



BSI Standards Publication

High-voltage direct current (HVDC) systems — Guidance to the specification and design evaluation of AC filters

Part 4: Equipment

National foreword

This Published Document is the UK implementation of IEC TR 62001-4:2021. It supersedes PD IEC/TR 62001-4:2016, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee PEL/22, Power electronics.

A list of organizations represented on this committee can be obtained on request to its committee manager.

Contractual and legal considerations

This publication has been prepared in good faith, however no representation, warranty, assurance or undertaking (express or implied) is or will be made, and no responsibility or liability is or will be accepted by BSI in relation to the adequacy, accuracy, completeness or reasonableness of this publication. All and any such responsibility and liability is expressly disclaimed to the full extent permitted by the law.

This publication is provided as is, and is to be used at the recipient's own risk.

The recipient is advised to consider seeking professional guidance with respect to its use of this publication.

This publication is not intended to constitute a contract. Users are responsible for its correct application.

This publication is not to be regarded as a British Standard.

© The British Standards Institution 2021
Published by BSI Standards Limited 2021

ISBN 978 0 539 12722 5

ICS 29.200

Compliance with a Published Document cannot confer immunity from legal obligations.

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 30 September 2021.

Amendments/corrigenda issued since publication

| Date | Text affected |
|------|---------------|
|------|---------------|



TECHNICAL REPORT

**High-voltage direct current (HVDC) systems – Guidance to the specification and design evaluation of AC filters –
Part 4: Equipment**

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 29.200

ISBN 978-2-8322-1013-0

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

CONTENTS

| | |
|---|----|
| FOREWORD..... | 6 |
| INTRODUCTION..... | 8 |
| 1 Scope..... | 9 |
| 2 Normative references..... | 9 |
| 3 Terms and definitions | 9 |
| 4 Steady state rating | 9 |
| 4.1 General..... | 9 |
| 4.2 Calculation method | 9 |
| 4.2.1 General | 9 |
| 4.2.2 AC system pre-existing harmonics..... | 11 |
| 4.2.3 Combination of converter and pre-existing harmonics | 12 |
| 4.2.4 Equipment rating calculations..... | 12 |
| 4.2.5 Application of voltage ratings..... | 16 |
| 4.3 AC network conditions..... | 16 |
| 4.4 De-tuning effects..... | 16 |
| 4.5 Network impedance for rating calculations | 16 |
| 4.6 Outages..... | 17 |
| 5 Transient stresses and rating..... | 17 |
| 5.1 General..... | 17 |
| 5.2 Switching impulse studies | 18 |
| 5.2.1 Energization and switching..... | 18 |
| 5.2.2 Faults external to the filter..... | 20 |
| 5.2.3 Faults internal to the filter..... | 21 |
| 5.2.4 Transformer inrush currents | 22 |
| 5.3 Fast fronted waveform studies | 22 |
| 5.3.1 General | 22 |
| 5.3.2 Lightning strikes..... | 22 |
| 5.3.3 Busbar flashover studies | 22 |
| 5.4 Insulation co-ordination | 22 |
| 6 Losses | 24 |
| 6.1 Background..... | 24 |
| 6.2 AC filter component losses | 24 |
| 6.2.1 General | 24 |
| 6.2.2 Filter/shunt capacitor losses..... | 24 |
| 6.3 Reactor and resistor losses | 26 |
| 6.3.1 General | 26 |
| 6.3.2 Filter resistor losses..... | 27 |
| 6.3.3 Shunt reactor losses | 27 |
| 6.4 Criteria for loss evaluation..... | 27 |
| 6.4.1 General | 27 |
| 6.4.2 Fundamental frequency AC filter busbar voltage | 28 |
| 6.4.3 Fundamental frequency and ambient temperature..... | 28 |
| 6.4.4 AC system harmonic impedance..... | 28 |
| 6.4.5 Harmonic currents generated by the converter..... | 29 |
| 6.4.6 Pre-existing harmonic distortion | 29 |
| 6.4.7 Anticipated load profile of the converter station..... | 29 |

