

BS EN 60071-5:2015



BSI Standards Publication

Insulation co-ordination

Part 5: Procedures for high-voltage direct current (HVDC) converter stations

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National foreword

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The UK participation in its preparation was entrusted to Technical Committee GEL/28, Electrical Insulation Co-ordination.

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

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Part 5: Procedures for high-voltage direct current (HVDC)
converter stations
(IEC 60071-5:2014)

Coordination de l'isolement -
Partie 5: Procédures pour les stations de conversion à
courant continu haute tension (CCHT)
(IEC 60071-5:2014)

Isolationskoordination -
Teil 5: Verfahren für Hochspannungs-Gleichstrom-
Stromrichterstationen (HGÜ-Stromrichterstationen)
(IEC 60071-5:2014)

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Foreword

The text of document 28/218/FDIS, future edition 1 of IEC 60071-5, prepared by IEC/TC 28 "Insulation co-ordination" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 60071-5:2015.

The following dates are fixed:

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standard or by endorsement
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standards conflicting with the
document have to be withdrawn

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The text of the International Standard IEC 60071-5:2014 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

IEC 60099-5:1996	NOTE	Harmonized as EN 60099-5:1996 ¹⁾ (modified).
IEC 60505:2011	NOTE	Harmonized as EN 60505:2011 (not modified).
IEC 60721-3-0:1984	NOTE	Harmonized as EN 60721-3-0:1993 (not modified).
IEC/TR 60919-2:2008	NOTE	Harmonized as CLC/TR 60919-2:2010 (not modified).
IEC 60700-1:1998	NOTE	Harmonized as EN 60700-1:1998 (not modified).
IEC 60700-1:1998/A1:2003	NOTE	Harmonized as EN 60700-1:1998/A1:2003 (not modified).
IEC 60700-1:1998/A2:2008	NOTE	Harmonized as EN 60700-1:1998/A2:2008 (not modified).

¹⁾ Superseded by EN 60099-5:2013 (IEC 60099-5:2013) - DOW = 2016-06-26.

Annex ZA (normative)

Normative references to international publications with their corresponding European publications

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE 1 When an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu

<u>Publication</u>	<u>Year</u>	<u>Title</u>	<u>EN/HD</u>	<u>Year</u>
IEC 60060-1	-	High-voltage test techniques - Part 1: General definitions and test requirements	EN 60060-1	-
IEC 60071-1	2006	Insulation co-ordination - Part 1: Definitions, principles and rules	EN 60071-1	2006
IEC 60071-2	1996	Insulation co-ordination - Part 2: Application guide	EN 60071-2	1997
IEC 60099-4 (mod)	2004	Surge arresters - Part 4: Metal-oxide surge arresters without gaps for a.c. systems	EN 60099-4	2004
IEC 60633	-	Terminology for high-voltage direct current (HVDC) transmission	EN 60633	-
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		-

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INTRODUCTION

The IEC 60071 series consists of the following parts under the general title *Insulation co-ordination*:

Part 1: Definitions, principles and rules

Part 2: Application guide

Part 4: Computational guide to insulation co-ordination and modelling of electrical networks

Part 5: Procedures for high-voltage direct current (HVDC) converter stations

INSULATION CO-ORDINATION –

Part 5: Procedures for high-voltage direct current (HVDC) converter stations

1 General

1.1 Scope

This part of IEC 60071 provides guidance on the procedures for insulation co-ordination of high-voltage direct current (HVDC) converter stations, without prescribing standardized insulation levels.

This standard applies only for HVDC applications in high-voltage a.c. 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 standard.

1.2 Additional background

The use of power electronic thyristor valves in a series and/or parallel arrangement, along with the unique control and protection strategies employed in the conversion process, has ramifications requiring particular consideration of overvoltage protection of equipment in converter stations compared with substations in a.c. systems. This standard outlines the procedures for evaluating the overvoltage stresses on the converter station equipment subjected to combined d.c., a.c. power frequency, harmonic and impulse voltages. The criteria for determining the protective levels of series and/or parallel combinations of surge arresters used to ensure optimal protection are also presented.

The basic principles and design objectives of insulation co-ordination of converter stations, in so far as they differ from normal a.c. system practice, are described.

Concerning surge arrester protection, this standard deals only with metal-oxide surge arresters, without gaps, which are used in modern HVDC converter stations. The basic arrester characteristics, requirements for these arresters and the process of evaluating the maximum overvoltages to which they may be exposed in service, are presented. Typical arrester protection schemes and stresses of arresters are presented, along with methods to be applied for determining these stresses.

This standard includes insulation co-ordination of equipment connected between the converter a.c. bus (including the a.c. harmonic filters, the converter transformer, the circuit breakers) and the d.c. line side of the smoothing reactor. The line and cable terminations in so far as they influence the insulation co-ordination of converter station equipment are also covered.

Although the main focus of the standard is on conventional HVDC systems where the commutation voltage bus is at the a.c. filter bus, outlines of insulation co-ordination for the capacitor commutated converter (CCC) as well as the controlled series compensated converter (CSCC) and some other special converter configurations are covered in the annexes.

This standard discusses insulation co-ordination related to line commutated converter (LCC) stations. The insulation coordination of voltage sourced converters (VSC) is not part of this standard.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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 60071-1:2006, *Insulation co-ordination – Part 1: Definitions, principles and rules*

IEC 60071-2:1996, *Insulation co-ordination – Part 2: Application guide*

IEC 60099-4:2004, *Surge arresters – Part 4: Metal-oxide surge arresters without gaps for a.c. systems*

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

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.

