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TECHNICAL REPORT

colour inside

High-voltage direct current (HVDC) systems – Guidance to the specification and design evaluation of AC filters – Part 1: Overview

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

Part 1: Overview

FOREWORD

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IEC TR 62001-1 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 2016. This edition constitutes a technical revision.

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

a) general updating of the document to reflect changes in practice;
b) 10.2.4 on fuseless capacitors has been transferred to IEC TR 62001-4;
c) Clause 11 on future developments has been expanded;
d) 10.3.3 and Annex F on voltage sourced converters have been deleted as their content is covered by IEC TR 62543.

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

DTR	Report on voting
22F/614/DTR	22F/623A/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/standardsdev/publications.

A list of all parts in the IEC TR 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.

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- withdrawn,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.

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[1] – AC side harmonics and appropriate harmonic limits for high-voltage direct current (HVDC) systems with voltage sourced converters (VSC)

This document concerns specific issues of AC filter design related to VSC HVDC systems.

Parts 1 to 4 are written with focus on line commutated converters.

[1] Under preparation. Stage at the time of publication: IEC/RPUB 62001-5:2021.

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

Part 1: Overview

1 Scope

This part of IEC 62001, which is a Technical Report, deals with the specification and design evaluation of AC side harmonic performance and AC side filters for HVDC schemes. It is intended to be primarily for the use of the utilities and consultants who are responsible for issuing the specifications for new HVDC projects and evaluating designs proposed by prospective suppliers.

This document provides guidance on the specifications of AC filters for high-voltage direct current (HVDC) systems with line-commutated converters and filter performance calculation.

The scope of this document covers AC side filtering for the frequency range of interest in terms of harmonic distortion and audible frequency disturbances. Where the term "HVDC converter" or "HVDC station" is referred to without qualification, in this document, it is understood to refer to LCC technology. It excludes filters designed to be effective in the power line carrier (PLC) and radio interference spectra.

The bulk of this document concentrates on the "conventional" AC filter technology and LCC (line-commutated converter) HVDC. Voltage sourced converter (VSC) specific issues are discussed in CIGRE Technical Brochure 754 [1][2] and in IEC TR 62001-5 [2].

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
specification
document which defines the overall system requirements for an AC filter and the AC system environment in which it operates

Note 1 to entry: Such a document is normally issued by utilities to the prospective HVDC manufacturers. It also ensures the uniformity of proposals and sets guidelines for the evaluation of bids.

Note 2 to entry: The term as used here does not refer to the detailed engineering specifications relating to individual items of equipment, which are prepared by the HVDC manufacturer as a result of the filter design process.

Note 3 to entry: The specification defines the technical basis for a contract between two parties: the customer (3.2) and the contractor (3.3).

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2 Numbers in square brackets refer to the Bibliography.

3.2
customer
organization which is purchasing the HVDC converter station, including the AC filters

Note 1 to entry: The term "customer" is taken to cover similar terms which may be used in specifications, such as owner, client, buyer, utility, user, employer and purchaser, and also covers a consultant representing the customer.

3.3
contractor
organization which has the overall responsibility for delivery of the HVDC converter station, including the AC filters, as a system

Note 1 to entry: The contractor may in turn contract one or more sub-suppliers of individual items of equipment.

Note 2 to entry: The term "contractor" is taken to cover similar terms which may be used in specifications, such as manufacturer, or supplier.

Note 3 to entry: Where the context clearly refers to the pre-contract stage of a project, the word "bidder" has been used instead of "contractor", to indicate a prospective contractor, or tenderer.

3.4
branch
arm
set of components (capacitor, inductor, resistor), either in singular or interconnected arrangement, which may be isolated off load for maintenance

SEE: Figure 22

Note 1 to entry: In interconnected arrangement, it forms a smallest tuned filter unit.

3.5
sub-bank
one or more branches which can be switched (connected or disconnected) on load for reactive power control

SEE: Figure 22

Note 1 to entry: The switch does not necessarily need to have fault clearing capability.

3.6
bank
one or more sub-banks which can be switched together by a circuit breaker

SEE: Figure 22

4 Outline of specifications of AC filters for HVDC systems

4.1 General

When installing an HVDC converter station in an AC system, the way in which it may affect the quality of power supply in that system is always an important issue. One of the main power quality topics is that of harmonic performance.

The AC side current of an HVDC converter has a highly non-sinusoidal waveform, and, if allowed to flow in the connected AC system, might produce unacceptable levels of distortion. AC side filters are therefore required as part of the total HVDC converter station, in order to reduce the harmonic distortion of the AC side current and voltage to acceptably low levels.

HVDC converters also consume substantial reactive power, a large proportion of which is normally supplied locally within the converter station. Shunt connected AC filters appear as capacitive sources of reactive power at fundamental frequency, and normally in conventional HVDC schemes the AC filters are used to compensate most or all of the reactive consumption of the converter. Additional shunt capacitors and reactors may also be used to ensure that the desired reactive balance is maintained within specified limits under defined operational conditions.

The design of the AC filters therefore normally has to satisfy these two requirements of harmonic filtering and reactive power compensation, for various operational states and load levels. Optimization of this design is the task of the AC filter designer, and the constraints under which the design is made are defined in the specification.