| | | |
|-------|--|----|
| 7 | Design issues and special applications | 30 |
| 7.1 | General..... | 30 |
| 7.2 | Performance aspects..... | 30 |
| 7.2.1 | Low order harmonic filtering and resonance conditions with AC system | 30 |
| 7.2.2 | Definition of interference factors to include harmonics up to 5 kHz | 31 |
| 7.2.3 | Triple-tuned filter circuits..... | 32 |
| 7.2.4 | Harmonic AC filters on tertiary winding of converter transformers | 33 |
| 7.3 | Rating aspects | 34 |
| 7.3.1 | Limiting high harmonic currents in parallel-resonant filter circuits | 34 |
| 7.3.2 | Transient ratings of parallel circuits in multiple tuned filters..... | 34 |
| 7.3.3 | Overload protection of high-pass harmonic filter resistors | 34 |
| 7.3.4 | Back-to-back switching of filters or shunt capacitors | 35 |
| 7.3.5 | Short time overload – reasonable specification of requirements | 35 |
| 7.3.6 | Low voltage filter capacitors without fuses | 36 |
| 7.4 | Filters for special purposes..... | 36 |
| 7.4.1 | Harmonic filters for damping transient overvoltages | 36 |
| 7.4.2 | Non-linear filters for low order harmonics/transient overvoltages | 37 |
| 7.4.3 | Series filters for HVDC converter stations | 38 |
| 7.4.4 | Re-tunable AC filters..... | 41 |
| 7.5 | Impact of new HVDC station in vicinity of an existing station | 42 |
| 7.6 | Redundancy issues and spares | 43 |
| 7.6.1 | Redundancy of filters – Savings in ratings and losses | 43 |
| 7.6.2 | Internal filter redundancy..... | 44 |
| 7.6.3 | Spare parts..... | 44 |
| 8 | Protection..... | 45 |
| 8.1 | Overview..... | 45 |
| 8.2 | General..... | 45 |
| 8.3 | Bank and sub-bank overall protection | 47 |
| 8.3.1 | General | 47 |
| 8.3.2 | Short-circuit protection | 47 |
| 8.3.3 | Overcurrent protection | 47 |
| 8.3.4 | Thermal overload protection | 47 |
| 8.3.5 | Differential protection..... | 48 |
| 8.3.6 | Earth fault protection..... | 48 |
| 8.3.7 | Overvoltage and undervoltage protection..... | 48 |
| 8.3.8 | Special protection functions and harmonic measurements..... | 49 |
| 8.3.9 | Busbar and breaker failure protection | 49 |
| 8.4 | Protection of individual filter components | 49 |
| 8.4.1 | Unbalance protection for filter and shunt capacitors | 49 |
| 8.4.2 | Protection of low voltage tuning capacitors | 51 |
| 8.4.3 | Overload protection and detection of filter detuning | 51 |
| 8.4.4 | Temperature measurement for protection | 51 |
| 8.4.5 | Measurement of fundamental frequency components | 51 |
| 8.4.6 | Capacitor fuses..... | 51 |
| 8.4.7 | Protection and rating of instrument transformers..... | 52 |
| 8.4.8 | Examples of protection arrangements..... | 53 |
| 8.5 | Personnel protection | 53 |
| 9 | Audible noise..... | 56 |
| 9.1 | General..... | 56 |

| | | |
|--------|--|----|
| 9.2 | Sound active components of AC filters..... | 56 |
| 9.3 | Sound requirements | 58 |
| 9.4 | Noise reduction | 58 |
| 10 | Seismic requirements | 59 |
| 10.1 | General..... | 59 |
| 10.2 | Load specification | 60 |
| 10.2.1 | Seismic loads | 60 |
| 10.2.2 | Additional loads | 61 |
| 10.2.3 | Soil quality..... | 61 |
| 10.3 | Method of qualification | 61 |
| 10.3.1 | General | 61 |
| 10.3.2 | Qualification by analytical methods..... | 61 |
| 10.3.3 | Design criteria..... | 62 |
| 10.3.4 | Documentation for qualification by analytical methods..... | 63 |
| 10.4 | Examples of improvements in the mechanical design | 63 |
| 11 | Equipment design and test parameters..... | 63 |
| 11.1 | General..... | 63 |
| 11.1.1 | Technical information and requirements | 63 |
| 11.1.2 | Technical information to be provided by the customer | 64 |
| 11.1.3 | Customer requirements | 64 |
| 11.1.4 | Technical information to be presented by the bidders..... | 66 |
| 11.1.5 | Ratings | 66 |
| 11.2 | Capacitors | 67 |
| 11.2.1 | General | 67 |
| 11.2.2 | Design aspects | 67 |
| 11.2.3 | Electrical data..... | 70 |
| 11.2.4 | Tests | 71 |
| 11.3 | Reactors | 71 |
| 11.3.1 | General | 71 |
| 11.3.2 | Design aspects | 71 |
| 11.3.3 | Electrical data..... | 72 |
| 11.3.4 | Tests | 73 |
| 11.4 | Resistors | 74 |
| 11.4.1 | General | 74 |
| 11.4.2 | Design aspects | 74 |
| 11.4.3 | Electrical data..... | 75 |
| 11.4.4 | Tests | 76 |
| 11.5 | Arresters..... | 77 |
| 11.5.1 | General | 77 |
| 11.5.2 | Design aspects | 78 |
| 11.5.3 | Electrical data..... | 78 |
| 11.5.4 | Arresters: tests | 79 |
| 11.6 | Instrument transformers | 79 |
| 11.6.1 | Voltage transformers..... | 79 |
| 11.6.2 | Current transformers..... | 80 |
| 11.7 | Filter switching equipment..... | 82 |
| 11.7.1 | General | 82 |
| 11.7.2 | Design aspects | 82 |
| 11.7.3 | Electrical data..... | 85 |

