IEC TR 62001-5

Edition 1.0 2021-08

TECHNICAL REPORT

colour inside

High-voltage direct current (HVDC) systems – Guidance to the specification and design evaluation of AC filters – Part 5: AC side harmonics and appropriate harmonic limits for HVDC systems with voltage sourced converters (VSC)

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IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

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FOREWORD

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IEC TR 62001-5 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.

The text of this document is based on the following documents:

Draft	Report on voting
22F/616/DTR	22F/621B/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 document is English.

A list of all parts in the IEC 62001 series, published under the general title *High-voltage direct current (HVDC) systems – Guidance to the specification and design evaluation of AC filters*, 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- withdrawn,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

The IEC TR 62001 series is structured in five parts:

IEC TR 62001-1 – Overview

This part concerns specifications of AC filters for high-voltage direct current (HVDC) systems with line-commutated converters, permissible distortion limits, harmonic generation, filter arrangements, filter performance calculation, filter switching and reactive power management and customer specified parameters and requirements.

IEC TR 62001-2 – Performance

This part deals with current-based interference criteria, field measurements and verification.

IEC TR 62001-3 – Modelling

This part addresses the harmonic interaction across converters, pre-existing harmonics, AC network impedance modelling, simulation of AC filter performance.

IEC TR 62001-4 – Equipment

This part concerns steady-state and transient ratings of AC filters and their components, power losses, audible noise, design issues and special applications, filter protection, seismic requirements, equipment design and test parameters.

IEC TR 62001-5 – AC side harmonics and appropriate harmonic limits for high-voltage direct current (HVDC) systems with voltage sourced converters (VSC)

This part concerns specific issues of AC filter design related to VSC HVDC systems. The rapid proliferation, increasing power, and technical advances of voltage source converter (VSC) HVDC technology in recent years has had a revolutionary impact on large-scale electrical power transmission. In the sphere of harmonics and filtering, the introduction of VSC technology has been highly significant. The harmonic signature of these converters is not only smaller in magnitude than equivalent line commutated converter (LCC) HVDC schemes, but also radically different in nature. Due to the switching and control methods which may be used for VSC, the generation of non-integer harmonics (interharmonics) may be an inherent characteristic of the conversion process. The frequency range of interest has also extended upwards.

The existing national and international regulations and recommendations governing harmonics were originally written considering the types of converters and associated harmonics relevant at the time of their production. With the arrival of new conversion technologies, the guidelines available are proving inadequate to deal with new harmonic profiles. Individual regulatory bodies are hastening to adapt their practices to the new technology and this document aims to aid them by providing a firm basis of appropriate technical knowledge.

The implications of VSC transmission for harmonic generation are perhaps not widely enough understood throughout the industry in terms of the frequencies and magnitudes produced and the necessity (or otherwise) of having dedicated filters. The modelling of a VSC as a harmonic voltage source rather than a current source may also not be fully appreciated in its implications for regulatory methodologies. The generation of interharmonics due to the control techniques used by some VSC HVDC converters also has profound implications.

A further topic of interest is the effect of VSC installations on pre-existing (background) harmonics. Some designs of VSC now produce a waveform so clean that it is quasi-sinusoidal and in many applications harmonic filters may not be required for mitigation of the harmonics generated by the converter. However, the converter will have a harmonic impedance as seen from the network, and it is important to be able to assess this harmonic impedance and calculate its impact in terms of possible amplification (or damping) of the pre-existing network harmonics. In some instances, this amplification of pre-existing harmonics may be the only reason for having to install filtering for a HVDC VSC.

The above aspects mainly refer to steady-state power quality issues. A separate topic is the interaction of the VSC HVDC control system with physical resonances in the connected power system. Electric power grid development is tending towards an increasing installation of underground and submarine cables, especially in the context of dispersed renewable generation. In addition, the phase-out of conventional generation together with the increasing installation of new generation sources coupled via converters and the changing characteristics of network loads will result in a reduction of harmonic damping in the system. Some converter control loops can have a bandwidth of several hundred hertz, and thus are able to interact with grid resonances. As a consequence, oscillations related to system harmonic resonances might appear and new mitigation techniques and assessment methods may become a challenge. Depending on system damping, such oscillations may be damped, sustained in steady-state or increase until some form of tripping or shutdown occurs. This phenomenon has become widely known as "harmonic stability" and although the suitability of this name may be questioned, it has been adopted in this document.

HIGH-VOLTAGE DIRECT CURRENT (HVDC) SYSTEMS – GUIDANCE TO THE SPECIFICATION AND DESIGN EVALUATION OF AC FILTERS –

Part 5: AC side harmonics and appropriate harmonic limits for HVDC systems with voltage sourced converters (VSC)

1 Scope

This part of IEC TR 62001, which is a Technical Report, provides guidance on the state-of-the art of VSC technology in relation to harmonics and predicted future developments, on the harmonic profile of present and predicted future VSC architectures and how they are characterised and modelled – as voltage sources, current sources, or otherwise. It also assesses the harmonic impedance of VSC and the possible impact on pre-existing background harmonics emanating from loads or generation units in the supply network and considers how VSC harmonics are assessed under current IEC standards and national regulations, and identify areas where improvements could be made, research can be needed, or other bodies consulted, for example when considering interharmonics. This document can be a reference source on the subject, which will also contain recommendations for use by those charged with modifying existing standards to adapt to VSC HVDC systems.

Issues relating to harmonics on the DC side of the converters, including DC grids, are deliberately not covered in this document, but are addressed by a separate CIGRE Technical Brochure [1][1].

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 TR 62543, *High-voltage direct current (HVDC) power transmission using voltage sourced converters (VSC)*

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

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 62543 and IEC 62747 apply.

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

- ISO Online browsing platform: available at https://www.iso.org/obp

[1] Numbers in square brackets refer to the Bibliography.

- IEC Electropedia: available at http://www.electropedia.org/

3.1.1
harmonic
integer harmonics and interharmonics

Note 1 to entry: The terms "harmonic" and "interharmonic" are used to describe components of a periodic time domain signal in the frequency domain. To do this, the periodical signal is expressed as a Fourier series. From a physical point of view, harmonics and interharmonics are indistinguishable – they are merely signals of different frequencies.

Due to the fact that definitions of the terms "harmonic" and "interharmonic" differ slightly in various standards, it is essential to clarify the definitions used in this document in relation to those standards.

The International Electrotechnical Vocabulary [2] defines in IEV 161-02-18:1990 a harmonic as "a component of order greater than one of the Fourier series of a periodic quantity". The harmonic order is defined in IEV 161-02-19:1990 as "the integral number given by the ratio of the frequency of a harmonic to the fundamental frequency".

IEC 61000-4-7 [3] excludes other reference frequencies and connects the definition of the IEV specifically to the power system frequency. Due to this, a harmonic becomes a "frequency which is an integer multiple of the fundamental frequency of the power system". Furthermore, IEC 61000-4-7 states that, "for brevity", the RMS value of a harmonic component is simply called a "harmonic".

The same aforementioned standards define the term "interharmonic" as the components of a periodic quantity whose order is non-integer.

To avoid constantly referring to "harmonics and interharmonics", throughout this document the term "harmonics" is used to cover both integer harmonics and interharmonics, except where it is desired to distinguish some aspect which is particular to either one.

3.2 Abbreviated terms

Acronym	Phrase
DC	direct current
DFIG	doubly-fed induction generator
EHV	extra high voltage
EM	electro-magnetic
EMC	electro-magnetic compatibility
EMT	electro-magnetic transient
EN	european norms
FCC	forced commutated converters
FDM	frequency division multiplexed
FACTS	flexible alternating current transmission system
FFT	fast fourier transform
GTO	gate turn-off thyristor
HVDC	high voltage direct current
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IEV	international electrotechnical vocabulary
IGBT	insulated gate bipolar transistor
IGCT	integrated gate-commutated thyristor
ITU	International Telecommunication Union
LCC	line commutated converter
LTI	linear time invariant
MIMO	multiple input multiple output