

AS 60071.12:2024



STANDARDS
Australia



Insulation co-ordination

**Part 12: Application guidelines for LCC HVDC converter stations
(IEC 60071-12:2022 (ED. 1.0), MOD)**



AS 60071.12:2024

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- Electric Energy Society of Australia
- Electrical Regulatory Authorities Council, Australia
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Preface

This Standard was prepared by the Standards Australia Committee EL-043, High Voltage Installations.

The objective of this document is to apply guidelines on the procedures for insulation co-ordination of line commutated converter (LCC) stations for high-voltage direct current (HVDC) project, whose aim is evaluating the overvoltage stresses on the converter station equipment subjected to combined DC, AC power frequency, harmonic and impulse voltages, and determining the specified withstand voltages for equipment.

This document deals only with metal-oxide surge arresters, without gaps, which are used in modern HVDC converter stations. The criteria for determining the protective levels of series and/or parallel combinations of surge arresters used to ensure optimal protection are also presented. Typical arrester protection schemes and stresses of arresters are presented.

Annex A contains examples of insulation co-ordination for LCC HVDC converters which support the concepts described in the main text, and the basic analytical techniques used.

This document is an adoption with national modifications, and has been reproduced from, IEC 60071-12:2022, *Insulation co-ordination – Part 12: Application guidelines for LCC HVDC converter stations*.

The modifications are additional requirements and are set out in [Appendix ZZ](#), which has been added at the end of the source text.

[Appendix ZZ](#) lists the variations to IEC 60071-12:2022 for the application of this document in Australia and New Zealand.

This Standard provides for the use of the following Australian Standards as equivalent to the IEC Standards referenced herein:

IEC Standards	AS Standards
IEC 60071-11, <i>Insulation co-ordination – Part 11: Definitions, principles and rules for HVDC system</i>	AS 60071.11:2024, <i>Insulation co-ordination, Part 11: Definitions, principles and rules for HVDC system (IEC 60071-11:2022 (ED. 1.0) MOD)</i>
IEC 60099-4:1991, <i>Surge arresters – Part 4: Metal-oxide surge arresters without gaps for a.c. systems</i>	AS 60099.4:2022, <i>Surge arresters, Part 4: Metal-oxide surge arresters without gaps for a.c. systems (IEC 60099-4:2014 (ED. 3.0) MOD)</i>

As this document has been reproduced from an International Standard the following applies:

- (a) In the source text “this part of 60071” should read “this document”.
- (b) A full point substitutes for a comma when referring to a decimal marker.

Australian or Australian/New Zealand Standards that are identical adoptions of international normative references may be used interchangeably. Refer to the online catalogue for information on specific Standards.

The terms “normative” and “informative” are used in Standards to define the application of the appendices or annexes to which they apply. A “normative” appendix or annex is an integral part of a Standard, whereas an “informative” appendix or annex is only for information and guidance.

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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.
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IEC 60071-12 has been prepared by IEC technical committee 99: Insulation co-ordination and system engineering of high voltage electrical power installations above 1,0 kV AC and 1,5 kV DC. It is an International Standard.

On the basis of technical experience gained and the development of [HVDC](#), sufficient consensus has emerged to establish a series insulation co-ordination standard for [HVDC](#) system. The standard series for [HVDC](#) system belongs to IEC 60071 standard series, and a list of all parts in the IEC 60071 series, published under the general title *Insulation co-ordination*, can be found on the IEC website.

This International Standard replaces, in conjunction with IEC 60071-11¹⁾, IEC 60071-5 published in 2014. IEC 60071-5 provides basic principles and guidance for insulation coordination of high-voltage direct current (HVDC) converter stations. IEC 60071-11 specifies the principles on the procedures for the determination of the specified withstand voltages, creepage distance and air clearances for the equipment and the installations of these systems. IEC 60071-12 provides guidelines on the procedures for insulation co-ordination of line commutated converter (LCC) stations for high-voltage direct current (HVDC) project, whose aim is to give guidance for the determination of the specified withstand voltages for equipment.

IEC 60071-12 retains the technical content of IEC 60071-5 of the guidelines on the procedures for insulation coordination of LCC converter stations, and there are no essentially technical amendments. An example for LCC HVDC converter station in a pole with two 12-pulse converters in series is provided in annex. Examples of insulation co-ordination for controlled series capacitor converter (CSCC) and capacitor commutated converters (CCC) in IEC 60071-5 are no longer dealt with in this document.

The text of this International Standard is based on the following documents:

Draft	Report on voting
99/368/FDIS	99/379/RVD

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 International Standard 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.

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.

1) Under preparation. Stage at the time of publication: IEC/CFDIS 60071-11:2022.

Australian Standard®

Insulation co-ordination

Part 12: Application guidelines for LCC HVDC converter stations (IEC 60071-12:2022 (ED. 1.0) MOD)

1 Scope

This part of IEC 60071 applies guidelines on the procedures for insulation co-ordination of line commutated converter ([LCC](#)) stations for high-voltage direct current ([HVDC](#)) project, whose aim is evaluating the overvoltage stresses on the converter station equipment subjected to combined DC, AC power frequency, harmonic and impulse voltages, and determining the specified withstand voltages for equipment.

This document deals only with metal-oxide surge arresters, without gaps, which are used in modern [HVDC](#) converter stations. The criteria for determining the protective levels of series and/or parallel combinations of surge arresters used to ensure optimal protection are also presented. Typical arrester protection schemes and stresses of arresters are presented.

[Annex A](#) contains examples of insulation co-ordination for [LCC HVDC](#) converters which support the concepts described in the main text, and the basic analytical techniques used.