| | |
|---|----|
| 11.7.4 Test requirements | 86 |
| Annex A (informative) Example of seismic response spectra (from IEEE Std 693-2005)..... | 88 |
| Bibliography | 89 |
| Figure 1 – Circuit for rating evaluation..... | 10 |
| Figure 2 – Inrush current into a 12/24 th double-tuned filter | 19 |
| Figure 3 – Voltage across the low voltage capacitor of a 12/24 th double-tuned filter at switch-on..... | 20 |
| Figure 4 – Voltage across the HV capacitor bank of a 12/24 th double-tuned filter under fault conditions | 21 |
| Figure 5 – Typical arrangements of surge arresters | 23 |
| Figure 6 – Non-linear low order filter for Vienna Southeast HVDC station..... | 37 |
| Figure 7 – Single-tuned series filter and impedance plot..... | 38 |
| Figure 8 – Triple-tuned series filter and impedance plot..... | 39 |
| Figure 9 – Mixed series and shunt AC filters at Uruguiana HVDC station..... | 40 |
| Figure 10 – Re-tunable AC filter branch..... | 42 |
| Figure 11 – Example of a protection scheme for an unearthed shunt capacitor | 54 |
| Figure 12 – Example of a protection scheme for a C-type filter..... | 55 |
| Figure 13 – Electrical spectrum | 57 |
| Figure 14 – Force spectrum | 57 |
| Figure 15 – Comparison of internal, fuseless and external fused capacitor unit designs..... | 69 |
| Figure A.1 – Seismic response spectra..... | 88 |
| Table 1 – Typical losses in an all-film capacitor unit | 25 |
| Table 2 – Electrical data for capacitors..... | 70 |
| Table 3 – Electrical data for reactors | 73 |
| Table 4 – Electrical data for resistors | 75 |
| Table 5 – Electrical data for arresters..... | 79 |
| Table 6 – Electrical data for current transformers | 81 |
| Table 7 – Electrical data for filter switching equipment..... | 86 |

INTERNATIONAL ELECTROTECHNICAL COMMISSION

**HIGH-VOLTAGE DIRECT CURRENT (HVDC) SYSTEMS –
GUIDANCE TO THE SPECIFICATION AND DESIGN
EVALUATION OF AC FILTERS –****Part 4: Equipment**

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 62001-4 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 change with respect to the previous edition:

- a) general updating of the document to reflect changes in practice;
- b) Annex A deleted as its content is covered by IEC 61803.

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

| | |
|-------------|------------------|
| Draft | Report on voting |
| 22F/615/DTR | 22F/622B/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.

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 HVDC systems with voltage sourced converters (VSC)

This part concerns specific issues of AC filter design related to high-voltage direct current (VSC) systems with voltage sourced converters (HVDC).

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

Part 4: Equipment

1 Scope

This part of IEC TR 62001, which is a Technical Report, provides guidance on the basic data of AC side filters for high-voltage direct current (HVDC) systems and their components such as ratings, power losses, design issues and special applications, protection, seismic requirements, equipment design and test parameters.

This document covers AC side filtering for the frequency range of interest in terms of harmonic distortion and audible frequency disturbances. It excludes filters designed to be effective in the power line carrier (PLC) and radio interference spectra.

It concerns the conventional AC filter technology and LCC (line-commutated converter) HVDC but much of this applies to any filter equipment for VSC (voltage sourced converter) HVDC.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

No terms and definitions are listed in this document.

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

4 Steady state rating

4.1 General

The calculation of the steady state ratings of the harmonic filter equipment is the responsibility of the contractor. Clause 4 gives guidance on the calculation of equipment rating parameters and the different factors to be considered in the studies. It is the responsibility of the customer to provide the appropriate system and environmental data and also to clarify the operational conditions, such as filter outages and network contingencies, which need to be taken into account.

4.2 Calculation method

4.2.1 General

Steady state rating of filter equipment for an LCC HVDC system is based on a solution of the following circuit which represents the HVDC converter, the filter banks and the AC supply system. See Figure 1.