

TECHNICAL REPORT



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

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CONTENTS

FOREWORD.....	7
INTRODUCTION.....	9
1 Scope.....	10
2 Normative references	10
3 Terms and definitions	10
4 Outline of specifications of AC filters for HVDC systems.....	11
4.1 General.....	11
4.2 Boundaries of responsibility	12
4.3 Scope of studies	14
4.4 Scope of supply	14
4.5 Technical data to be supplied by contractor	15
4.6 Alternative proposals by bidders	15
5 Permissible distortion limits	16
5.1 General.....	16
5.2 Voltage distortion.....	17
5.2.1 General	17
5.2.2 Definitions of performance criteria	17
5.2.3 Discussion and recommendations.....	18
5.2.4 Determination of limits	18
5.2.5 Pre-existing harmonic levels.....	21
5.2.6 Relaxed limits for short term and infrequent conditions.....	22
5.2.7 Treatment of interharmonic frequencies.....	22
5.3 Distortion limits pertaining to the HV and EHV network equipment.....	23
5.3.1 HVAC transmission system equipment.....	23
5.3.2 Harmonic currents in synchronous machines	23
5.3.3 Nearby HVDC installations	24
5.4 Telephone interference	24
5.4.1 General	24
5.4.2 Causes of telephone interference	24
5.4.3 Definitions of performance criteria	24
5.4.4 Discussion.....	25
5.4.5 Determination of limits	25
5.4.6 Pre-existing harmonic levels.....	27
5.4.7 Limits for temporary conditions	27
5.5 Special criteria.....	28
6 Harmonic generation	28
6.1 General.....	28
6.2 Converter harmonic generation	28
6.2.1 Idealized conditions	28
6.2.2 Realistic conditions.....	30
6.3 Calculation methodology.....	32
6.3.1 General	32
6.3.2 Harmonic currents for performance, rating and other calculations.....	32
6.3.3 Combining harmonics from different converter bridges.....	33
6.3.4 Consistent sets.....	33
6.3.5 Harmonic generation for different DC power ranges.....	34

6.4	Sensitivity of harmonic generation.....	35
6.4.1	Direct current, control angle and commutation overlap.....	35
6.4.2	Effect of asymmetries on characteristic harmonics.....	35
6.4.3	Converter equipment parameter tolerances	35
6.4.4	Tap steps	36
6.4.5	Theoretically cancelled harmonics	36
6.4.6	Negative and zero sequence voltages	36
6.4.7	Converter transformer saturation	37
6.4.8	Harmonic interaction across the converter	37
6.4.9	Back-to-back systems.....	38
6.5	Externally generated harmonics	38
7	Filter arrangements	38
7.1	Overview	38
7.2	Advantages and disadvantages of typical filters	39
7.3	Classification of filter types	40
7.4	Tuned filters.....	40
7.4.1	Single tuned filters.....	40
7.4.2	Double tuned filters	42
7.4.3	Triple tuned filters.....	44
7.5	Damped filters	45
7.5.1	Single tuned damped filters.....	45
7.5.2	Double tuned damped filters.....	48
7.6	Choice of filters.....	49
8	Filter performance calculation.....	50
8.1	Calculation procedure.....	50
8.1.1	General	50
8.1.2	Input data	50
8.1.3	Methodology	50
8.1.4	Calculation of converter harmonic currents	51
8.1.5	Selection of filter types and calculation of their impedances	52
8.1.6	Calculation of performance	52
8.2	Detuning and tolerances	53
8.2.1	General	53
8.2.2	Detuning factors	54
8.2.3	Resistance variations	55
8.2.4	Modelling.....	55
8.3	Network impedance for performance calculations	55
8.3.1	General	55
8.3.2	Network modelling using impedance envelopes	56
8.3.3	Sector diagram	57
8.3.4	Circle diagram	58
8.3.5	Discrete polygons	59
8.3.6	Zero-sequence impedance modelling.....	61
8.3.7	Detailed modelling of AC network for performance calculation	61
8.4	Outages of filter banks and sub-banks	62
8.5	Considerations of probability.....	63
8.6	Flexibility regarding compliance	65
8.7	Ratings of the harmonic filter equipment	65
9	Filter switching and reactive power management.....	66

9.1	General.....	66
9.2	Reactive power interchange with AC network.....	66
9.2.1	General	66
9.2.2	Impact on reactive compensation and filter equipment.....	66
9.2.3	Evaluation of reactive power interchange.....	67
9.3	HVDC converter reactive power capability	68
9.4	Bank/sub-bank definitions and sizing	68
9.4.1	General	68
9.4.2	Sizing	69
9.5	Hysteresis in switching points	71
9.6	Converter Q-V control near switching points	72
9.7	Operation at increased converter control angles	72
9.8	Filter switching sequence and harmonic performance	72
9.9	Demarcation of responsibilities	73
9.9.1	General	73
9.9.2	Customer.....	73
9.9.3	Contractor	74
10	Customer specified parameters and requirements	74
10.1	General.....	74
10.2	AC system parameters.....	74
10.2.1	Voltage.....	74
10.2.2	Voltage unbalance.....	75
10.2.3	Frequency	75
10.2.4	Short circuit level.....	75
10.2.5	Filter switching.....	75
10.2.6	Reactive power interchange.....	76
10.2.7	System harmonic impedance	76
10.2.8	Zero sequence data.....	76
10.2.9	System earthing.....	76
10.2.10	Insulation level	76
10.2.11	Creepage distances.....	76
10.2.12	Pre-existing voltage distortion.....	76
10.3	Harmonic distortion requirements.....	77
10.3.1	General	77
10.3.2	Redundancy requirements	77
10.4	Environmental conditions	77
10.4.1	Temperature.....	77
10.4.2	Pollution	77
10.4.3	Wind.....	77
10.4.4	Ice and snow loading (if applicable).....	78
10.4.5	Solar radiation	78
10.4.6	Isokeraunic levels.....	78
10.4.7	Seismic requirements	78
10.4.8	Audible noise.....	78
10.5	Electrical environment.....	78
10.6	Requirements for filter arrangements and components.....	79
10.6.1	Filter arrangements	79
10.6.2	Filter capacitors.....	79
10.6.3	Test requirements.....	79

10.7	Protection of filters.....	79
10.8	Loss evaluation.....	79
10.9	Field measurements and verifications	79
10.10	General requirements	79
11	Future developments	80
11.1	General.....	80
11.2	Non-standard filter technology	80
11.2.1	General	80
11.2.2	Automatically tuned reactors.....	80
11.2.3	Single-phase redundancy	83
11.2.4	Stand-alone active filters	84
11.2.5	Compact design.....	86
11.3	Other LCC converter technology	86
11.3.1	General	86
11.3.2	Series commutated converters.....	86
11.3.3	Transformerless converters	89
11.3.4	Unit connection.....	89
11.4	Changing external environment.....	90
11.4.1	Increased pre-existing levels of harmonic distortion.....	90
11.4.2	Developments in communication technology.....	90
11.4.3	Changes in structure of the power supply industry.....	91
11.4.4	Focus on power quality.....	91
11.4.5	Fewer large synchronous generators and more renewable and distributed generation.....	91
Annex A (informative)	Alternative type of procurement procedure.....	92
Annex B (informative)	Formulae for calculating the characteristic harmonics of a bridge converter	93
Annex C (informative)	Definition of telephone interference parameters	95
C.1	General.....	95
C.2	Criteria according to European practice	95
C.3	Criteria according to North American practice	96
C.4	Discussion	98
Annex D (informative)	Equivalent frequency deviation.....	99
Annex E (informative)	Reactive power management	100
E.1	HVDC converter reactive power capability	100
E.1.1	Steady-state capability	100
E.1.2	Temporary capability	102
E.2	Converter Q-V control near switching points	103
E.3	Step change in voltage on switching a filter	104
Bibliography	106
Figure 1	– Idealized current waveforms on the AC side of converter transformer	29
Figure 2	– Realistic current waveforms on the AC side of converter transformer including effect of non-idealities.....	30
Figure 3	– Comparison of harmonic content of current waveform under idealized and realistic conditions	31
Figure 4	– Typical variation of characteristic harmonic magnitude with direct current.....	34
Figure 5	– Single tuned filter and frequency response.....	41

Figure 6 – Double tuned filter and frequency response	42
Figure 7 – Triple tuned filter and frequency response	44
Figure 8 – 2 nd order damped filter and frequency response	46
Figure 9 – 3 rd order damped filter and frequency response	46
Figure 10 – C-type filter and frequency response	47
Figure 11 – Double tuned damped filter and frequency response	48
Figure 12 – Circuit model for filter calculations	51
Figure 13 – AC system impedance general sector diagram, with minimum impedance	58
Figure 14 – AC system impedance general sector diagram, with minimum resistance	58
Figure 15 – AC system impedance general circle diagram, with minimum resistance	59
Figure 16 – Example of harmonic impedances for harmonics of order 2 to 4	60
Figure 17 – Example of harmonic impedances for harmonics of order 5 to 8	60
Figure 18 – Example of harmonic impedances for harmonics of order 9 to 13	61
Figure 19 – Example of harmonic impedances for harmonics of order 14 to 49	61
Figure 20 – Illustration of basic voltage quality concepts with time/location statistics covering the whole system (adapted from IEC TR 61000-3-6:2008)	64
Figure 21 – Example of range of operation where specifications on harmonic levels are not met for a filter scheme solution	65
Figure 22 – Branch, sub-bank and bank definition	69
Figure 23 – Typical switching sequence	73
Figure 24 – Reactive power components	74
Figure 25 – Design principle of a self-tuned reactor using DC control current in an orthogonal winding	82
Figure 26 – Control principle for self-tuned filter	82
Figure 27 – One method of switching a redundant single phase filter	84
Figure 28 – Various possible configurations of series compensated HVDC converters	88
Figure E.1 – Capability diagram of a converter under different control strategies	100
Figure E.2 – Converter capability with $\gamma_{\min} = 17^\circ$, $\gamma_{\max} = 40^\circ$, $\alpha_{\min} = 5^\circ$, $\alpha_{\max} = 35^\circ$ and $U_{\text{dio max}} = 1,2U_{\text{dio N}}$	101
Figure E.3 – Reactive power absorption of a rectifier as a function of α with $U_{\text{dio}} = U_{\text{dio N}}$, $d_x = 9,4 \%$ and $d_r = 0,2 \%$	103
Figure E.4 – Reactive power absorption of a inverter as a function of γ with $U_{\text{dio}} = U_{\text{dio N}}$, $d_x = 9,4 \%$ and $d_r = 0,2 \%$	103

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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EVALUATION OF AC FILTERS –****Part 1: Overview****FOREWORD**

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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.

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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 62001-5¹ – 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).

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.