatible. Typically, an HVDC system provides unique or superior capabilities in the following aspects:

– long distance bulk power transmission;
– asynchronous interconnections;
– long distance cable;
– controllability;
– lower losses;
– environmental concerns;
– limitation of short-circuit currents.

The voltage sourced converter (VSC) HVDC transmission system is a new generation of HVDC transmission technology, which can increase the reliability of power grids and provide an alternative to connecting wind farms or solar farms to power grids, providing power to islands, connecting asynchronous grids and building direct current (DC) grids. VSC HVDC can provide:

– independent decoupled control of active and reactive power;
– power supply for weak or even passive networks without a need for AC network to provide commutating voltage;
– simultaneous support of both active and reactive power to the AC power systems, which is beneficial for enhancing system reliability and improving power quality.

Simply due to these technical merits, the market demand for VSC HVDC transmission technology is spreading widely over the world. VSC HVDC has been selected for a number of transmission projects aimed at exchanging energy between areas and connection of remote renewable energy sources such as offshore wind farms to onshore.

With the fast development of the VSC HVDC power transmission industry, IEC standardization work has been carried out accordingly. Up to the time of writing, more than four IEC documents, related to VSC DC equipment and systems have been published. Among these, IEC 62747, IEC TR 62543, IEC 62501, and the IEC TS 62751 series provide essential information for the design and operation of VSC HVDC transmission systems.

This document provides, as a supplement to above publications, a basic guide in VSC HVDC transmission system design and operation.

This document is part one of a series of three intended technical reports, covering steady-state performance, while parts two and three (yet to be published) are intended to cover transient performance and dynamic performance, respectively.

PERFORMANCE OF VOLTAGE SOURCED CONVERTER (VSC) BASED HIGH-VOLTAGE DIRECT CURRENT (HVDC) TRANSMISSION –

Part 1: Steady-state conditions

1 Scope

The objective of this Technical Report is to present the "state of the art" with respect to general guidance on the steady-state performance demands of VSC HVDC transmission systems. It concerns the steady-state performance of two-terminal VSC HVDC transmission systems utilizing converters with power flow capability in both directions.

Different configurations of a VSC HVDC transmission system are covered in this document, including the symmetrical monopolar, asymmetrical monopolar, bipolar with earth return, bipolar with dedicated metallic return and rigid bipolar configurations.

There are many variations between different VSC HVDC transmission systems. This document does not consider these in detail; consequently, it cannot be used directly as a specification for a particular project, but rather to provide the general basis for the system steady-state performance demands.

Normally, the performance specifications are based on a complete system including two VSC HVDC converter stations. However, sometimes a VSC HVDC transmission system can also be separately specified and purchased from multiple vendors instead of single turnkey vendor. In such cases, due consideration can be given to the coordination of each part with the overall VSC HVDC system performance objectives and the interface of each with the system can be clearly defined. The major components of the VSC HVDC transmission system are presented in IEC 62747.

Referring to IEC 62747, an HVDC substation/converter station is defined as that part of the VSC HVDC transmission system which consists of one or more VSC converter units installed in a single location together with buildings, reactors, filters, reactive power supply, control, monitoring, protective, measuring and auxiliary equipment. The AC substations are not covered in this document.

This document provides guidance and supporting information on the procedure for system design and the technical issues involved in the system design of VSC HVDC transmission projects for both owners and contractors. This document can be used as the basis for drafting a procurement specification and as a guide during project implementation.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 62747:2014, *Terminology for voltage-sourced converters (VSC) for high-voltage direct current (HVDC) systems*
IEC 62747:2014/AMD1:2019

3 Terms, definitions, and abbreviated terms

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

IEC and ISO 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 Terms and definitions

3.1.1
VSC phase unit
equipment used to connect the two DC terminals to one AC terminal

Note 1 to entry: In the simplest implementation, the VSC phase unit consists of two VSC valves, and in some case, it can include also valve reactors. The VSC phase unit can also include control and protection equipment, and other components.

[SOURCE: IEC 62747:2014, 7.7]

3.1.2
VSC unit
three VSC phase units, together with VSC unit control equipment, essential protective and switching devices, DC storage capacitors, phase reactors and auxiliaries, if any, used for conversion

[SOURCE: IEC 62747:2014, 7.6]

3.1.3
VSC converter unit
indivisible operative unit comprising all equipment between the point of connection on the AC side and the point of connection on the DC side, essentially one or more VSC converters, together with one or more interface transformers, converter unit control equipment, essential protective and switching devices and auxiliaries, if any, used for conversion

[SOURCE: IEC 62747:2014, 7.5, modified – Addition of "VSC" to the term "converter unit" and in the definition replacement of "common coupling" with "connection" and "VSC units" with "VSC converters".]

3.1.4
VSC converter station
part of an VSC HVDC system which consists of one or more VSC converter units including DC switchgear, DC fault current controlling devices, if any, installed in a single location together with buildings, reactors, filters, reactive power supply, control, monitoring, protective, measuring and auxiliary equipment

3.1.5
VSC HVDC system
high-voltage direct current transmission system connecting two VSC converter stations transferring energy in the form of HVDC including related transmission lines and/or cables, switching stations, if any, as well as other equipment and sub-systems needed for operation

3.2 Abbreviated terms

The following abbreviated terms are used in the document.

AC	alternating current
AM	amplitude modulation
ASMP	asymmetrical monopole
BPS	bypass switch
BtB	back-to-back
BES	battery energy storage
C&P	control and protection
CPS	converter paralleling switch
DC	direct current
DCCT	current transformer for DC application
DCVT	voltage transformer for DC application
DG	diesel generator
DMR	dedicated metallic return
DMRTS	dedicated metallic return transfer switch
EMC	electromagnetic compatibility
ERTS	earth return transfer switch
FACTS	flexible AC transmission systems
FB	full-bridge
GIL	gas-insulated transmission line
GIS	gas-insulated metal enclosed switchgear
HB	half-bridge
HV	high voltage
HVDC	high-voltage direct current
IGBT	insulated-gate bipolar transistor
ITU	international telecommunication union
LCC	line-commutated converter
MMC	modular multi-level converter
MV	medium voltage
NBS	neutral bus switch
NBES	neutral bus earthing switch
PCC	point of common coupling
PLC	power line carrier
p.u.	per unit
RF	radio frequency
RFI	radio frequency interference
RMS	root mean square
SCADA	supervisory control and data acquisition
SCL	short-circuit level
SCR	short-circuit ratio
SMP	symmetrical monopole

SNR	signal-to-noise ratio
SSTI	sub-synchronous torsional interaction
STATCOM	static synchronous reactive power compensator
UPS	uninterruptible power system
VCU	valve control units
VBC	valve base controller
VBE	valve base electronics
VSC	voltage sourced converter

4 Classifications of VSC HVDC systems

4.1 General

Generally, in studies of projects of the classifications of VSC HVDC systems, this document focuses on the two-terminal point-to-point configuration. The economic considerations can take into account the capital costs, the cost of losses, cost of outages and other expected annual expenses. The voltage and current ratings for a given power rating can be optimized to achieve the lowest system cost, including the evaluated cost of losses. Ordinarily, the user does not need to specify the direct voltage and current ratings, unless there are specific reasons to do so, for example, for compatibility with an already existing station, to provide for a future extension or for some other reasons.

The VSC HVDC system can be operated in different configurations such as with or without transmission lines, monopolar or bipolar configurations, etc., which are further divided and shown below:

– symmetrical monopolar HVDC system,
– asymmetrical monopolar HVDC system,
– bipolar HVDC system,
– back-to-back HVDC system.

In each configuration above, the VSC HVDC system can also be classified in terms of:

– series and parallel connections of the VSC converter units,
– interface transformer arrangements.

4.2 Symmetrical monopolar HVDC system

In a symmetrical monopole (SMP), the HVDC system employs one VSC converter per station feeding a symmetrical transmission line with equal line to ground voltages on the positive and negative poles and no low impedance ground connection. One of the advantages is that the interface transformers are not exposed to DC voltage under normal operating conditions hence their design is similar to that of conventional high voltage AC transmission transformers. A defined impedance to ground is needed at DC side or AC side in order to control the DC voltages to ground including balancing the positive and negative pole DC voltages. Figure 1 shows a simplified illustration of an SMP system with AC side earthing impedance.

