

# CONSOLIDATED VERSION



---

## High-voltage direct current (HVDC) systems – Application of active filters

INTERNATIONAL  
ELECTROTECHNICAL  
COMMISSION

---

ICS 29.240.99

ISBN 978-2-8322-3332-0

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

# REDLINE VERSION



---

## High-voltage direct current (HVDC) systems – Application of active filters



## CONTENTS

FOREWORD .....	5
1 Scope .....	7
2 Normative references .....	7
3 Terms and definitions .....	7
3.1 Active and passive filters .....	8
3.2 Active filter topologies .....	8
shunt active filter .....	8
3.3 Power semiconductor terms .....	9
3.4 Converter topologies .....	9
4 Active filters in HVDC applications .....	10
4.1 General .....	10
4.2 Semiconductor devices available for active filters .....	11
5 Active d.c. filters .....	11
5.1 Harmonic disturbances on the d.c. side .....	11
5.2 Description of active d.c. filters .....	12
5.2.1 General .....	12
5.2.2 Types of converters available .....	12
5.2.3 Connections of the active d.c. filter .....	14
5.2.4 Characteristics of installed active d.c. filters .....	16
5.3 Main components in a d.c. active filter .....	17
5.3.1 General .....	17
5.3.2 Passive part .....	17
5.3.3 Current transducer .....	19
5.3.4 Control system .....	19
5.3.5 Amplifier .....	20
5.3.6 Transformer .....	20
5.3.7 Protection circuit and arrester .....	20
5.3.8 Bypass switch and disconnectors .....	20
5.4 Active d.c. filter control .....	20
5.4.1 General .....	20
5.4.2 Active d.c. filter control methods .....	21
5.5 Example – Performance of the Skagerrak 3 HVDC Intertie active d.c. filter .....	24
5.6 Conclusions on active d.c. filters .....	25
6 Active a.c. filters in HVDC applications .....	26
6.1 General .....	26
6.2 Harmonic disturbances on the a.c. side of a HVDC system .....	26
6.3 Passive filters .....	27
6.3.1 Conventional passive filters .....	27
6.3.2 Continuously tuned passive filters .....	27
6.4 Reasons for using active filters in HVDC systems .....	28
6.5 Operation principles of active filters .....	29
6.5.1 Shunt connected active filter .....	29
6.5.2 Series connected active filter .....	30
6.6 Parallel and series configuration .....	30
6.6.1 General .....	30
6.6.2 Hybrid filter schemes .....	30

6.7	Converter configurations.....	31
6.7.1	Converters.....	31
6.8	Active a.c. filter configurations.....	34
6.8.1	Active a.c. filters for low voltage application.....	34
6.8.2	Active a.c. filters for medium voltage application.....	34
6.8.3	Active a.c. filters for HVDC applications.....	34
6.9	Series connected active filters.....	36
6.10	Control system.....	36
6.10.1	General.....	36
6.10.2	Description of a generic active power filter controller.....	36
6.10.3	Calculation of reference current.....	37
6.10.4	Synchronous reference frame (SRF).....	38
6.10.5	Other control approaches.....	39
6.10.6	HVDC a.c. active filter control approach.....	39
6.11	Existing active a.c. filter applications.....	39
6.11.1	Low and medium voltage.....	39
6.11.2	High voltage applications.....	39
6.12	Overview on filter solutions for HVDC systems.....	40
6.12.1	Solution with conventional passive filters.....	40
6.12.2	Solution with continuously tuned passive filters.....	41
6.12.3	Solution with active filters.....	42
6.12.4	Solution with continuously tuned passive filters and active filters.....	42
6.12.5	Study cases with the CIGRÉ HVDC model.....	42
6.13	ACfilters for HVDC installations using VSC.....	44
6.14	Conclusions on active a.c. filters.....	45
	Bibliography.....	46
	Figure 1 – Shunt connection.....	8
	Figure 2 – Series connection.....	8
	Figure 3 – Conceptual diagram of allowable interference level and d.c. filter cost.....	10
	Figure 4 – Simple current source converter.....	13
	Figure 5 – Simple voltage sourced converter.....	14
	Figure 6 – Possible connections of active d.c. filters.....	15
	Figure 7 – Filter components in the active filter.....	18
	Figure 8 – Impedance characteristics of different passive filters.....	18
	Figure 9 – Basic control loop of an active d.c. filter.....	22
	Figure 10 – Measured transfer function of external system, Baltic Cable HVDC link.....	23
	Figure 11 – Feedforward control for the active d.c. filter.....	23
	Figure 12 – Measured line current spectra, pole 3 operated as monopole.....	25
	Figure 13 – Continuously tuned filter.....	27
	Figure 14 – Example of current waves.....	30
	Figure 15 – Series and parallel connection.....	31
	Figure 16 – Hybrid configuration.....	31
	Figure 17 – Three phase current-source converter.....	32
	Figure 18 – Three phase 2 level voltage-sourced converter (three-wire type).....	33
	Figure 19 – Three phase 3 level voltage-sourced converter (three-wire type).....	33