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 60071-11, ²⁾*Insulation co-ordination – Part 11: Definitions, principles and rules for [HVDC](#) system*

IEC 60099-4, *Surge arresters – Part 4: Metal-oxide surge arresters without gaps for a.c. systems*

IEC 60633, *High-voltage direct current ([HVDC](#)) transmission – Vocabulary*

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definition

For the purposes of this document, the terms and definitions given in IEC 60071-11 and the following apply.

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

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

3.1.1

crest value of continuous operating voltage

CCOV

highest continuously occurring crest value of the voltage at the equipment on the DC side of the converter station excluding commutation overshoots

2) Under preparation. Stage at the time of publication: IEC/CFDIS 60071-11:2022.

3.1.2**peak value of continuous operating voltage****PCOV**

highest continuously occurring crest value of the voltage at the equipment on the DC side of the converter station including commutation overshoots and commutation notches

3.1.3**valve protective firing**

means of protecting the thyristors from excessive forward voltage, rate of change of voltage or forward voltage applied during the reverse recovery time, by firing the thyristors into conduction

3.2 Symbols and abbreviated terms**3.2.1 General**

The list covers only the most frequently used symbols and abbreviated terms, some of which are illustrated graphically in the single-line diagram of [Figure 1](#) and [Figure 2](#). For a more complete list of symbols which has been adopted for **LCC HVDC** converter stations, and also for insulation co-ordination, refer to the standards listed in the normative references ([Clause 2](#)) and to the [Bibliography](#).

3.2.2 Subscripts

0(zero)	at no load (IEC 60633)
d	direct current or voltage (IEC 60633)
i	ideal (IEC 60633)
max	maximum (IEC 60633)
n	pertaining to harmonic component of order n (IEC 60633)

3.2.3 Letter symbols

K_a	altitude correction factor (IEC 60071-1)
K_c	co-ordination factor (IEC 60071-1)
K_s	safety factor (IEC 60071-1)
U_c	continuous operating voltage of an arrester
U_{ccov}	crest value of continuous operating voltage
U_{ch}	continuous operating voltage of an arrester including harmonics
U_{di0}	ideal no-load direct voltage (IEC 60633)
U_{di0max}	maximum value of U_{di0} taking into account AC voltage measuring tolerances, and transformer tap-changer offset by one step
U_s	highest voltage of an AC system (IEC 60071-1 and IEC 60071-2)
U_m	highest voltage for the equipment
U_{v0}	no-load phase-to-phase voltage on the valve side of converter transformer, r.m.s. value excluding harmonics

U_{rp}	representative overvoltage
U_{cw}	co-ordination withstand voltage
U_{rw}	required withstand voltage
U_w	specified withstand voltage (standard withstand voltage in alternating current)
α	delay angle (IEC 60633); “firing angle” also used in this standard
β	advance angle (IEC 60633)
γ	extinction angle (IEC 60633)
μ	overlap angle (IEC 60633)

3.2.4 Abbreviated terms

LCC	line commutated converter
VSC	voltage sourced converter
HVDC	high voltage direct current
HV	high voltage
LV	low voltage
CCOV	crest value of continuous operating voltage
GIS	gas-insulated switchgear
PCOV	peak continuous operating voltage
ECOV	equivalent continuous operating voltage
RSFO	representative slow-front overvoltage (the maximum voltage stress value)
RFFO	representative fast-front overvoltage (the maximum voltage stress value)
RSTO	representative steep-front overvoltage (the maximum voltage stress value)
RSIWV	required switching impulse withstand voltage
RLIWV	required lightning impulse withstand voltage
RSTIWV	required steep-front impulse withstand voltage
SIPL	switching impulse protective level
LIPL	lightning impulse protective level
STIPL	steep-front impulse protective level
SIWV	switching impulse withstand voltage
LIWV	lightning impulse withstand voltage
STIWV	steep-front impulse withstand voltage
p.u.	per unit

4 Typical LCC HVDC converter station schemes

[Figure 1](#) shows the single line diagram of typical LCC HVDC converter stations equipped with two 12-pulse converters in series. It can be noted that [Figure 1](#) shows possible arrester locations covered in this document. Some of these arresters can be redundant and could be excluded depending on the specific design.

[Figure 2](#) shows an example for a single line diagram and arrester arrangement of a back-to back converter station. Other arrangements with different earthing connections are also common, e.g., earthing at the mid-point between the two six-pulse bridges. The location of the smoothing reactor, if applicable, can change accordingly.

The AC and DC filter configurations could be more complex than those shown in these figures.