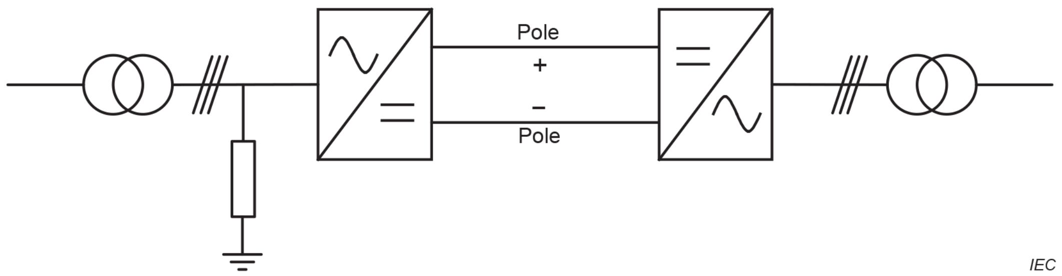

Figure 1 – Symmetrical monopolar VSC HVDC system

4.3 Asymmetrical monopolar HVDC system

4.3.1 General

With an asymmetrical monopole (ASMP), the asymmetrical monopolar configuration can be the first stage in the development of a bipolar scheme. An ASMP HVDC system typically features one converter at each end of the transmission line. Voltages of the two DC output terminals of the converter are asymmetrical. One end of the converter can be grounded directly on the DC side, through an impedance or through the electrode transmission line. The DC side configuration of an ASMP system can be with earth return or metallic return, as shown in Figure 2 and Figure 3.

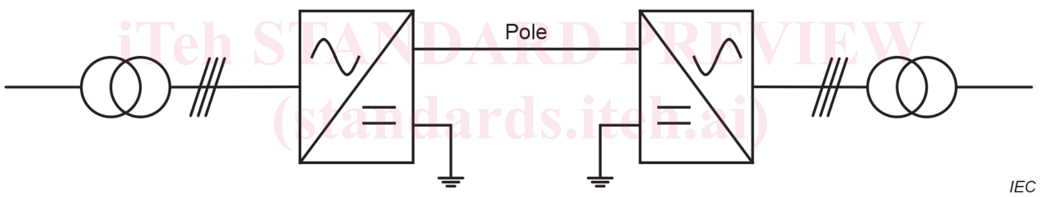

Figure 2 – Asymmetrical monopolar VSC HVDC system with earth return

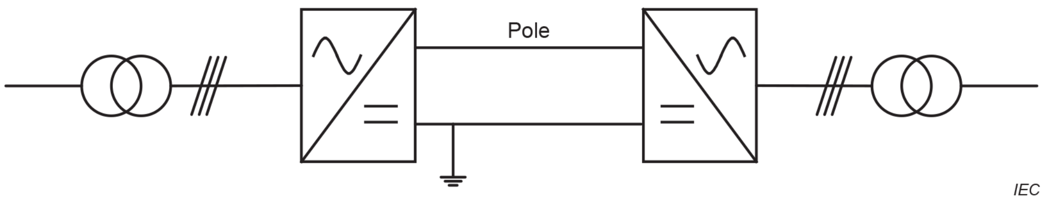

Figure 3 – Asymmetrical monopolar VSC HVDC system with metallic return

4.3.2 ASMP with earth return

For an ASMP with earth return scheme, as illustrated in Figure 2, the system also needs an earth electrode line and continuously operable earth electrodes at the two ends of the transmission. The presence of current through the earth involves issues such as corrosion, magnetic field effects, etc., covered in IEC TS 62334.

4.3.3 ASMP with metallic return

For an ASMP with metallic return scheme, as illustrated in Figure 3, the metallic return configuration can generally be used for technical and/or economical optimization such as:

a) as the first stage in the construction of a bipolar system and if long-term flow of earth current is undesirable during the interim period. In such circumstances, the return path can be through the other pole line, or;

b) if the transmission line length is short enough to make it uneconomical and undesirable to build earth electrode lines and earth electrodes, or;