The AC filters form a substantial part of a conventional HVDC converter station. The fundamental reactive power rating of the AC filters (including shunt capacitors where applicable) at each converter station has typically been in the range of 50 % to 60 % of the active power rating of the scheme. Together with the required switchyard equipment, the AC filters can occupy over half of the total land requirements of an HVDC scheme. The cost of manufacture, installation and commissioning of the AC filter equipment is significant, being typically in the approximate range of 10 % of the total station costs. In addition, the filter design studies can be extensive and may have an impact on many other aspects of station design (see [1], [4], [5]) and on the total project schedule. Once in operation, the AC filters will continue to have a major importance due to requirements for switching, maintenance, component spares, and reliability.

It is therefore important that the way in which the requirements for the AC filters are specified is such as to allow the design to be optimized in terms of all the above factors, while fulfilling the essential functions of disturbance mitigation and reactive power compensation.

In general, this document assumes that the purchase of an HVDC converter station, including AC filters, will be made on a turnkey or similar basis, such as has been the case for the majority of HVDC schemes to date. The discussions herein of aspects such as provision of technical information, allocation of risks and so on therefore apply principally to such an all-inclusive approach. If the alternative approach of specifying and purchasing equipment item by item were adopted, then these aspects of the document would have to be reconsidered in the context of the particular scheme, although the purely technical content of the document would still be applicable.

Most specifications for HVDC projects are issued in a final format after definition of the details of the project by the customer and possibly consultants. An alternative approach which has been used is discussed in Annex A.

4.2 Boundaries of responsibility

Before a specification enters into the detail of AC filter design requirements, it should first clearly define the boundaries of responsibility between customer and contractor.

In this respect, there are two extreme approaches.

a) The customer defines an AC system impedance, distortion limits and other performance criteria to be satisfied by calculation, the calculation method, and the parameters to be taken into account. The bidder, and later on the contractor, then makes studies and designs filters based on this information, and has the responsibility to prove, to the satisfaction of the customer, that the proposed filter design complies with all the specification requirements. The risk that the AC filters do not perform adequately under field conditions lies mainly with the customer.

b) At the other extreme, the customer defines only the maximum actual measured distortion and disturbance to be permitted (or even more simply, that there are no problems of distortion or disturbance). The customer may also specify field tests to confirm that the defined limits are not exceeded. The bidder, and later on the contractor, then has full responsibility for determining the AC system impedance, defining all relevant parameters, and designing AC filters which will perform in practice within the limits specified by the customer (or proposed as reasonable by the contractor) and withstand all actual operating conditions. Most risks in this case lie with the contractor.

For a customer with relatively little in-house study capability, approach b) might appear attractive. However, there are several disadvantages to b), as follows.

- It implies that at the tender stage, several prospective contractors will all have to make extensive studies of AC system impedance and local harmonic limit requirements. This will be expensive and difficult to achieve during a short tender period. Therefore, these studies should be conducted by the customer or his consultant during the longer period which is usually available before issue of the specification.
- As the contractor has to assume risks, there will be a corresponding impact on pricing.
- The customer may have to decide between completely different designs offered by bidders working on quite different assumptions about the AC system.
- There are significant practical difficulties in proving compliance during verification tests.
- There is unlikely to be any overall financial gain, as the customer will eventually pay for studies done by the bidder/contractor as part of the overall contract price.

In practice, most specifications adopt an approach which lies somewhere between these two extremes. For example, the customer may provide some information about the AC system configuration, maximum and minimum short-circuit powers, and expected future expansion, but not a full definition of AC system harmonic impedance.

The decision on where to place the boundary of responsibility will depend on the strategy of each individual customer and on the information and resources available to the customer. This document does not recommend a particular approach, but rather provides the detailed information necessary to guide decisions in this respect.

It is, however, strongly recommended that this overall question is carefully considered by the customer at an early stage, and that the boundaries of responsibility and delivery are clearly defined in the specification according to the customer's decision. The more detailed technical requirements of the specification should then follow in accordance. Failure to make a clear definition of responsibility, and to ensure that the detailed requirements of the specification are in accordance with the general definition of responsibility, creates risks of contractual conflict, delay and possible unsatisfactory performance of the AC filters.

Most essentially, the specification defines whether the criterion by which the filter performance is to be judged as satisfactory is to be

- demonstration by calculation of performance parameters, using the specified data, or
- measurement in the field after commissioning, or
- a combination of the above.

Demonstration by calculation ensures that the worst-case conditions can be taken into account, but allows scope for erroneous data or calculation methods. Measurement in the field may be considered as the definitive proof of correct design, but it may not be possible to make measurements under the most onerous environmental and AC and DC system conditions for which the design has been made. Also, the impact of pre-existing harmonic distortion in the AC system is taken into account, by measuring pre-existing harmonic levels with the HVDC converters blocked and with AC filters both disconnected and connected if the latter is possible considering reactive balance.

A combination of demonstration by calculation followed by eventual field measurement therefore provides the customer with the greatest assurance that the filter performance will be satisfactory.