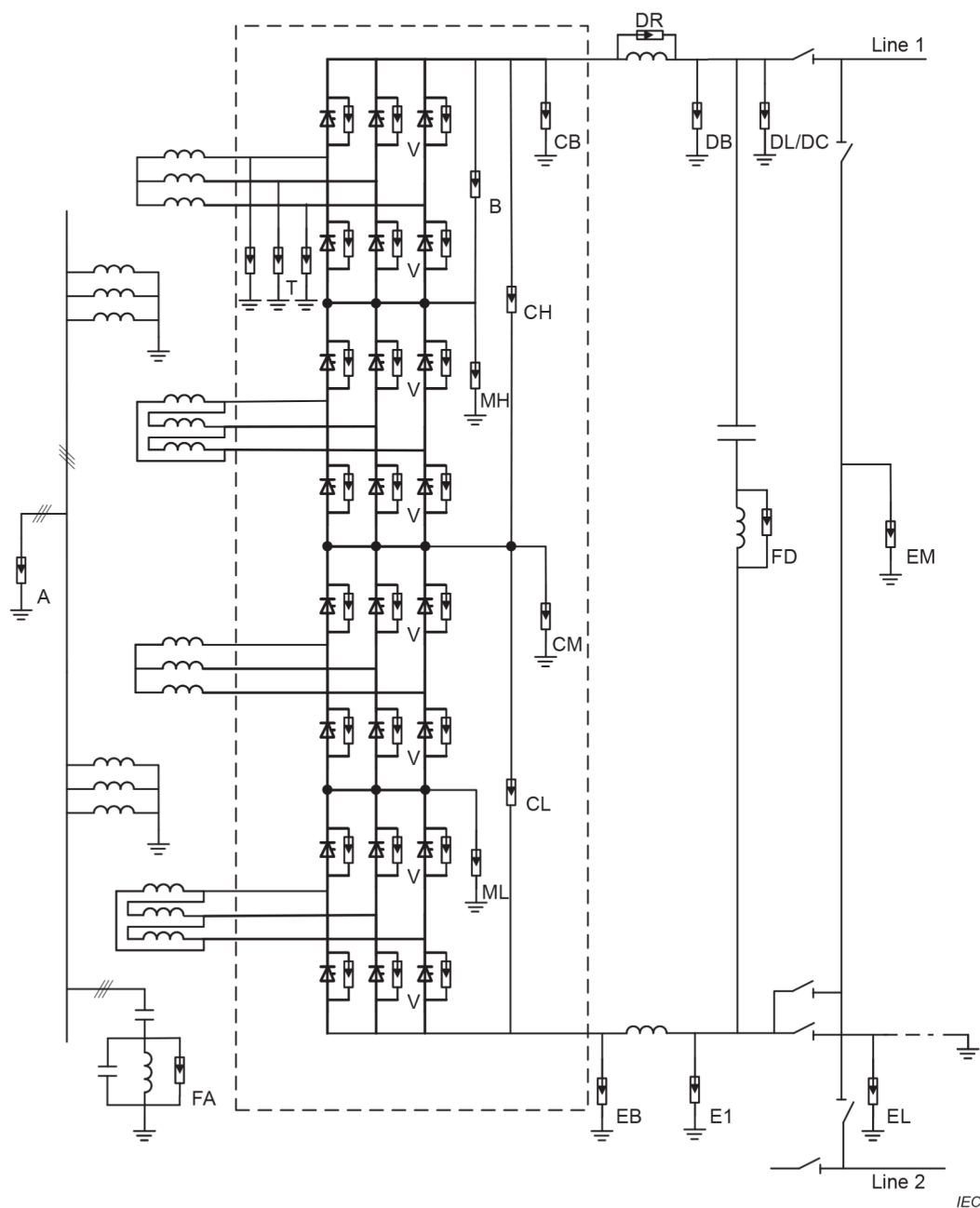
[Table 1](#) presents the graphical symbols used in this document.

The thyristor valves being voltage sensitive require strict overvoltage protection, which is provided by valve arresters that are connected directly across the valve terminals.

The valve arresters in combination with other arresters typically provide protection to transformer valve windings and in general separate phase-phase and phase-earth arresters are not provided. Transformer valve winding phase-to-earth arresters can be considered at 800 kV and above to lower the insulation levels especially to the top valve group.

Each voltage level and component are protected by either a single arrester or a combination of series or parallel connected arresters.

Arrester designations and details on their design and specific roles are presented in [Clause 6](#).

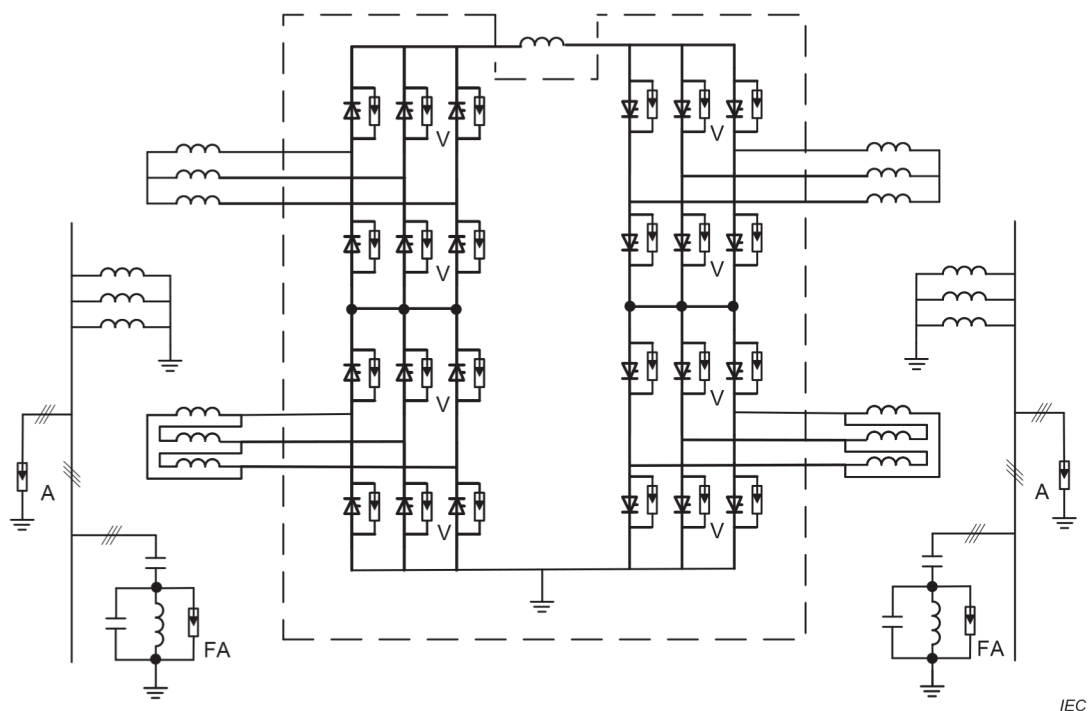


Key

A: AC bus arrester
FD: DC filter arrester

E1:	DC neutral bus arrester
EB:	converter neutral arrester
V:	valve arrester
T:	transformer valve winding arrester
DR:	smoothing reactor arrester
DL:	DC line arrester
CL:	LV converter unit arrester
CH:	HV converter unit arrester
FA:	AC filter arrester
EL:	electrode line arrester
EM:	metallic return arrester
B:	bridge arrester (6-pulse)
CB:	converter unit DC bus arrester
DB:	DC bus arrester
DC:	DC cable arrester
CM:	arrester between converters unit
MH:	mid-point bridge arrester (HV bridge)
ML:	mid-point bridge arrester (LV bridge)