Figure 20 – Single-phase voltage sourced converter .....	34
Figure 21 – Active filter connected to the HV system through a single-tuned passive filter .....	35
Figure 22 – Active filter connected to the HV system through a double-tuned passive filter .....	35
Figure 23 – Using an LC circuit to divert the fundamental current component .....	36
Figure 24 – Per-phase schematic diagram of active filter and controller .....	37
Figure 25 – Block diagram of IRPT .....	37
Figure 26 – Block diagram of SRF .....	39
Figure 27 – Plots from site measurements .....	41
Figure 28 – Filter configuration and a.c. system harmonic impedance data .....	43
Table 1 – The psophometric weighting factor at selected frequencies .....	12
Table 2 – Voltage to be supplied by the active part with different selections of passive parts .....	19
Table 3 – Major harmonic line currents, pole 3 operated as monopole .....	25
Table 4 – Preferred topologies for common LV and MV applications .....	31
Table 5 – Performance Requirements .....	43
Table 6 – Parameters of filters at a.c. substation A (375 kV) .....	44
Table 7 – Parameters of filters at a.c. substation B (230 kV) .....	44
Table 8 – Performance results of filters .....	44

## INTERNATIONAL ELECTROTECHNICAL COMMISSION

# HIGH-VOLTAGE DIRECT CURRENT (HVDC) SYSTEMS – APPLICATION OF ACTIVE FILTERS

## 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.

### **DISCLAIMER**

**This Consolidated version is not an official IEC Standard and has been prepared for user convenience. Only the current versions of the standard and its amendment(s) are to be considered the official documents.**

**This Consolidated version of IEC TR 62544 bears the edition number 1.1. It consists of the first edition (2011-08) [documents 22F/242/DTR and 22F/250/RVC] and its amendment 1 (2016-04) [documents 22F/377/DTR and 22F/381A/RVC]. The technical content is identical to the base edition and its amendment.**

**In this Redline version, a vertical line in the margin shows where the technical content is modified by amendment 1. Additions are in green text, deletions are in strikethrough red text. A separate Final version with all changes accepted is available in this publication.**

The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a technical report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

IEC/TR 62544, which is a technical report, has been prepared by subcommittee 22F: Power electronics for electrical transmission and distribution systems, of IEC technical committee 22: Power electronics.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of the base publication and its amendment will remain unchanged until the stability date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

**IMPORTANT – The 'colour inside' logo on the cover page of this publication 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.**

## HIGH-VOLTAGE DIRECT CURRENT (HVDC) SYSTEMS – APPLICATION OF ACTIVE FILTERS

### 1 Scope

This technical report gives general guidance on the subject of active filters for use in high-voltage direct current (HVDC) power transmission. It describes systems where active devices are used primarily to achieve a reduction in harmonics in the d.c. or a.c. systems. This excludes the use of automatically retuned components.

The various types of circuit that can be used for active filters are described in the report, along with their principal operational characteristics and typical applications. The overall aim is to provide guidance for purchasers to assist with the task of specifying active filters as part of HVDC converters.

Passive filters are specifically excluded from this report.

### 2 Normative references

The following referenced documents are indispensable for the application 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/TS 60071-5, *Insulation co-ordination – Part 5: Procedures for high-voltage direct current (HVDC) converter stations*

IEC 60633, *Terminology for high-voltage direct-current (HVDC) transmission*

IEC 61000 ( all parts), *Electromagnetic compatibility (EMC)*

IEC 61975, *High-voltage direct current (HVDC) installations – System tests*

IEC/TR 62001:2009, *High-voltage direct current (HVDC) systems – Guidebook to the specification and design evaluation of A.C. filters*

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

IEEE 519, *IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems*