भारतीय मानक **IS/IEC 60071-11 : 2022**

Indian Standard

इन्सुलेशन समन्वय

भाग 11 एचवीडीसी प्रणाली के लिए परिभाषाएँ, सिद्धांत और नियम

Insulation Co-ordination

Part 11 Definitions, Principles and Rules for HVDC System

ICS 29.080.30

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December 2024 **Price Group 12**

HVDC Power Systems Sectional Committee, ETD 40

NATIONAL FOREWORD

This Indian Standard which is identical to IEC 60071-11 : 2022 ‘Insulation co-ordination — Part 11: Definitions, principles and rules for HVDC system’ Issued by the International Electrotechnical Commission (IEC) was adopted by the Bureau of Indian Standards on the recommendation of the HVDC Power Systems Sectional Committee and approval of the Electrotechnical Division Council. This standard supersedes IS/IEC 60071-5 : 2014 Insulation co-ordination: Part 5 Procedures for high-voltage direct current (HVDC) converter stations.

This standard is published in various parts. Other parts in this series are:

Part 1	Definition principles and rules
Part 2	Application guide
Part 4	Computational guide to insulation co-ordination and modeling of electrical networks

The text of the IEC Standard has been approved as suitable for publication as an Indian Standard without deviations. Certain conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words ‘International Standard’ appears referring to this standard, they should be read as ‘Indian Standard’; and

b) Comma (,) has been used as a decimal marker, while in Indian Standards the current practice is to use a point (.) as the decimal marker.

In this adopted standard, reference appears to International Standards for which Indian Standards also exist. The corresponding Indian Standards, which are to be substituted, are listed below along with their degree of equivalence for the editions indicated:

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
IEC 60060-1 High-voltage test techniques — Part 1: General definitions and test requirements	IS 2071 (Part 1) : 2016/IEC 60060-1 : 2010 High-voltage test techniques: Part 1 General definitions and test requirements (*third revision*)	Identical
IEC 60071-1 : 2019 Insulation co-ordination — Part 1: Definitions, principles and rules	IS/IEC 60071-1 : 2019 Insulation co-ordination: Part 1 Definition, principles and rules (*first revision*)	Identical
IEC 60071-2 : 2018 Insulation co-ordination — Part 2: Application guidelines	IS/IEC 60071-2 : 2018 Insulation Coordination Part 2: Application guide (*first revision*)	Identical
IEC 60099-4 : 2014 Surge arresters — Part 4: Metal-oxide surge arresters without gaps for a.c. systems	IS 15086 (Part 4) : 2017/IEC 60099-4 : 2014 Surge arresters: Part 4 Metal-oxide surge arresters without gaps for a.c. systems	Identical

(*Continued on third cover*)

CONTENTS

INTRODUCTION

As the demand for electrical energy is growing, more and more HVDC projects have appeared, and the voltage up to ±1 100 kV so far. However, the nominal voltage, nominal current and insulation levels for HVDC system are not yet as standardized as the AC system.

In October 2016, IEC Technical Committee 28 (Insulation co-ordination) established AHG 8 (Ad hoc group 8) to make the roadmap for HVDC system insulation co-ordination standards.

After IEC TC 28 was merged into IEC TC 99 in 2017, JWG 13 (Joint working group 13) was built by IEC TC 99 and TC 115 and was responsible for making the series standards for HVDC system according to the approved roadmap, as follows:

a) Part 11: Definitions, principles and rules for HVDC system;

b) Part 12: Application guidelines for LCC HVDC converter stations;

c) Part 13: Application guidelines for VSC HVDC converter stations;

d) Part 14: Insulation co-ordination for AC/DC filters;

e) Part 15: Insulation co-ordination for DC transmission lines.

Indian Standard

INSULATION CO-ORDINATION

PART 11 DEFINITIONS, PRINCIPLES AND RULES FOR HVDC SYSTEM

1 Scope

This part of IEC 60071 applies to high-voltage direct current (HVDC) systems. It 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.

This document gives the insulation co-ordination principles related to line commutated converter (LCC) and voltage sourced converters (VSC) HVDC systems. The main principles of this document also apply to other special converter configurations of LCC, such as the capacitor commutated converter (CCC) as well as the controlled series compensated converter (CSCC), etc.

This document applies to insulation co-ordination of equipment connected between the converter AC bus (including the AC harmonic filters, the converter transformer, the circuit breakers) and the DC line side. The line and cable terminations in so far as they influence the insulation co-ordination of converter station equipment are also covered.

This document applies only for HVDC applications in power systems and not for industrial conversion equipment. Principles and guidance given are for insulation co-ordination purposes only. The requirements for human safety are not covered by this document.

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 60060-1, *High-voltage test techniques – Part 1: General definitions and test requirements*

IEC 60071-1:2019, *Insulation co-ordination – Part 1: Definitions, principles and rules*

IEC 60071-2:2018, *Insulation co-ordination – Part 2: Application guidelines*

IEC 60099-4:2014, *Surge arresters – Part 4: Metal-oxide surge arresters without gaps for a.c. systems*

IEC TS 60815-1:2008, *Selection and dimensioning of high-voltage insulators intended for use in polluted conditions – Part 1: Definitions, information and general principles*

IEC TS 60815-2:2008, *Selection and dimensioning of high-voltage insulators intended for use in polluted conditions – Part 2: Ceramic and glass insulators for a.c. systems*

IEC TS 60815-3:2008, *Selection and dimensioning of high-voltage insulators intended for use in polluted conditions – Part 3: Polymer insulators for a.c. systems*

3 Terms and definitions

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

NOTE Many of the following definitions refer to insulation co-ordination concepts (IEC 60071-1), or to arrester parameters (IEC 60099-4).

3.1
insulation co-ordination
selection of the dielectric strength of equipment in relation to the operating voltages and overvoltages which can appear on the system for which the equipment is intended and taking into account the service environment and the characteristics of the available preventing and protective devices

[SOURCE: IEC 60071-1:2019, 3.1, modified – The note to entry has been removed.]

3.2
nominal DC voltage
mean value of the DC voltage required to transmit nominal power at nominal current

3.3
highest DC voltage
highest value of DC voltage for which the equipment and system is designed to operate continuously, in respect of its insulation as well as other characteristics

3.4
symmetrical monopole
HVDC converter with symmetrical DC voltage outputs on the two pole terminals

Note 1 to entry: A symmetrical monopole is generally applicable only to the VSC HVDC systems.

Note 2 to entry: “Symmetrical monopole” is used even though there are two polarities with DC voltages, because only one converter is unable to provide the redundancy which is generally provided by “bipole”.

Note 3 to entry: In the symmetrical monopole operation, persistent overvoltage appears at the sound (healthy) pole when a fault occurs at the opposite pole.

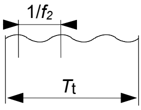
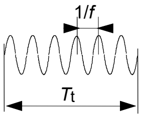
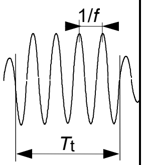
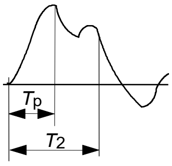
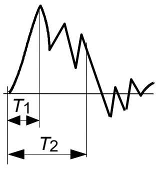
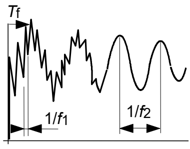
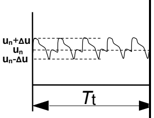
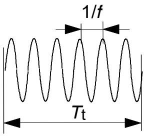
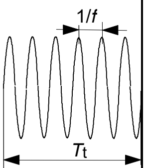
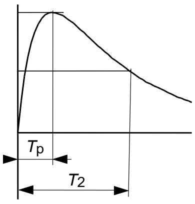
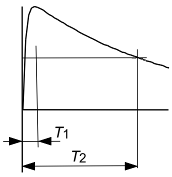
3.5
asymmetrical monopole
for the HVDC converter with asymmetrical DC voltage outputs on the two terminals, one terminal is generally earthed

3.6
bipole
in general, two asymmetrical monopoles form a bipolar DC circuit

3.7
overvoltage
voltage having a value exceeding the corresponding highest steady state voltage of the system

Note 1 to entry: Table 1 presents (as per IEC 60071-1) the classification of these voltages which are defined in 3.7.1 to 3.7.2.3.

Table 1 – Classes and shapes of overvoltages, standard voltage shapes and standard withstand voltage tests

Class	Low frequency			Transient		
	Continuous		Temporary	Slow-front	Fast-front	Very-fast-front
Voltage or over-voltage shapes						
Range of voltage or over-voltage shapes	$T_t \geq 3\ 600$s $1/T_t = f_1 =$ 0 Hz $f_2 < 2\ 500$ Hz	$f = 50$ Hz or 60 Hz $T_t \geq 3\ 600$s	10 Hz $< f <$ 500 Hz 0,02 s $\leq T_t \leq$ 3 600 s	20 µs $< T_p \leq$ 5 000 µs $T_2 \leq 20$ ms	0,1 µs $< T_1 \leq$ 20 µs $T_2 \leq 300$ µs	$T_f \leq 100$ ns 0,3 MHz $< f_1 <$ 100 MHz 30 kHz $< f_2 <$ 300 kHz
Standard voltage shapes	 $\frac{\Delta U}{U_n} \leq 3\%$ [b] T_t [a]	 $f = 50$ Hz or 60 Hz T_t [a]	 48 Hz $\leq f \leq$ 62 Hz $T_t = 60$ s	 $T_p = 250$ µs $T_2 = 2\ 500$ µs	 $T_1 = 1{,}2$ µs $T_2 = 50$ µs	[a]
Standard withstand voltage test	DC voltage test [a]	[a]	Short-duration power frequency test	Switching impulse test	Lightning impulse test	[a]

[a] To be specified by the relevant apparatus committees.

[b] Unless otherwise specified by the relevant Technical Committees, standard voltage shapes should be in accordance with IEC 60060-1.

3.7.1
temporary overvoltage

overvoltages of relatively long duration (ranging from 0,02 to 3 600 s as per IEC 60071-1)

Note 1 to entry: The overvoltage can be undamped or weakly damped.

3.7.2
transient overvoltage

short-duration overvoltage of a few millisecond or less, oscillatory or non-oscillatory, usually highly damped

[SOURCE: IEC 60071-1: 2019, 3.17.2, modified – The note to entry has been removed.]

3.7.2.1
slow-front overvoltage

transient overvoltage, usually unidirectional, with time to peak 20 µs $< T_p \leq 5\ 000$ µs, and tail duration $T_2 \leq 20$ ms

Note 1 to entry: For the purpose of insulation co-ordination, slow-front overvoltages are classified according to their shape, regardless of their origin. Although considerable deviations from the standard shapes occur on actual systems, in this standard it is considered sufficient in most cases to describe such overvoltages by their classification and peak value.

3.7.2.2
fast-front overvoltage

overvoltage at a given location on a system, due to a lightning discharge or other cause, the shape of which can be regarded, for insulation co-ordination purposes, as similar to that of the standard impulse (IEC 60060-1) used for lightning impulse tests

Note 1 to entry: Fast-front overvoltage is defined as transient overvoltage, usually unidirectional, with time to peak 0,1 µs < T_1 ≤ 20 µs, and tail duration T_2 ≤ 300 µs in IEC 60071-1:2019, 3.17.2.2.

Note 2 to entry: For the purpose of insulation co-ordination, fast-front overvoltages are classified according to their shape, regardless of their origin. Although considerable deviations from the standard shapes occur on actual systems, in this standard it is considered sufficient in most cases to describe such overvoltages by their classification and peak value.

3.7.2.3
very-fast-front overvoltage

transient overvoltage, usually unidirectional, with time to peak T_f < 0,1 µs, and with or without superimposed oscillations at frequency 30 kHz < f < 100 MHz

[SOURCE: IEC 60071-1:2019, 3.17.2.3, modified – The abbreviated term VFFO has been removed.]

3.7.2.4
steep-front overvoltage

transient overvoltage classified as a kind of fast-front overvoltage with time to peak 3 ns < T_1 < 1,2 µs

Note 1 to entry: A steep-front impulse voltage for test purposes is defined in IEC 60700-1.

Note 2 to entry: The front time is decided by means of system studies.

3.7.2.5
combined overvoltage

overvoltage consisting of two voltage components simultaneously applied between each of the two-phase terminals of a phase-to-phase (or longitudinal) insulation and earth

Note 1 to entry: Combined overvoltage can include temporary, slow-front, fast-front or very-fast front overvoltages.

Note 2 to entry: It is classified by the component of higher peak value.

3.8
representative overvoltage

U_rp

overvoltage assumed to produce the same dielectric effect on the insulation as overvoltage of a given class occurring in service due to various origins

Note 1 to entry: In this document, it is generally assumed that the representative overvoltages are characterized by their assumed or obtained maximum values.

[SOURCE: IEC 60071-1:2019, 3.19, modified – The notes to entry have been removed and replaced by a new Note 1.]

3.8.1
representative slow-front overvoltage

RSFO

voltage value between terminals of an equipment having the shape of a standard switching impulse

3.8.2

representative fast-front overvoltage

RFFO

voltage value between terminals of an equipment having the shape of a standard lightning impulse

3.8.3

representative steep-front overvoltage

RSTO

voltage value with a standard shape having a time to crest less than that of a standard lightning impulse, but not less than that of a very-fast-front overvoltage as defined by IEC 60071-1

Note 1 to entry: A steep-front impulse voltage for test purposes is defined in Figure 1 of IEC 60700-1:2015. The front time is decided by means of system studies.

3.9

co-ordination withstand voltage

U_{cw}

for each class of voltage, value of the withstand voltage of the insulation configuration, in actual service conditions, that meets the performance criterion

[SOURCE: IEC 60071-1:2019, 3.25]

3.10

required withstand voltage

U_{rw}

test voltage that the insulation must withstand in a standard withstand voltage test to ensure that the insulation will meet the performance criterion when subjected to a given class of overvoltages in actual service conditions and for the whole service duration

Note 1 to entry: The required withstand voltage has the shape of the co-ordination withstand voltage, and is specified with reference to all the conditions of the standard withstand voltage test selected to verify it

[SOURCE: IEC 60071-1:2019, 3.28]

3.11

specified withstand voltage

U_{w}

test voltage suitably selected equal to or above the required withstand voltage (U_{rw})

Note 1 to entry: For AC equipment, values of withstand voltages U_{w} are standardized as per IEC 60071-1. For HVDC equipment, the specified withstand voltages are rounded up to convenient practical values.

Note 2 to entry: The standard impulse shapes used for withstand tests on equipment as well as the test procedures are defined in IEC 60060-1 and IEC 60071-1. For some DC equipment (e.g. the thyristor valves), the standard impulse shapes may be modified in order to more realistically reflect expected conditions.

3.11.1

switching impulse withstand voltage

SIWV

withstand voltage of insulation with the shape of the standard switching impulse

3.11.2

lightning impulse withstand voltage

LIWV

withstand voltage of insulation with the shape of the standard lightning impulse

3.11.3
steep-front impulse withstand voltage

STIWV

withstand voltage of insulation with the shape parameters in 3.7.2.4

3.12
continuous operating voltage of an arrester

U_c

permissible r.m.s. value of power frequency voltage that may be applied continuously between the terminals of the arrester

[SOURCE: IEC 60099-4:2014, 3.10, modified – The words “designated” at the beginning of the definition and “in accordance with 8.7” at the end have been removed.]

3.13
equivalent continuous operating voltage of an arrester

ECOV

r.m.s. value of the sinusoidal power frequency voltage at a metal-oxide surge arrester stressed by operating voltage of any wave-shape that generates the same power losses in the metal oxide materials as the actual operating voltage

3.14
residual voltage of an arrester

U_{res}

peak value of voltage that appears between the terminals of an arrester during the passage of a discharge current

[SOURCE: IEC 60099-4:2014, 3.58, modified – The note to entry has been removed.]

3.15
co-ordination currents of an arrester

for a given system under study and for each class of overvoltage, the current through the arrester for which the representative overvoltage is determined

Note 1 to entry: Standard shapes of co-ordination currents for steep-front, lightning and switching current impulses are given in IEC 60099-4.

Note 2 to entry: The co-ordination currents are determined by system studies.

3.16
protective levels of an arrester

for each voltage class, residual voltage that appears between the terminals of an arrester during the passage of a discharge current corresponding to the co-ordination current

Note 1 to entry: For HVDC converter equipment, the following specific definitions 3.16.1 to 3.16.3 apply.

3.16.1
switching impulse protective level

SIPL

residual voltage of a surge arrester subjected to a discharge current corresponding to the co-ordination switching impulse current

3.16.2
lightning impulse protective level

LIPL

residual voltage of a surge arrester subjected to a discharge current corresponding to the co-ordination lightning impulse current

3.16.3

steep-front impulse protective level

STIPL

residual voltage of a surge arrester subjected to a discharge current corresponding to the co-ordination steep-front impulse current

3.17

directly protected equipment

equipment connected in parallel to a surge arrester for which the separation distance can be neglected and any representative overvoltage be considered equal to the corresponding protective level

3.18

creepage distance

shortest distance, or the sum of the shortest distances, along the insulating parts of the insulator between those parts which normally have the operating voltage between them

Note 1 to entry: The surface of cement or of any other non-insulating jointing material is not considered as forming part of the creepage distance.

Note 2 to entry: If a high resistance coating, e.g. semi-conductive glaze, is applied to parts of the insulating part of an insulator, such parts are considered to be effective insulating surfaces and the distance over them is included in the creepage distance.

[SOURCE: IEC TS 60815-1: 2008, 3.1.5]

3.19

unified specific creepage distance

USCD

creepage distance of an insulator divided by the maximum operating voltage across the insulator. It is generally expressed in mm/kV

[SOURCE: IEC TS 60815-4:2016, 3.1.1, modified – The note to entry has been removed.]

3.20

separation distance

distance between the high voltage terminal of the protected equipment and the connection point of the arrester high voltage conductor

3.21

performance criterion

basis on which the insulation is selected so as to reduce to an economically and operationally acceptable level the probability that the resulting voltage stresses imposed on the equipment will cause damage to equipment insulation or affect continuity of service

Note 1 to entry: The performance criterion is usually expressed in terms of an acceptable failure rate (number of failures per year, years between failures, risk of failure, etc.) of the insulation configuration.

[SOURCE: IEC 60071-1:2019, 3.23]

4 Symbols and abbreviations

4.1 General

The list provided in 4.2 below covers only the most frequently used symbols and abbreviations, some of which are illustrated graphically in the single-line diagram of Figure A.1 and Table A.1. For a more complete list of symbols which has been adopted for HVDC converter stations, and also for insulation co-ordination, refer to the standards listed in the normative references (Clause 2) and to the Bibliography.

4.2 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)

4.3 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_{ch}	continuous operating voltage of an arrester including harmonics
U_{n}	nominal voltage of DC system
U_{s}	highest voltage of an AC system (IEC 60071-1 and 60071-2)
U_{m}	highest voltage for the equipment
U_{50}	50 % disruptive discharge voltage
U_{rp}	representative overvoltage
U_{cw}	co-ordination withstand voltage
U_{rw}	required withstand voltage
U_{w}	specified withstand voltage (standard withstand voltage in AC）
σ	the standard deviation
N	the number of the conventional deviations

4.4 Abbreviations

HVDC	high voltage direct current
DC (d.c.)	direct current
AC (a.c.)	alternating current
LCC	line commutated converter
VSC	voltage sourced converter
CCC	capacitor commutated converter
CSCC	controlled series compensated converter
CCOV	crest value of continuous operating voltage
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
USCD	unified specific creepage distance
RUSCD	reference unified specific creepage distance

5 Principles of insulation co-ordination

5.1 General

The primary objectives of insulation co-ordination are:

- to determine the maximum steady state, temporary and transient overvoltage levels to which the various components of a system may be subjected in practice;
- to select the insulation strength and characteristics of equipment, including the protective devices, used in order to ensure a safe, economic and reliable installation in the event of overvoltages.

5.2 Essential differences between AC and DC systems

The insulation co-ordination applied to an HVDC converter station is basically the same in principle as that of an AC substation. However, essential differences exist which warrant particular consideration when dealing with HVDC converter stations. For example, there is a need to consider the following:

a) the requirements of series-connected valve groups involving surge arresters connected across individual valves and between terminals away from earth potential which involves the use of different insulation levels for different parts of the HVDC converter station;

b) the topology of the converter circuits with no direct exposure to the external overvoltage since these circuits are bounded by inductances of converter transformers and smoothing reactors;

c) the presence of reactive power sources and harmonic filters on both the AC and DC sides giving rise to potential overvoltages and higher probability of resonance conditions;

d) applications involving long overhead transmission lines and/or cables without intervening switching stations, with potential for resonance conditions on the DC side;

e) the presence of converter transformers with the valve side not directly connected to earth potential, and a DC voltage offset;

f) the characteristics of the converter valves resulting in composite voltage wave shapes (which include in some cases a combination of direct voltage, fundamental frequency voltage, harmonic voltages and high frequency components), commutation failures, etc.;

g) control malfunction resulting in possible valve misfires, trigger failure, current extinction;

h) fast control and protection action reducing overvoltages;

i) voltage polarity effects of DC stress which, by attracting greater contaminants to the DC insulation because of constant polarity, lead to greater creepage and clearance requirements and to worse pollution and flashover performance compared with AC insulation under the same environment;

j) interaction between the AC and DC systems, particularly where the AC system is relatively weak;

k) the various operating modes of the converter such as monopolar, bipolar, parallel or multiterminal;

l) no standard insulation levels exist in the case of DC systems so far.

5.3 Insulation co-ordination procedure

The general method of investigation for an HVDC converter station contains the following:

a) selection of the DC circuit configuration, for example location of the DC smoothing reactors, location of the DC side earthing, converter transformer valve winding connection (star or delta) to the higher DC voltage terminal;

b) selection of arrester arrangement according to the selected DC circuit configuration;

c) evaluation of the characteristics of the AC system at the commutation bus and the DC system and their interaction to determine different representative overvoltages and current/energy stresses imposed on surge arresters;

d) optimization of the design by iterative assessment of equipment insulation and arrester requirements.

5.4 Differences of withstand voltage selection in AC and DC systems

As described in IEC 60071-1, there are four main steps in the insulation co-ordination procedure which can be identified in Table 2.

Table 2 – Comparison of the insulation co-ordination procedure of AC and DC systems

Procedure	AC systems	DC systems
step 1:	determination of the representative overvoltages (U_{rp})	
step 2:	determination of the co-ordination withstand voltages (U_{cw})	
step 3:	determination of the required withstand voltages (U_{rw})	
step 4:	determination of the standard rated withstand voltages (U_w)	determination of the specified withstand voltages (U_w)

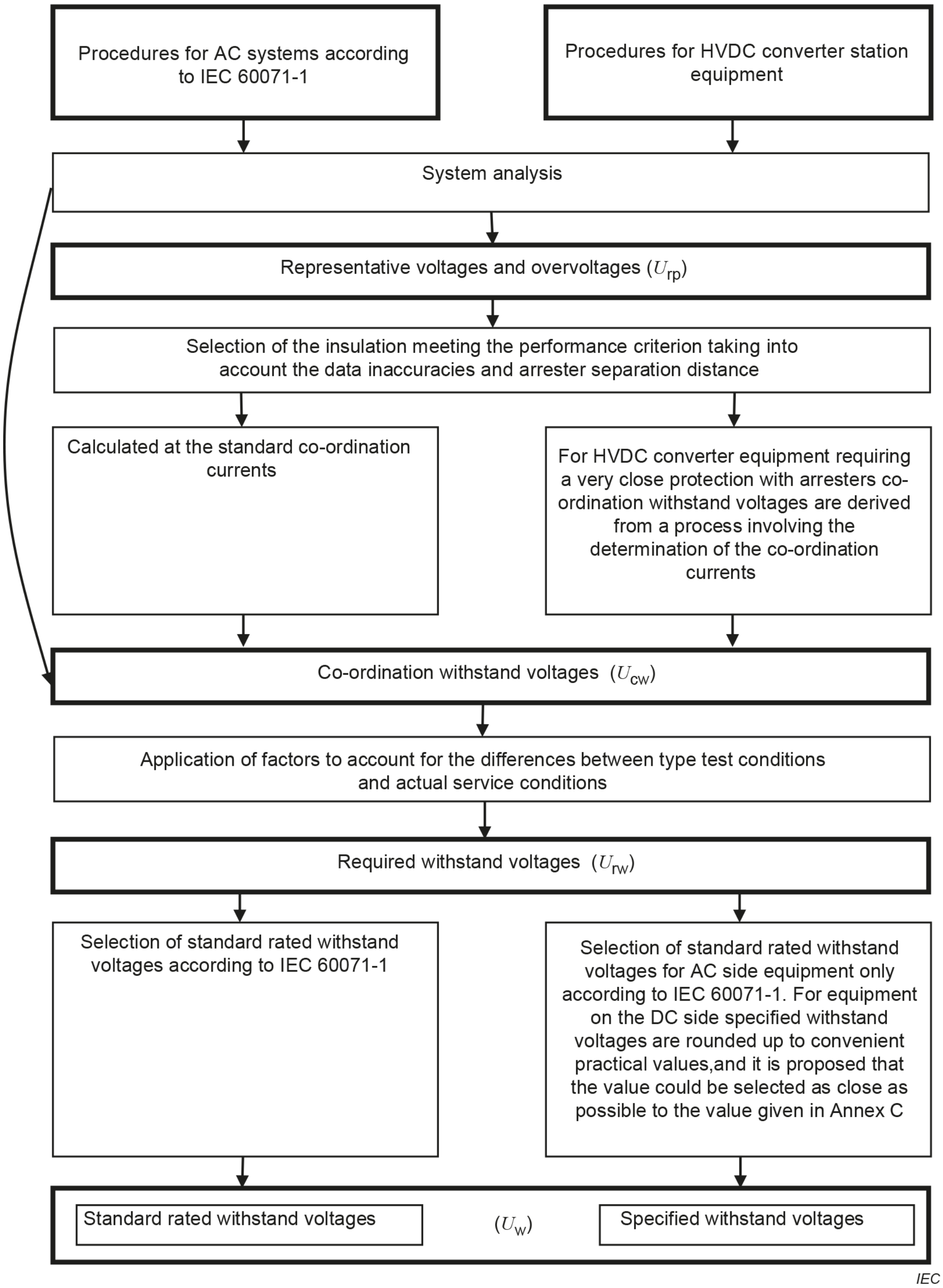


Figure 1 – Comparison of the selection between withstand voltages for AC equipment and for HVDC converter station equipment

Figure 1 is a flow chart showing the procedure in selecting the withstand voltages (U_w) in both AC (Figure 1 of IEC 60071-1:2019) and DC systems with the differences in the DC case being identified.

The individual steps involved in the selection process are detailed in IEC 60071-1 for the AC system application and in Clause 6 of this document for the DC system.

6 Design procedure of insulation co-ordination

6.1 General

Because of the essential differences between AC and DC systems leading to some deviations in the process of insulation co-ordination as discussed in 5.2, it is useful in Clause 6 to define clearly the design objectives to be achieved as a result of the co-ordination procedures described in 6.2 to 6.7. This applies to some extent to the AC side of the HVDC converter station but to a greater extent to the DC side, particularly because several valve groups are normally connected in series. The valves and other equipment entirely separate from earth are therefore arranged to be protected by means of appropriate surge arresters as illustrated in Figure A.1 and Figure A.2.

The first design objective is thus to make a suitable choice of the locations of various arresters based on all the available or assembled necessary system details, as follows:

- the DC converter scheme;
- the AC network;
- the DC and earth electrode lines and cables (if any);
- the AC side of the HVDC converter station.

The next important design objective is to plan and conduct studies for determining surge arrester requirements.

The main objective is the determination of the withstand voltages to achieve the desired reliability.

6.2 Arrester characteristics

At present, overvoltage protection of HVDC converter stations has been based exclusively on metal-oxide surge arresters without gaps (according to IEC 60099-4), therefore the insulation level of the HVDC system is directly determined by the characteristics and arrangement of the arrester. The actual arrangement of the arresters depends on the configuration of the HVDC converter station and the type of transmission circuit, Figure A.1, Figure A.2 and Figure A.3 show several possible arrester locations of HVDC converter stations. The basic criteria used however is that each voltage level and the equipment connected to it is adequately protected at a cost commensurate with the desired reliability and equipment withstand capability (see 3.21). Detailed description is given in the application guide.

6.3 Insulation characteristics

As in AC substations, there are two types of insulation used in HVDC systems, self-restoring, which applies to air, and non-self-restoring which applies to e.g. oil and paper. However, gases that may be used can fall under both types of insulation. Because the operation condition of equipment in DC system is more complex than that in AC system, in DC applications the composite effect of DC, AC and impulse (also polarity reversal) voltages shall be considered. The characteristics of the individual insulation are outside the scope of this document.

6.4 Determination of the representative overvoltages (U_{rp})

The representative overvoltage as defined in IEC 60071-1 is equal to the maximum overvoltage of each class of overvoltages, this general concept applies to both AC and DC systems, but a particular application of this concept for DC systems is to consider that representative overvoltages are equal to protection levels of arresters for directly protected equipment.

The representative overvoltages are determined by considering relevant faults and examining the results of the calculation to find out the representative type of overvoltage. Once the type of overvoltage has been determined, the peak value of the waveform chosen may be adjusted to take into consideration the duration and shape of the overvoltage as per IEC 60071-2:2018, Clause 2. This adjustment can be considered to be taken into account when applying factors to protective levels of arresters as per 6.6.

6.5 Determination of the co-ordination withstand voltages (U_{cw})

The determination of the co-ordination withstand voltages consists of determining the lowest values of the withstand voltages of the insulation meeting the performance criterion when subjected to the representative overvoltages under service conditions.

The insulation co-ordination procedure recommended in IEC 60071-1 implies the application of a co-ordination factor (K_c) to the representative overvoltages (U_{rp}) to obtain the co-ordination withstand voltages (U_{cw}), which means: $U_{cw} = K_c \times U_{rp}$(refer to IEC 60071-1:2019, 5.3).

For equipment on the DC side, the deterministic method (refer to IEC 60071-2:2018, 5.3) is actually used so that, for such equipment, the deterministic co-ordination factor K_{cd} (refer to IEC 60071-2:2018, 5.3.3.1) which is used instead of K_c. The co-ordination factor K_{cd} applied to the representative overvoltages includes:

- allowance for limitations in modelling and in data for calculating the overvoltages, and for the co-ordination currents taking into account the strong non-linearity of the arrester characteristics;
- allowance for shape and duration of overvoltages.

For DC applications, if the calculated value of U_{rp} is the highest value for reasonable contingencies, the value of U_{cw} can be taken to be equal to U_{rp}.

For HVDC system AC side, simulations of overvoltage events combined with the simultaneous evaluation of the risk of failure, using the relevant insulation characteristics, permit the direct determination of the statistical co-ordination withstand voltages without the intermediate step of determining the representative overvoltages (see Figure 1).

6.6 Determination of the required withstand voltages (U_{rw})

The determination of the required withstand voltages of the insulation consists of converting the co-ordination withstand voltages to appropriate standard test conditions. This is accomplished by multiplying the co-ordination withstand voltages by factors which compensate the differences between the actual service conditions of the insulation and the standard reference conditions as per IEC 60060-1.

As with AC systems, the insulation of the equipment is classified into self-restoring insulation and non-self-restoring insulation according to IEC 60071-1. Self-restoring insulation consists primarily of air gaps and the external insulation of insulators while non-self-restoring insulation consists primarily of oil and cellulose dielectric materials as used in converter transformers and reactors. The valves have properties similar to self-restoring insulation material due to the fact that redundant units are provided to maintain the required withstand voltage even in the event of random failures of valve units within the valve between maintenance periods.

Arresters are used to protect equipment insulation as in AC applications; however, the arresters are not necessarily directly connected to earth, but are also connected directly across equipment elevated from earth potential. For valves, the arresters are located close to the valve in order to eliminate distance effects.

The essential difference compared with AC applications is that in HVDC applications the insulation is stressed by composite AC, DC and impulse voltages. Composite voltages require consideration of both resistive and capacitive voltage distribution and can result in high voltage stresses. These high-voltage stresses are, however, taken into account in the design and testing of the equipment.

The required withstand voltages (U_{rw}) for switching, lightning and steep-front are determined by multiplying the corresponding co-ordination withstand voltages (U_{cw}) with relevant factors. Based upon the withstand voltages, the test voltages for each equipment are determined according to the respective equipment standards. Referring to IEC 60071-1:2019, Figure 1, the required withstand voltages U_{rw} are obtained by applying to the co-ordination withstand voltage the altitude correction factor K_{a} for external insulation, and a safety factor K_{s} whose value depends on the type of insulation internal or external. The safety factor K_{s} includes:

- allowance for ageing of insulation;
- allowance for changes in arrester characteristics;
- allowance for dispersion in the product quality.

For HVDC converter stations, the deterministic method is applied and, for altitudes up to 1 000 m, experience has shown that the required withstand voltages of equipment can be obtained by applying a factor to the corresponding protective level of the arrester. Such a factor includes all the preceding ones discussed at the beginning of this subclause. Table 3 provides a set of indicative values for this factor which may be used as design objectives if not specified by the user or the relevant apparatus committees. In Table 3, all equipment is considered to be directly protected by an arrester. If this is not the case, e.g. for some of the equipment on the AC side, distance effect for fast and very-fast transients shall be taken into account and indicative ratios should be raised accordingly (refer to IEC 60071-1 and IEC 60071-2, co-ordination factor and co-ordination withstand voltages).

Table 3 – Indicative values of ratios of required impulse withstand voltage to impulse protective level

Type of equipment	**Indicative values of required impulse withstand voltage/impulse protective level**[a, c]		
	RSIWV/SIPL	**RLIWV/LIPL**	**RSFIWV/STIPL**[b]
AC switchyard – busbars, outdoor insulators, and other conventional equipment	1,20	1,25	1,25
AC filter components	1,15	1,25	1,25
Transformers (in oil)			
line side	1,20	1,25	1,25
valve side	1,15	1,20	1,25
Converter valves	1,15	1,15	1,20
DC valve hall equipment	1,15	1,15	1,25
DC switchyard equipment (including DC filters etc. and DC reactor)	1,15	1,20	1,25

[a] Indicated values are stated for general design objectives only. Appropriate final ratios (higher or lower) can be selected according to the chosen performance criteria.

[b] STIPL for LCC valve arresters.

[c] Indicative ratios are on the basis that any equipment is directly protected with a surge arrester.

6.7 Determination of the specified withstand voltage (U_w)

The specified withstand voltages are values equal to or higher than the required withstand voltages. For AC equipment, the specified withstand voltages correspond to standard values as stated in IEC 60071-1.

For HVDC equipment, the specified withstand voltages are rounded up to convenient practical values. It is proposed that the value could be selected as close as possible to the value given in Annex C.

7 Requirements for withstand voltage tests

Withstand voltage tests are performed to demonstrate, with suitable confidence, that the actual withstand voltage of the insulation is not lower than the corresponding specified withstand voltage.

Unless otherwise specified by the relevant apparatus committees, the following withstand voltage tests should be performed on HVDC system equipment:

- DC withstand voltage tests;
- impulse withstand voltage tests;
- power-frequency withstand voltage tests (unless otherwise specified by the relevant apparatus committees, only applicable for AC equipment).

In general, withstand voltage tests consist of dry tests performed in a standard situation (test arrangement specified by the relevant apparatus committees and the standard reference atmospheric conditions). However, for non-weather protected external insulation, the DC, power-frequency and switching impulse withstand voltage tests consist of wet tests performed under the conditions specified in IEC 60060-1.

The test procedures and evaluation criteria for withstand voltage tests are specified by the relevant apparatus committees.

8 Creepage distances

8.1 General

The creepage distance on the insulators is one of the factors that dictates the performance of external insulations at continuous operating voltages (AC, DC or mixed). When wetted, contamination on the insulators reduces their ability to support the operating voltages. Rain, snow, dew or fog are some of the weather conditions that can initiate this process. The withstand capability of contaminated insulators is also affected by other factors such as the shed profile, the orientation angle and the diameter of the insulators. In the case of bushings, DC current measuring devices, DC voltage dividers and other similar equipment, the internal construction of the core impacts both the internal and external voltage distribution. All these factors should be considered in determining the type and shape of the insulators suitable for the applications.

There have been cases of bushing flashover on various operating DC schemes where contamination deposits have been lightly wetted by dew, fog or rain. In addition, flashover have occurred due to unequal wetting of external insulators, such as horizontally mounted bushings, although this phenomenon is independent of the creepage distance.

For more details regarding unified creepage distance, readers can refer to the IEC 60815 series.

8.2 Base voltage for creepage distance

The base voltage across the insulation used together with the unified specific creepage distance is as follows:

a) for the phase-to-earth insulation on the AC side of the converter (AC equipment): the highest continuous r.m.s. value of the phase-to-earth operating voltage;

b) for the phase-to-phase insulation on the AC side of the converter (AC equipment): the highest r.m.s. value of the phase-to-phase operating voltage;

c) for the insulation of the DC equipment subjected to a pure DC voltage: the maximum continuous DC voltage across the equipment;

d) for the case of mixed voltage waveforms composed of DC fundamental and harmonics: the r.m.s. value of the voltage (e.g. valves and DC filter components);

e) for the case of mixed voltage waveforms composed of AC fundamental frequency and harmonics: the highest r.m.s. value of the voltage (e.g. AC filter components).

The required creepage distances are defined based on IEC TS 60815-1:2008, 8.3, which, for the purposes of standardization, includes five classes of pollution characterizing site pollution severity (SPS).

8.3 Creepage distance for outdoor insulation under DC voltage

The trend in the industry for several years has been to use larger specific creepage distances in HVDC applications under polluted operating conditions of around 60 mm/kV for porcelain insulators. Several mitigation techniques have been used on existing HVDC systems to solve this problem. Although the application of silicone grease has been successful in avoiding flashovers, the frequency of reapplying the grease coating is high under polluted conditions. An alternative method involves the application of room temperature vulcanized rubber (RTV) on the surface of the insulators. Technological advances in this area have resulted in improved performance. The application of booster sheds has also been successful in avoiding bushing flashovers. The use of composite housings for bushings and other devices have been successfully applied in solving the flashovers in HVDC stations, even with smaller specific creepage distances. Operating experience of composite insulator and bushings shows that around 75 % of the creepage associated with an equivalent porcelain insulator is found to result in satisfactory performance. The hydrophobicity of composite material makes it suitable in applications involving unequal wetting as well. Recently, composite insulators and composite bushings have been satisfactorily used, especially, at 500 kV and above.

8.4 Creepage distance for indoor insulation under DC or mixed voltage

For an indoor clean and controlled (valve hall) environment with humidity control, a minimum specific creepage distance of about 14 mm/kV (based on the appropriate base voltage as calculated in 8.2) has been widely used and has not experienced any flashover. The creepage path, in any case, may not be an especially suitable parameter to define the converter valve internal insulation and the arcing distance may be more appropriate.

For indoor HVDC installations (indoor DC yard) with uncontrolled environment, satisfactory performance has been demonstrated for creepage distance between 20 mm/kV to 30 mm/kV under the assumption that condensation is avoided.

8.5 Creepage distance of AC insulators

In accordance with IEC TS 60815-2 for ceramic and glass insulators and IEC TS 60815-3 for polymer insulators, the user can:

- determine the reference unified specific creepage distance (RUSCD) from the site pollution severity (SPS) class (specified in IEC TS 60815-2:2008, Figure 1, and IEC TS 60815-3:2008, Figure 1);
- evaluate the suitability of different insulator profiles;

- determine the necessary USCD by applying corrections for insulator shape, size, position, etc. to the RUSCD;
- if required, determine the appropriate test methods and parameters to verify the performance of the selected insulators.

9 Clearances in air

Details concerning required clearances in air to assure a specified impulse voltage insulation for AC applications are presented in IEC 60071-1 and IEC 60071-2, while IEC 60071-1:2019, Annex B gives the correlations between impulse withstand voltages and minimum air clearances. The clearances in DC applications are based on insulation levels of equipment which are determined to provide the appropriate margin over the protective level of the arresters rather than on standard equipment levels. Annex C shows an example of possible insulation levels recommended for HVDC Grids, as well as examples of possible minimum clearance distances for rod – structure gap configurations and conductor – structure.

The procedure for calculation of minimum air clearances for different voltage shapes is well described in IEC 60071-2. The 50 % disruptive discharge voltage U_{50} used for air clearance calculation is to be determined in accordance with IEC 60071-2 from the following formula:

$$U_{50} = \frac{U_w}{(1 - N \times \sigma)} \tag{1}$$

where:

U_w is the specified withstand voltage (LIWL or SIWL) determined by insulation co-ordination studies, kV;

U_{50} is the 50 % disruptive discharge voltage for the appropriate voltage wave shape, kV;

σ is the standard deviation, predetermined by IEC 60071-2;

N is the number of the conventional deviations.

NOTE The number of standard deviations depends on the disruptive discharge probability of external insulation under switching and lightning considered in the design, according to IEC 60071-2:2018, Annex B. The normal practice for air clearance design is N = 1,3 for AC applications recommended as per IEC 60071-2, which corresponds to a withstand probability of 90 %. For outdoor clearances in HVDC, N = 2 has been recommended in [1][1], corresponding to a withstand probability of 98 %.

The U_{50} value shall be based on the value of gap factor appropriate to the electrode shape.

In calculating U_w atmospheric correction factors shall be applied for non-standard atmospheric conditions in accordance with IEC 60060-1.

The minimum clearance is selected as the larger clearance determined from switching and lightning impulse withstand of equipment.

In HVDC applications, the presence of composite AC, DC and impulse voltages shall be considered [2].

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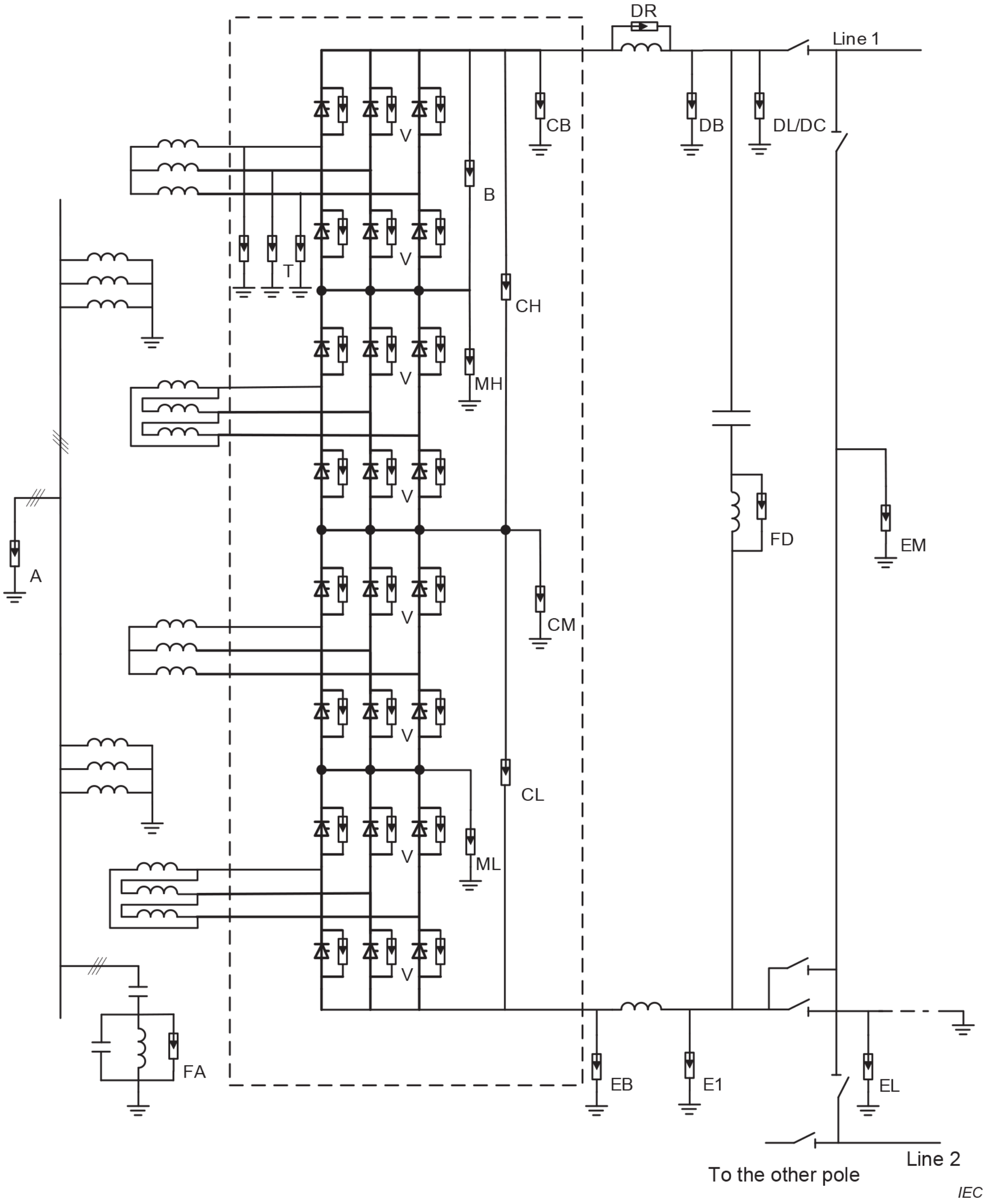
[1] Numbers in square brackets refer to the Bibliography.

Annex A
(informative)

Typical HVDC converter station schemes

Figure A.1 shows the single line diagram of possible LCC HVDC converter station equipped with two 12-pulse converter bridges in series. Figure A.2 and Figure A.3 show the single line diagram of possible bipole and symmetrical monopole VSC converter station. Figure A.1 [1], Figure A.2 and Figure A.3 show possible arrester locations covered in this document. Some of these arresters may be redundant and could be excluded depending on the specific design.

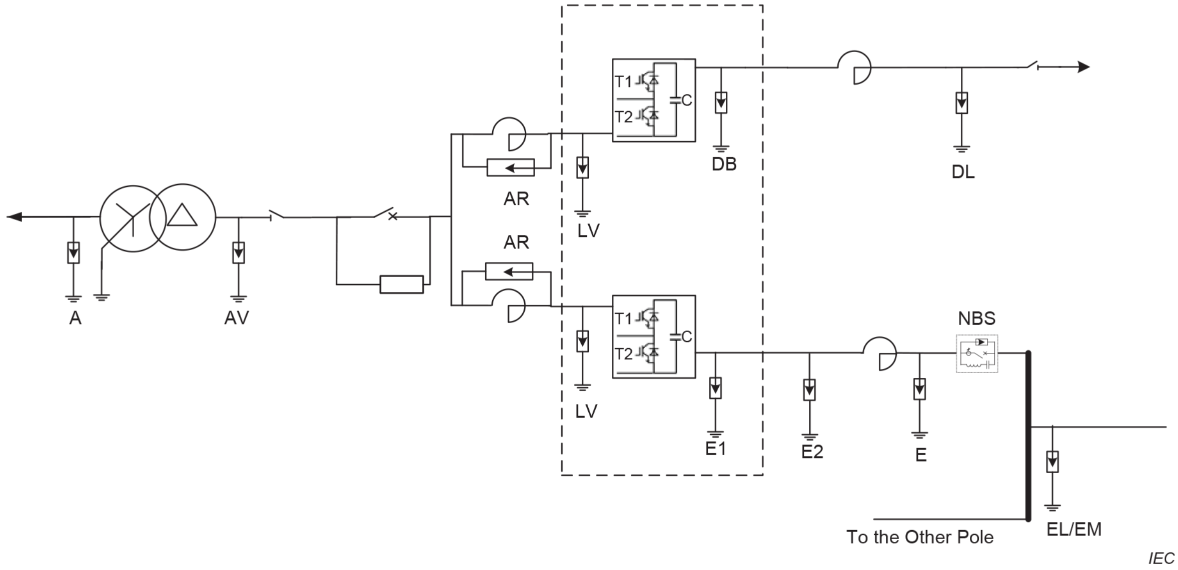
For the purpose of this document, Table A.1 presents the graphical symbols used in Annex A.



Key

A:	AC bus arrester	FA:	AC filter arrester
FD:	DC filter arrester	EL:	Electrode line arrester
E1:	DC neutral bus arrester	EM:	Metallic return arrester
EB:	Converter neutral arrester	B:	Bridge arrester (6-pulse)
V:	Valve arrester	CB:	Converter unit DC bus arrester
T:	Transformer valve winding arrester	DB:	DC bus arrester
DR:	Smoothing reactor arrester	DC:	DC cable arrester
DL:	DC line arrester	CM:	Arrester between converters unit
CL:	LV converter unit arrester	MH:	Mid-point bridge arrester (HV bridge)
CH:	HV converter unit arrester	ML:	Mid-point bridge arrester (LV bridge)

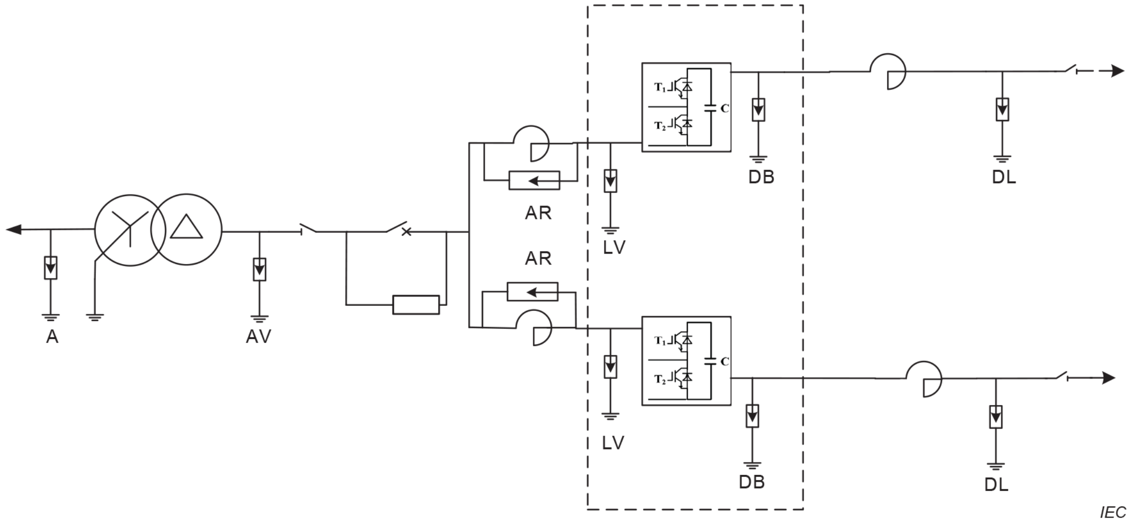
Figure A.1 – Possible arrester locations in one pole of bipole LCC converter station with 12-pulse converters in series



Key

A:	AC side arrester	LV:	Reactor valve side arrester (bridge arm)
AV:	Connecting transformer valve side arrester	DB:	DC bus arrester
AR:	Arrester between reactor terminals(bridge arm)	DL:	DC line arrester
E/E1/E2:	Neutral bus arrester	EL/EM:	Electrode line / Metallic return arrester
NBS:	Neutral bus switch		

Figure A.2 – Possible arrester locations in one pole of bipolar of VSC converter stations

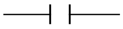
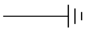


Key

A:	AC side arrester	LV:	Reactor valve side arrester (bridge arm)
AV:	Connecting transformer valve side arrester	DB:	DC bus arrester
AR:	Arrester between reactor terminals(bridge arm)	DL:	DC line arrester
NV:	Connecting transformer Neutral point arrester		

Figure A.3 – Possible arrester locations in symmetrical monopole VSC converter stations

Table A.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

Annex B
(informative)

Example of air clearances calculation

B.1 Introductory remarks

This Annex B gives an example of the description and method of calculation air clearances for DC applications like HVDC. The procedure for calculation of air gap breakdown strength is already well described in IEC 60071-2. Therefore, the methods described there as well as the stated formulas are used in order to calculate the minimum air clearances for different voltage stresses. Thus, all limitations mentioned in IEC 60071-2 are also applicable within this Annex B. Nowadays, the air clearances in HVDC applications are mainly determined by the impulse stresses resulting from transient events like lightning strikes or ground faults within the system, rather than on steady state DC voltage stresses, the given examples are limited to the calculation of air clearances resulting from standard switching and lightning impulse stresses.

The presented examples are intended to be informative and tutorial and are very schematic. The purpose is to provide help to the user to estimate the size of the required air clearance. The examples mainly summarize the steps starting from a certain withstand voltage U_w of the insulation towards a minimum required air clearance d.

For the sake of simplicity, it is assumed that an atmospheric correction for non-standard atmospheric conditions in accordance with IEC 60060-1 is already applied on the withstand voltage U_w. This means that U_w is a value at standard reference atmosphere according to IEC 60060-1.

B.2 Calculated minimum air clearance for switching impulse stress

B.2.1 General

In order to calculate the minimum required air clearance for standard switching impulse voltage stresses, the 50 % disruptive discharge voltage U_{50} of self-restoring insulation at standard reference atmosphere is required. This voltage is calculated based on the specified withstand voltage U_w at standard reference atmosphere as described in Clause 9 (See Formula (1)).

According to IEC 60071-2:2018, Annex F, the minimum air clearance for standard switching impulses can be calculated by:

$$d = \sqrt[0{,}6]{\frac{U_{50}}{500 \times K}} \tag{B.1}$$

where

d is the calculated minimum air clearance to withstand the switching impulse stress, m;

K is the switching impulse gap factor of the electrode configuration under investigation.

It is important to mention that all basic conditions and limitation as described in IEC 60071-2, are still valid and need to be considered when calculating the required minimum air clearance for a certain switching impulse stress.

B.2.2 Example calculation

Considering a required switching impulse withstand voltage of 1 050 kV and a conductor-plane arrangement with gap factor of 1,15, as recommended in IEC 60071-2:2018, Annex F:

RSIWV = 1 050 kV

σ = 6 %

U_w = 1 050 kV

U_{50} = $\frac{U_w}{0,88}\,\mathrm{kV}$ = 1 193 kV

d = $\sqrt[0,6]{\frac{U_{50}}{500\times 1,15}}$ = 3,375 m

The calculated minimum air clearance for electrode configuration like conductor-plane with a gap factor of 1,15 shall not be smaller than 3,375 m in order to withstand a switching impulse stress of 1 050 kV with a design discharge probability of 2σ.

B.3 Calculated minimum air clearance for lightning impulse stress

B.3.1 General

In order to calculate the minimum required air clearance for standard lightning impulse voltage stresses, the 50 % disruptive discharge voltage U_{50} of self-restoring insulation at standard reference atmosphere is required. This voltage is calculated based on the specified withstand voltage U_w at standard reference atmosphere as described in Clause 9 (See Formula (1)).

According IEC 60071-2:2018, Annex F, the minimum air clearance for standard lightning impulses can be calculated by:

$$d=\frac{U_{50}}{(0,74+0,26\times K)\times 530} \tag{B.2}$$

where

d is the calculated minimum air clearance to withstand the lightning impulse stress, m;

K is the switching impulse gap factor of the electrode configuration under investigation.

It is important to mention that all basic conditions and limitation as described in IEC 60071-2:2018, Annex F are still valid and need to be considered when calculating the required minimum air clearance for a certain lightning impulse stress.

B.3.2 Example calculation

Considering a required lightning impulse withstand voltage of 1 425 kV and an electrode configuration like conductor-plane gap factor of 1,15.

RLIWV = 1 425 kV

σ = 3 %

U_w = 1 425 kV

$$U_{50} = \frac{U_\mathrm{W}}{0{,}94}\,\mathrm{kV} = 1\ 516\ \mathrm{kV}$$

$$d = \frac{U_{50}}{(0{,}74 + 0{,}26 \times K) \times 530} = 2{,}753\ \mathrm{m}$$

The calculated minimum air clearance for electrode configuration type conductor – plane with a gap factor of 1,15 shall not be smaller than 2,753 m in order to withstand a lightning impulse stress of 1 425 kV with a designed withstand probability of 2 σ.

Annex C
(normative)

Example of typical DC voltages with possible insulation levels and corresponding air clearances

C.1 Introductory remarks

This Annex C gives a first proposal for a linking between recommended DC voltages, possible insulation levels as well as minimum air clearances. For DC applications and especially HVDC systems, no standard insulation levels are used in order to allow optimization of the overall system. This annex provides an example of DC voltages tentative to be used in HVDC Grids systems, with possible insulation levels and its corresponding clearances. The range of insulation levels provided are just an indication and shall be treated as informative guide for the user. The clearances and voltage levels values stated in this Annex C can change in the future depending on system solution and innovations available in the field.

The given examples of rated DC voltages, possible insulation levels and its corresponding air clearances are only applicable for outdoor installations in HVDC grids. Thus, indoor installations like the valve hall, reactor rooms or DC halls are explicitly excluded. Moreover, if reasonable and economical, other values for DC voltages, insulation levels and air clearances can be chosen.

Due to the fact that the current experience of steady state DC voltages and insulation stresses are mainly results from HVDC applications, the lowest recommended DC voltage is 200 kV. For lower DC voltages and UHV such as 800 kV and 1 100 kV, it is recommended to perform an insulation co-ordination according the guidelines of IEC 60071-1 and IEC 60071-2.

C.2 List of typical DC voltagesand possible insulation levels

The following peak values, expressed in kV, are proposed as the specified impulse withstand voltages: 20, 40,60, 75, 95, 125, 145, 170, 200, 250, 325, 380, 450, 550, 650, 750, 850, 950, 1 050, 1 175, 1 300, 1 425, 1 550, 1 675, 1 800, 1 950, 2 100, 2 250, 2 400, 2 550, 2 700, 2 900, 3 100.

Table C.1 shows the relationship of typical DC voltages and presumed switching and lightning impulse withstand voltages as example.

C.3 Example of presumed switching impulse insulation levels and minimum air clearances

Table C.2 provides examples of the minimum phase-to-earth clearance for different switching impulse withstand voltage levels. It is calculated based on the methods described in Clause B.2. The minimum air clearances are calculated for the electrode configuration Rod – Structure assuming a reference gap factor of 1,1 as well as for the Conductor – Structure configuration with reference gap factor 1,3. Standard reference atmosphere according IEC 60060-1 are considered.

The clearances may be lower if it has been proven on actual or similar configurations that the standard impulse withstand voltages are met. The distances are not applicable to equipment which has an impulse type test included in the specification, since mandatory clearance might hamper the design of the equipment, increase its cost and impede progress.

The clearances may also be lower, where it has been confirmed by operational experience and/or system design that overvoltages are lower than those indicated in the table or that the gap configuration is more favourable than that assumed for the recommended clearances.

Table C.1 – Typical DC voltages and switching/lightning impulse withstand voltage

Typical DC voltage kV	**Presumed rated switching impulse withstand voltage** kV (peak value)	**Presumed rated lightning impulse withstand voltage** kV (peak value)
200	550	550
		650
250	550	550
		650
	650	650
		750
320	650	650
		750
	750	750
		850
	850	850
		950
400	850	850
		950
	950	950
		1 050
		1 175
500/525[a]	950	950
		1 050
	1 050	1 050
		1 175
	1 175	1 175
		1 300
		1 425
600	1 175	1 175
		1 300
	1 300	1 300
		1 425
	1 425	1 425
		1 550
800	1 550	1 550
		1 675
	1 675	1 675
		1 800
		1 950
The corresponding values shall be chosen depending on the specific system configuration.		
[a] Either of 500 kV or 525 kV is applicable.		

Table C.2 – Correlation between presumed rated switching impulse withstand voltages and minimum phase-to-earth air clearances

Presumed rated switching impulse withstand voltage kV	**Minimum phase-to-earth clearance** mm			
	N = 1,3[b]		N = 2	
-	**Rod – Structure**	**Conductor – Structure**	**Rod – Structure**	**Conductor – Structure**
550	1 150	-	1 250	1 000
650	1 500	1 150	1 700	1 250
750	1 900	1 600	2 100	1 600
850	2 400	1 800	2 600	2 000
950	2 900	2 200	3 100	2 400
1 050	3 400	2 600	3 700	2 800
1 175	4 100	3 100	4 400	3 300
1 300	4 800	3 600	5 200	4 000
1 425	5 600	4 200	6 100	4 600
1 550	6 400	4 900	7 000	5 300
1 675	7 400[a]	5 600[a]	7 900	6 000
1 800	8 300[a]	6 300[a]	9 000	6 800
1 950	9 500[a]	7 200[a]	10 200	7 800

[a] Tentative values still under consideration.

[b] Values have been rounded to be in agreement with IEC 60071-1.

C.4 Example of presumed lightning impulse insulation levels and minimum air clearances

Table C.3 provides examples of the minimum phase-to-earth clearance for different lightning impulse withstand voltage levels. It is calculated based on the methods described in Clause B.3. The minimum air clearances are calculated for the electrode configuration Rod – Structure assuming a reference gap factor of 1,1 as well as for the Conductor – Structure configuration with reference gap factor 1,3. Standard reference atmosphere according IEC 60060-1 are considered.

The clearances may be lower if it has been proven on actual or similar configurations that the standard impulse withstand voltages are met. The distances are not applicable to equipment which has an impulse type test included in the specification, since mandatory clearance might hamper the design of the equipment, increase its cost and impede progress.

The clearances may also be lower, where it has been confirmed by operational experience and/or system design that overvoltages are lower than those indicated in the table or that the gap configuration is more favourable than that assumed for the recommended clearances.

C.5 Possible/Presumed specified DC withstand voltages

C.5.1 General

In order to further guide the standardization of insulation level, the recommended values of insulation withstand voltages are given in C.5.2, C.5.3 for information.

C.5.2 Specified DC withstand voltages

According to the current practical situation of HVDC project, it is proposed the application of 1,5 times the nominal voltage of DC system (U_n) to obtain the specified DC withstand voltage (U_w), which means: U_w = 1,5 × U_n, if not specified by the relevant apparatus committees.

C.5.3 List of specified power frequency withstand voltages

For the equipment installed in AC side of HVDC system, the r.m.s. values shall be taken from IEC 60071-1:2019, 5.6.

Table C.3 – Correlation between presumed rated lightning impulse withstand voltages and minimum phase-to-earth air clearances

Presumed rated lightning impulse withstand voltage kV	**Minimum phase-to-earth clearance** mm			
	N = 1,3[a]		**N = 2**	
-	**Rod – Structure**	**Conductor – Structure**	**Rod – Structure**	**Conductor – Structure**
550	1 100	-	1 100	-
650	1 300	-	1 300	-
750	1 500	-	1 500	-
850	1 700	1 600	1 700	1 600
950	1 900	1 700	1 900	1 800
1 050	2 100	1 900	2 100	2 000
1 175	2 350	2 200	2 300	2 200
1 300	2 600	2 400	2 600	2 500
1 425	2 850	2 600	2 800	2 700
1 550	3 100	2 900	3 100	2900
1 675	3 350	3 100	3 300	3 100
1 800	3 600	3 300	3 600	3 400
1 950	3 900	3 600	3 900	3 700
2 100	4 200	3 900	4 100	3 900

[a] Values have been rounded to be in agreement with IEC 60071-1.

Annex D
(informative)

Typical arrester characteristics

Figure D.1 [1] presents a typical gapless metal oxide arrester characteristics used in insulation co-ordination studies. The x-axis represent the co-ordinating current in amperes and the y-axis represents the protective voltage in p.u. of the 10 kA fast-front protective value.

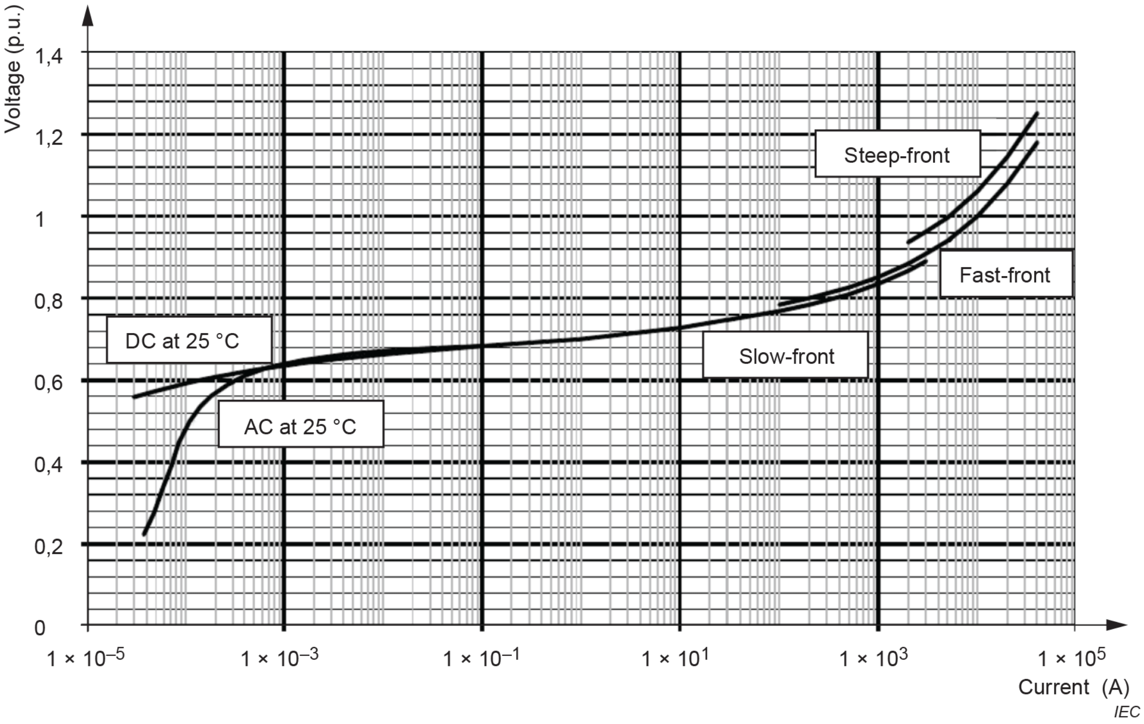


Figure D.1 – Typical arrester V-I characteristics

Annex E
(informative)

The Correlation of clauses between IEC 60071-11 and IEC 60071-5:2014

The Correlation of clauses between IEC 60071-11 and IEC 60071-5:2014 are as follows:

IEC 60071-11	IEC 60071-5:2014
1 Scope	1
2 Normative references	2
3 Terms and definitions	3
4 Symbols and abbreviations	4
4.1 General	4.1
4.2 Subscripts	4.2
4.3 Letter symbols	4.3
4.4 Abbreviations	4.4
5 Principles of insulation co-ordination	6
5.1 General	6.1
5.2 Essential differences between AC and DC systems	6.2
5.3 Insulation co-ordination procedure	6.3
5.4 Differences of withstand voltage selection in AC and DC systems	6.4
6 Design procedure of insulation co-ordination	9
6.1 General	9.1
6.2 Arrester characteristics	8.1
6.3 Insulation characteristics	9.3
6.4 Determination of the representative overvoltages (U_{rp})	9.4
6.5 Determination of the co-ordination withstand voltages (U_{cw})	9.5
6.6 Determination of the required withstand voltages (U_{rw})	9.6
6.7 Determination of the specified withstand voltage (U_{w})	9.7
7 Requirements for withstand voltage tests	-
8 Creepage distances	11
8.1 General	11.1
8.2 Base voltage for creepage distance	11.2
8.3 Creepage distance for outdoor insulation under DC voltage	11.3
8.4 Creepage distance for indoor insulation under DC or mixed voltage	11.4
8.5 Creepage distance of AC insulators	11.5
9 Clearances in air	12
Annex A (informative) Typical HVDC converter station arrester protection schemes	
Annex B (informative) Example of air clearances calculation	
Annex C (normative) Example of typical DC voltages with possible insulation levels and corresponding air clearances	
Annex D (informative) Typical arrester characteristics	Annex D
Annex E (informative) The Correlation of clauses between IEC 60071-11 and IEC 60071-5:2014	

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(*Continued from second cover*)

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
IEC TS 60815-1 : 2008 Selection and dimensioning of high-voltage insulators intended for use in polluted conditions — Part 1: Definitions, information and general principles	IS 16683 (Part 1) : 2018/ IEC TS 60815-1 : 2008 Selection and dimensioning of high-voltage insulators intended for use in polluted conditions: Part 1 Definitions, information and general principles	Identical
IEC TS 60815-2 : 2008 Selection and dimensioning of high-voltage insulators intended for use in polluted conditions — Part 2: Ceramic and glass insulators for a.c. systems	IS 16683 (Part 2) : 2018/ IEC TS 60815-2 : 2008 Selection and dimensioning of high-voltage insulators intended for use in polluted conditions: Part 2 Ceramic and glass insulators for a.c. systems	Identical
IEC TS 60815-3 : 2008 Selection and dimensioning of high-voltage insulators intended for use in polluted conditions — Part 3: Polymer insulators for a.c. systems	IS 16683 (Part 3) : 2018/ IEC TS 60815-3 : 2008 Selection and dimensioning of high-voltage insulators intended for use in polluted conditions: Part 3 Polymer insulators for a.c. systems	Identical

Only English language text has been retained while adopting it in this Indian Standard, and as such the page numbers given here are not the same as in the International Standard.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated expressing the result of a test, shall be rounded off in accordance with IS 2 : 2022 ‘Rules for rounding off numerical values (*second revision*)’. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

This Indian Standard has been developed from Doc No.: ETD 40 (25760).

Amendments Issued Since Publication

Amend No.	Date of Issue	Text Affected

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Published by BIS, New Delhi