Figure 1 — Possible arrester locations in a pole with two 12-pulse converters in series

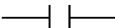


Key

A:	AC bus arrester
V:	valve arrester
FA:	AC filter arrester

Figure 2 — Possible arrester locations for a back-to-back converter station

Table 1 — Symbol description

Symbol	Description
	Single valve (thyristor) IEC 60617-S00057:2001-07
	Arrester IEC 60617-S00373:2001-07
	Reactor IEC 60617-S00849:2001-07
	Capacitor IEC 60617-S00567:2001-07
	Earth IEC 60617-S00200:2001-07

5 Voltages and overvoltages in service

5.1 Continuous operating voltages at various locations in the converter station

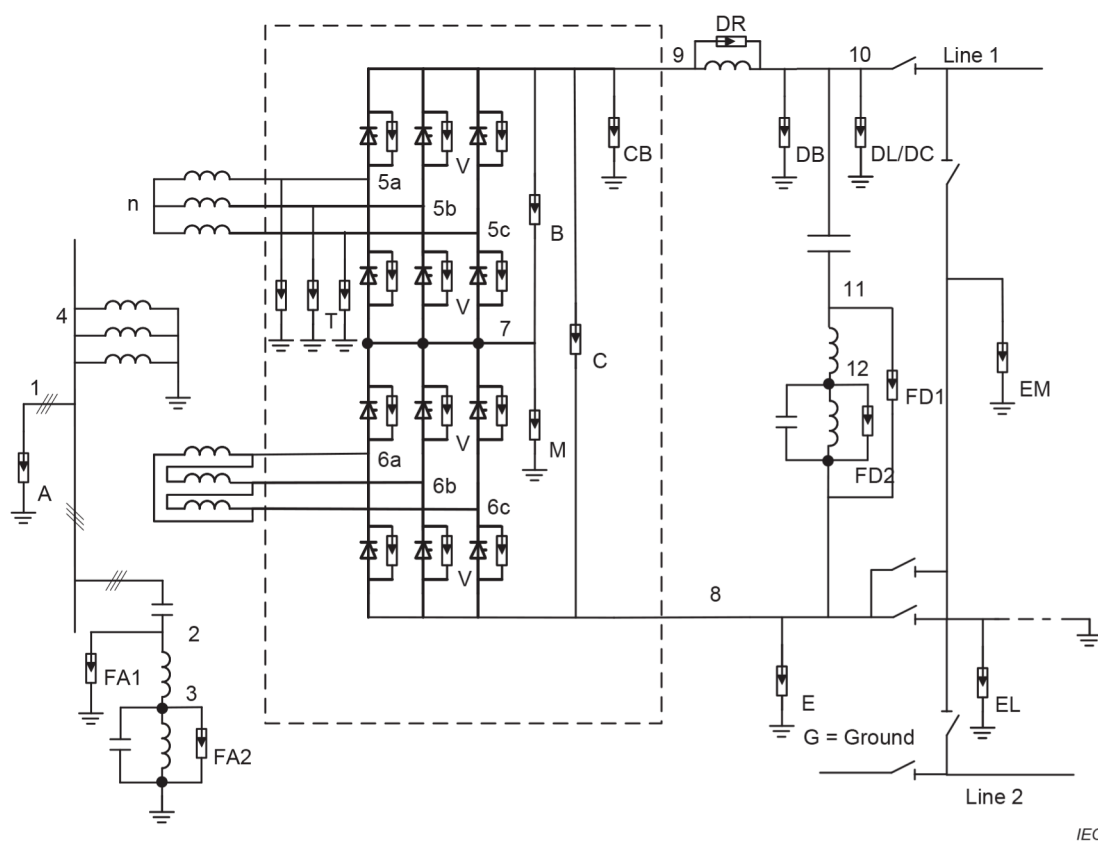
The continuous operating voltages at various locations in an [LCC HVDC](#) converter station differ from the AC system in that they consist of not simply the fundamental frequency voltages. They could be a combination of direct voltage, fundamental frequency voltage, harmonic voltages, and high frequency transients, depending upon the location.

[Table 3](#) shows an [LCC HVDC](#) converter station in a pole with one 12-pulse converter configuration. In general phase-earth arresters on the valve side of the converter transformer (T) are not provided for [LCC HVDC](#) schemes up to 600 kV.

[Figure 1](#) shows an [LCC HVDC](#) scheme with two 12-pulse converters in series per pole configuration, which has been used for the early 600 kV scheme and some 800 kV schemes.

[Figure 4](#) shows typical waveforms of continuous operating voltages excluding commutation overshoots at various locations in the [LCC HVDC](#) converter station either to earth (G) or to another point for the typical configuration of [Figure 3](#). The numbers and alphabetical designations, in [Figure 3](#), identify node numbers and arrester designations respectively. These waveforms have been produced with a simulation tool considering typical DC parameters.

Note that [Figure 1](#), [Figure 2](#) and [Figure 3](#) show possible arrester locations, and some of them can be eliminated because of specific designs.

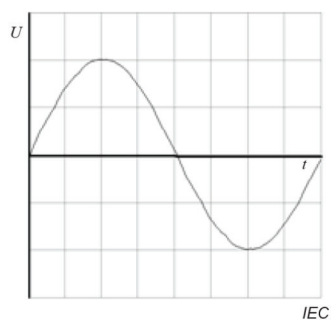


Key

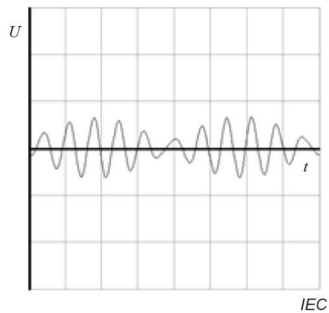
A:	AC bus arrester
M:	mid-point bridge arrester
E:	DC neutral bus arrester
V:	valve arrester
T:	transformer valve winding arrester
DR:	smoothing reactor arrester
DL:	DC line arrester
FA1, FA2:	AC filter arresters
CB:	converter unit DC bus arrester
EM:	metallic return arrester
EL:	electrode line arrester
B:	bridge arrester (6-pulse)
C:	converter unit arrester
DB:	DC bus arrester
DC:	DC cable arrester
FD1, FD2:	DC filter arresters

Figure 3 — LCC HVDC converter station in a pole with one 12-pulse converter

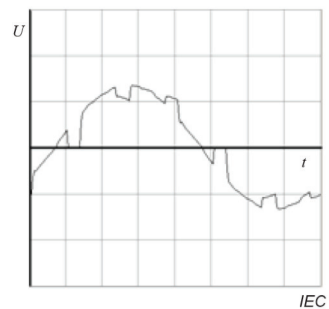
Loc. (1-G), (4-G)



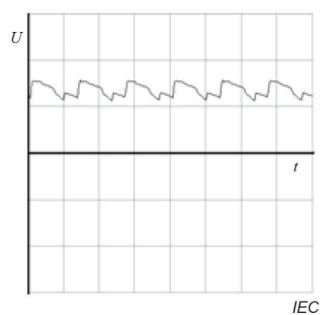
Loc. (2-G)



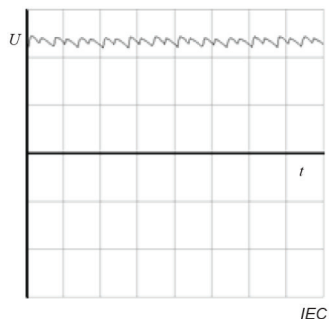
Loc. (5), (6) (ph-ph)



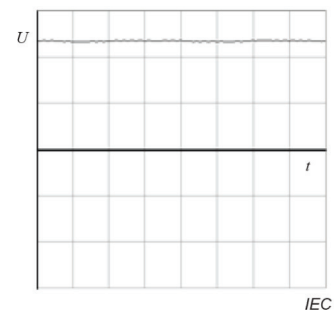
Loc. (7-8), (9-7)



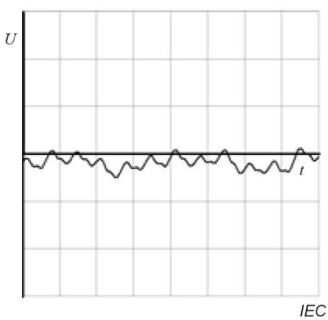
Loc. (9-8)



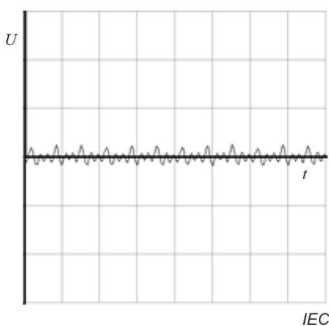
Loc. (10-G)



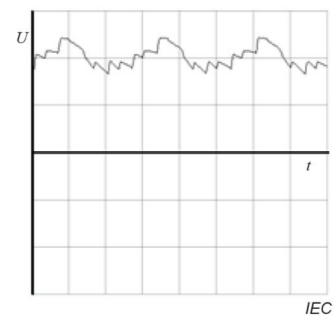
Loc. (8-G)



Loc. (11-G), (10-9)



Loc. (n-G)



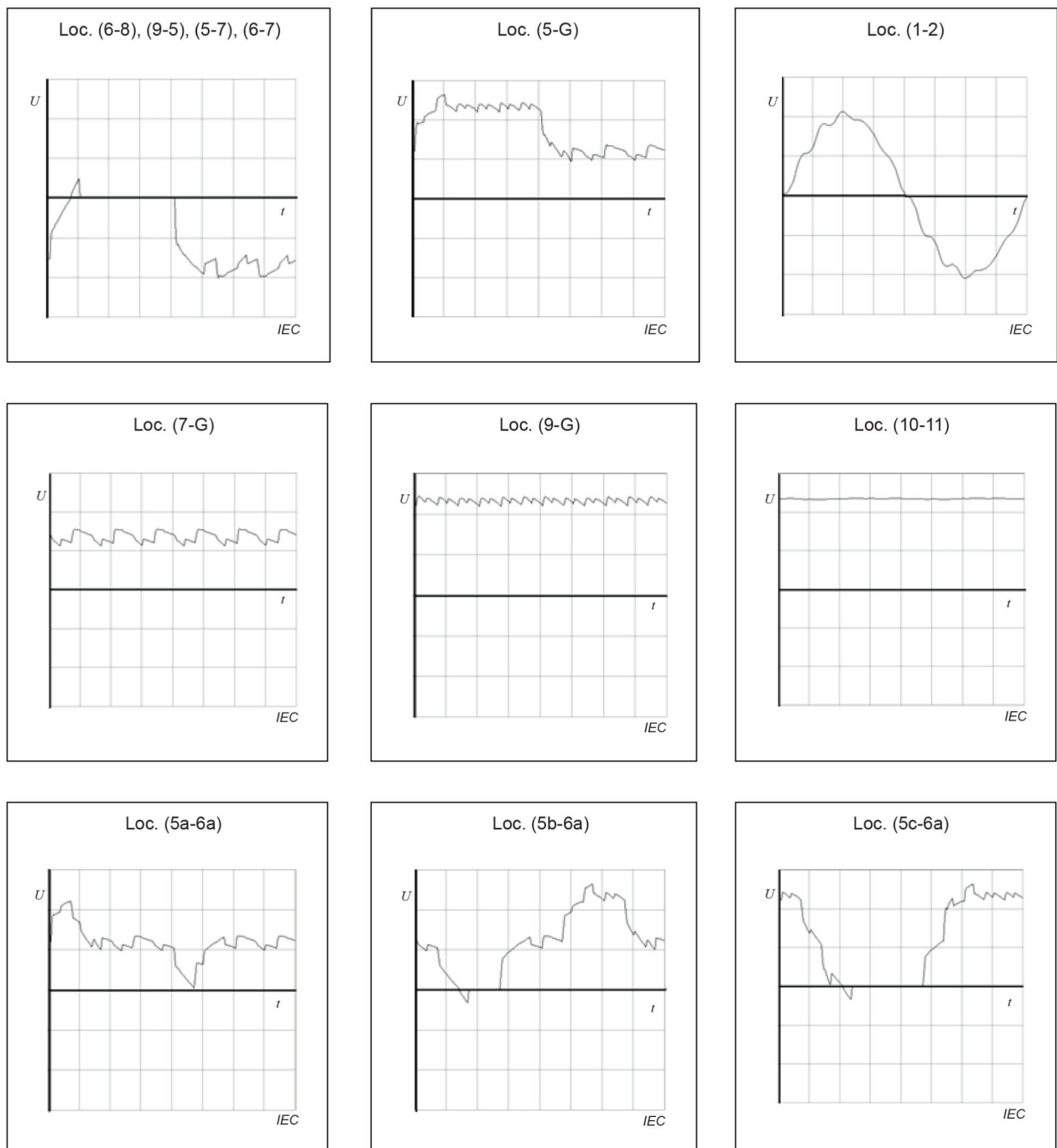


Figure 4 — Continuous operating voltages at various locations (location identification according to Figure 3)

The harmonics generated on the AC side are assumed to be filtered by the connected filters and thus the voltage at Loc. (1-G) and (4-G) is considered sine wave of fundamental frequency without any harmonics.

Voltage shape at Loc. (1-2) is also predominantly a fundamental frequency sine wave but superimposed by harmonics. The content of harmonics strongly depends on the filter configuration, tuning frequencies as well as operating condition of the converters. Typically, the content is less than 30 % of the fundamental frequency.

The voltages across the 6-pulse bridges (Loc. (7-8) and (9-7)) are the DC voltages across the bridges consisting of about 60° arcs of line-line AC voltages (60°- μ , duration) and the average of line-line voltages (duration, μ).

The voltage at the 6-pulse bridge to earth (Loc. (7-G)) can be identical to Loc. (7-8) if the station is earthed via the station earth as well as during symmetrical operation of a bipole. However, in case of unsymmetrical bipolar operation or monopolar operation an additional DC offset will be superimposed.

The voltage across the 12-pulse converter (Loc. (9-8)) comprises of 30° arcs of line-line AC voltages with superimposed influence of firing delay and overlap angles.

The voltage across the 12-pulse converter to earth (Loc. (9-G)) can be identical to Loc. (9-8) or include an additional dc offset due to the same reasons as described for Loc. (7-G) (see above).

Voltage shapes of Loc. (5b-6a) and (5c-6a) show the voltage between two different phases of the two six-pulse groups. This wave shape is relevant only in case of three-phase 3-winding transformers.

The voltage at Loc. (10-G) is the smoothed out voltage due to the influence of the smoothing reactor and DC filter, if applicable.

The voltages at Loc. (6-8) and (9-5) are the voltages across a valve in rectifier mode indicating the valve conduction period and commutation in its own row and the other row of thyristors in a 6-pulse bridge.

The voltage across the transformer valve winding phase-phase is shown in Loc. (5), (6) (ph-ph). The zero voltage shows the commutation process involving the valves connected to the corresponding two phases, while the notches indicate the commutation involving valves that are connected to one of the phases.

Neutral bus voltage (Loc. (8-G)) and voltages across the filters are indicative of typical voltages and they depend on electrode circuit and filter parameters. Loc. (8-G) can also include a DC offset especially during monopolar metallic return operation.

The voltage at location (n-G) has a DC component equal to 3/4 of pole voltage (Loc. (10-G)) plus the ripple of the lower 6-pulse bridge and half of the ripple of the upper 6-pulse bridge.

5.2 Peak continuous operating voltage (**PCOV**) and crest continuous operating voltage (**CCOV**)

The switching action of the valves produces high frequency turn-on and turn-off commutation transient voltages which are superimposed on the commutation voltage. The overshoot at turn off increases the transformer valve-side winding voltage and in particular the off-state (reverse-blocking) voltage across the valves and associated valve arresters. The amplitude of the overshoot is determined by:

- a) the inherent characteristics of the thyristors (particularly the recovery charge);
- b) the distribution of the recovery charge in a series-connected string of thyristors in a valve;
- c) the damping resistors and capacitors at individual thyristor levels;
- d) the various capacitances and inductances within the valve and commutation circuit;
- e) the firing and overlap angles;
- f) the valve commutation voltage at the instant of turn-off.

The continuous operating voltage waveform across the (Loc. (6-8) and (9-5)) and valve arrester (V), during rectifier operation, is shown in [Figure 5](#).

The **CCOV** (defined in [Clause 3](#)) is proportional to the U_{di0max} , and is given by:

$$U_{\text{ccov}} = \frac{\pi}{3} \cdot U_{\text{di0max}} = \sqrt{2} \cdot U_{\text{v0}}$$

Refer to 3.2.3 for the definition of U_{di0max} and U_{v0} .

Operation with large delay angles α increases the commutation overshoots, and special care shall be taken that these do not overstress the arresters.

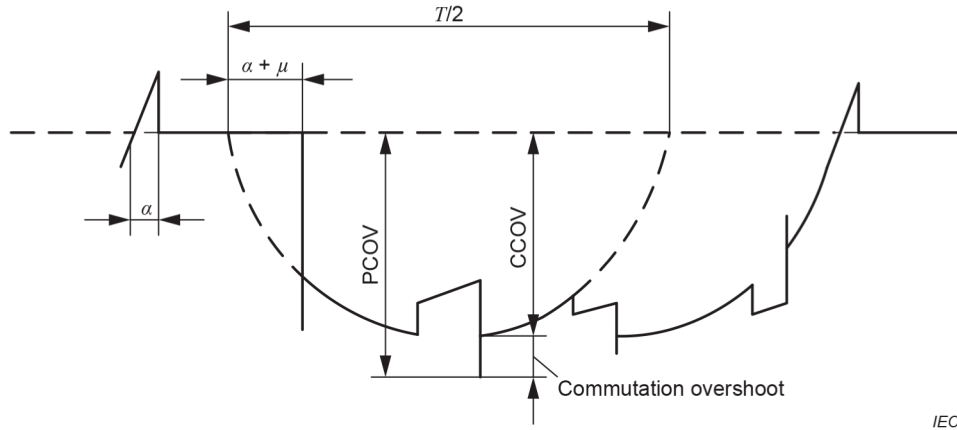


Figure 5 — Operating voltage of a valve arrester (V), rectifier operation and definition of PCOV and CCOV

The continuous operating voltage waveforms across the mid-point arrester (M) (Loc. (7-G)) and across the converter bus arrester (CB) (Loc. (9-G)) are shown in Figure 6 and Figure 7, respectively.

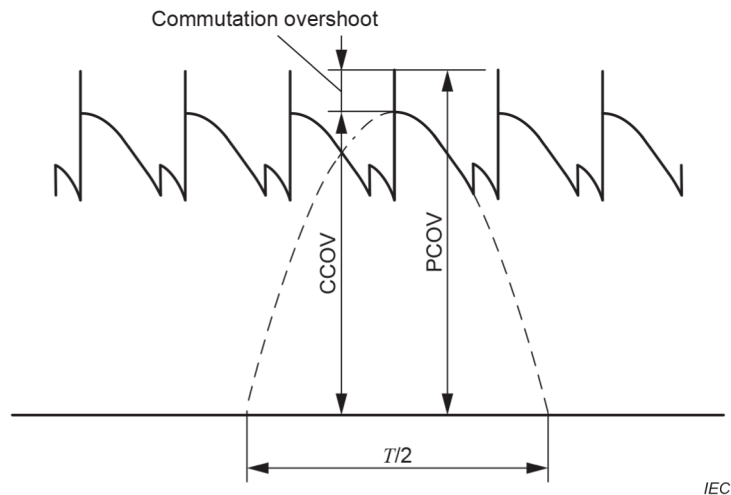


Figure 6 — Operating voltage of a mid-point arrester (M), rectifier operation

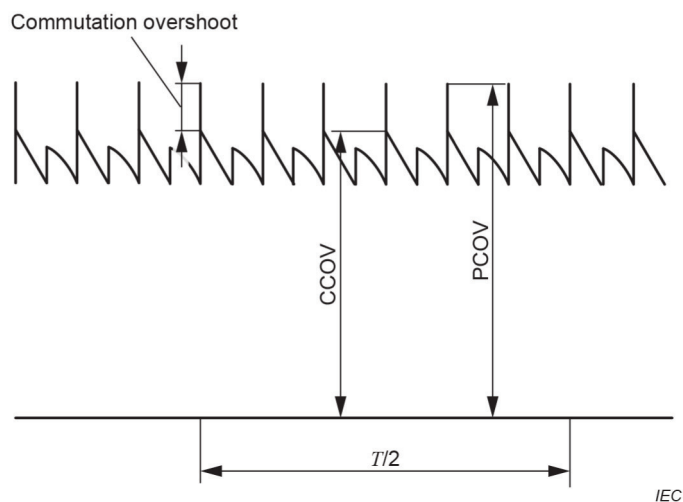


Figure 7 — Operating voltage of a converter bus arrester (CB), rectifier operation

5.3 Sources and types of overvoltages

Overvoltages on the AC side can originate from switching, faults, load rejection or lightning. The dynamic characteristics of the AC network, its impedance and also its effective damping at dominant transient oscillation frequencies, and the proper modelling of the converter transformers, static and synchronous compensators and the filter components, are important in evaluating the overvoltages. If the lengths of busbars in the AC switchyard are significant, they shall be taken into account in the evaluation of lightning and fast-front overvoltages (e.g., distance effects) and in the location of arresters.

Overvoltages on the DC side can originate from either the AC system or the DC line and/or cable, or from in-station flashovers, or other fault events.

In assessing the overvoltages, the configuration of the AC and DC systems shall be taken into account as well as the dynamic performance of the valves and controls, and credible worst case combinations, as discussed in [Clauses 6](#) and [8](#).

Impacts on arrester requirements are discussed in [Clause 6](#).

While the origin of overvoltages can result from different phenomena (switching, fault and lightning) and described above, the overvoltages are categorized according to their shape and duration as:

- temporary overvoltages (power frequency overvoltage of relatively long duration),
- transient overvoltages (short-duration overvoltage of few milliseconds or less, oscillatory or non-oscillatory, usually highly damped).

Transient overvoltages can be further classified as:

- slow front overvoltages,
- fast-front overvoltages,
- very-fast-front overvoltages,
- steep-front overvoltages.

5.4 Temporary overvoltage

5.4.1 General

A temporary overvoltage is defined as an oscillatory overvoltage of relatively long duration which is undamped or only weakly damped. The temporary overvoltages can originate either from the AC side or the DC side.

5.4.2 Temporary overvoltage on the AC side

These overvoltages are usually generated due to switching operations or faults. The highest temporary overvoltages usually occur in conjunction with sudden loss of load caused by faults either on the AC system or the DC system with AC reactive sources still connected. If the connected reactive elements and the AC system result in resonance conditions the temporary overvoltages can be more severe both from the overvoltage magnitude and arrester energy duty point of view.

Together with the highest AC operating voltages (U_s), the temporary overvoltage will be decisive for setting the rated voltage of AC bus arresters (A).

Temporary overvoltages together with high firing or extinction angles should also be considered for valve arresters (V).

Temporary overvoltages due to AC side faults resulting in asymmetrical and distorted AC voltages result in second harmonic voltages on the DC side which in turn cause third harmonic voltages on the AC side stressing the AC filter arrester (FA). When the converters are blocked with firing pulses given to by-pass pairs, the arresters across the non-conducting valves can be exposed to phase-phase voltages.

5.4.3 Temporary overvoltages on the DC side

An uncontrolled energization of the rectifier with the far end being blocked could result in high overvoltages, especially for a cable transmission system.

Another case that can result in overvoltages is the blocking of an inverter at high current without firing of a by-pass pair. This will result in an application of fundamental frequency voltage at the inverter, and if the DC circuit is resonant close to the fundamental frequency, could result in high overvoltages stressing the DC bus arrester (CB).

5.5 Slow-front overvoltages

5.5.1 General

Slow-front and temporary overvoltages occurring on the AC side are important to the study of arrester applications. Together with the highest AC operating voltages (U_s) they determine the overvoltage protection and insulation levels of the AC side of the [LCC HVDC](#) converter station. They also influence valve insulation co-ordination.

5.5.2 Slow-front overvoltages on the AC side

5.5.2.1 General

Slow-front overvoltages on the AC bus of an [LCC HVDC](#) converter station, can be caused by switching on transformers, reactors, static var compensators, AC filters and capacitor banks connected to the converter AC bus, and by fault initiation and fault clearing as well as by closing and reclosing of lines. Slow-front overvoltages occur with high amplitude only for the first half cycle of the transient with significantly reducing amplitudes for subsequent cycles. Slow-front overvoltages which originate at locations in the AC network remote from the [LCC HVDC](#) converter station usually have magnitudes which are relatively low in comparison with those caused by events occurring close to the converter AC bus.

During the operating life of the equipment, switching of equipment connected to the converter AC bus can occur many times. The overvoltages caused by these routine switching operations are generally less severe than the slow-front overvoltages caused by faults. However, the switching-off of a circuit breaker can, in rare cases, produce a restrike phenomenon and this gives rise to overvoltage.

The selection of AC arresters for [LCC HVDC](#) converter stations should consider the presence of existing arresters connected in parallel in the AC network in order to prevent the existing arresters from being overloaded during slow-front and temporary overvoltages.

5.5.2.2 Overvoltages due to switching operations

Because of the frequency of these operations, it is generally desirable that the surge arresters used to protect equipment do not absorb appreciable energy during these events. Hence, in some cases, the slow-front overvoltages arising from such routine operations are minimized by the use of circuit breakers incorporating closing and/or opening resistors, or by synchronizing the closing and/or opening of the circuit breaker poles, or equipping the breaker with arresters across the poles. The [LCC HVDC](#) control system can also be used to effectively damp certain overvoltages such as temporary overvoltages.

Energization of transformers causes inrush current, due to saturation effects, containing harmonics dominated by second order harmonics and other low order harmonics. If one or more of these harmonic currents meet resonant condition, in a network with low damping, high harmonic voltages are produced in the network leading to overvoltage. In an [LCC HVDC](#) converter station, resonant conditions are often more severe because of the presence of AC filters and capacitor banks. These capacitances lower the resonance frequency and second or third harmonic resonances can be present.

The temporary overvoltages can last for several seconds, or in rare cases up to a minute.

5.5.2.3 Overvoltages due to faults

When an asymmetric fault occurs in the AC network, transient and temporary overvoltages occur on the healthy phases, influenced by the zero sequence network. In solidly earthed systems that are typical for networks connected to [LCC HVDC](#) converter stations, the transient overvoltages (phase-to-earth) normally range from 1,4 p.u. to 1,7 p.u. and the temporary overvoltage from 1,2 p.u. to 1,4 p.u.

Symmetric as well as asymmetric faults could result in transformer saturation. The influence of transformer saturation on overvoltages depends on the instant of fault inception as well as fault clearance. It is therefore necessary to vary the fault conditions when this phenomenon is studied. This fault case is discussed further in [Clause 6](#).

The highest temporary overvoltages most likely occur in conjunction with sudden three-phase faults and complete load rejection if the converters block at the same time as a consequence of the fault without simultaneous disconnection of the filters. The filters and capacitor banks together with the AC system can result in low resonance frequencies. The temporary overvoltages due to faults can be more severe both from the overvoltage point of view and with regard to possible arrester energy stresses. The presence of filters tuned or damped at frequencies between the second and the fifth harmonic can often be effective in reducing the distortion of the voltage and thereby the stresses on the arresters. AC active filters can also be used for this purpose.

5.5.3 Slow-front overvoltages on the DC side

Except for the AC side overvoltages transmitted through the converter transformers, the DC side insulation co-ordination for slow-front overvoltages and temporary overvoltages is mainly determined by fault generated slow-front overvoltages on the DC side.

Events to be considered include DC line-to-earth faults, DC side switching operations, events resulting in an open earth electrode line, generation of superimposed AC voltages due to faults in the converter control (e.g., complete loss of control pulses) misfiring, commutation failures, earth faults and short-circuits within the converter unit. These contingencies are discussed in more detail in [Clause 6](#).