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: 2006, 3.1]

3.2

nominal d.c. voltage

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

3.3

highest d.c. voltage

highest value of d.c. voltage for which the equipment is designed to operate continuously, in respect of its insulation as well as other characteristics

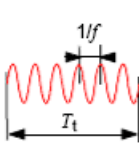
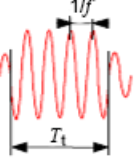
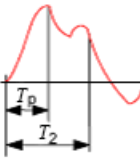
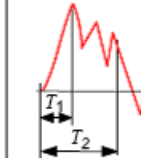
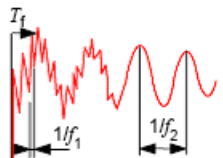
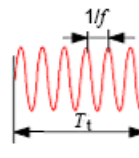
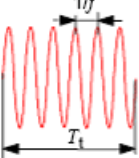
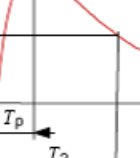
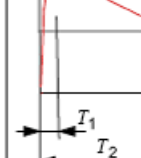
3.4

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 3.4.1 to 3.4.2.3.

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	$f = 50 \text{ Hz or } 60 \text{ Hz}$ $T_t \geq 3\,600 \text{ s}$	$10 \text{ Hz} < f < 500 \text{ Hz}$ $0,02 \text{ s} \leq T_t \leq 3\,600 \text{ s}$	$20 \mu\text{s} < T_p \leq 5\,000 \mu\text{s}$ $T_2 \leq 20 \text{ ms}$	$0,1 \mu\text{s} < T_1 \leq 20 \mu\text{s}$ $T_2 \leq 300 \mu\text{s}$	$T_t \leq 100 \text{ ns}$ $0,3 \text{ MHz} < f_1 < 100 \text{ MHz}$ $30 \text{ kHz} < f_2 < 300 \text{ kHz}$
Standard voltage shapes	 $f = 50 \text{ Hz or } 60 \text{ Hz}$ T_t^a	 $48 \text{ Hz} \leq f \leq 62 \text{ Hz}$ $T_t = 60 \text{ s}$	 $T_p = 250 \mu\text{s}$ $T_2 = 2\,500 \mu\text{s}$	 $T_1 = 1,2 \mu\text{s}$ $T_2 = 50 \mu\text{s}$	a
Standard withstand voltage test	a	Short-duration power frequency test	Switching impulse test	Lightning impulse test	a

^a To be specified by the relevant apparatus committees.

3.4.1

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 may be undamped or weakly damped.

3.4.2

transient overvoltage

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

[SOURCE: IEC 60071-1: 2006, 3.17.3]

3.4.2.1

slow-front overvoltage

transient overvoltage, usually unidirectional, with time to peak $20 \mu\text{s} < T_p \leq 5\,000 \mu\text{s}$, and tail duration $T_2 \leq 20 \text{ ms}$

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.

[SOURCE: IEC 60071-1:2006, 3.17.3.1]

3.4.2.2

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 $0,1 \mu\text{s} < T_1 \leq 20 \mu\text{s}$, and tail duration $T_2 \leq 300 \mu\text{s}$ in IEC 60071-1:2006, 3.17.3.2.

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.

3.4.2.3

very-fast-front overvoltage

transient overvoltage, usually unidirectional, with time to peak $T_f < 0,1 \mu\text{s}$, and with or without superimposed oscillations at frequency $30 \text{ kHz} < f < 100 \text{ MHz}$

[SOURCE: IEC 60071-1:2006, 3.17.3.3]

3.4.2.4

steep-front overvoltage

transient overvoltage classified as a kind of fast-front overvoltage with time to peak $3 \text{ ns} < T_1 < 1,2 \mu\text{s}$

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.

3.4.2.5

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.

3.5

representative overvoltages

U_{rp}

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

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

[SOURCE: IEC 60071-1:2006, 3.19]

3.5.1

representative slow-front overvoltage

RSFO

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

Note 1 to entry: This note applies to the French language only.

3.5.2

representative fast-front overvoltage

RFFO

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

Note 1 to entry: This note applies to the French language only.

3.5.3

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 60700-1:2008. The front time is decided by means of system studies.

Note 2 to entry: This note applies to the French language only.

3.6

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 (IEC 60071-1)

3.7

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. 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 60071-1:2006, 3.27]

3.8

withstand voltage

U_w

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

Note 1 to entry: For a.c. equipment, values of withstand voltages U_w are standardized as per IEC 60071-1. For HVDC equipment, there are no standardized values for the withstand voltages which 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 d.c. equipment (e.g. the thyristor valves), the standard impulse shapes may be modified in order to more realistically reflect expected conditions.

3.8.1

switching impulse withstand voltage

SIWV

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

Note 1 to entry: This note applies to the French language only.

3.8.2

lightning impulse withstand voltage

LIWV

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

Note 1 to entry: This note applies to the French language only.

3.8.3**steep-front impulse withstand voltage****STIWV**

withstand voltage of insulation with the shape specified in IEC 60071-1

Note 1 to entry: This note applies to the French language only.

3.9**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 60099-4:2004, 3.9]

3.10**continuous operating voltage of an arrester including harmonics** **U_{ch}**

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

Note 1 to entry: It may be noted that this definition only pertains to coordination of arrester protective levels and not to assessing arrester energy duty.

3.11**crest value of continuous operating voltage****CCOV**

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

See: Figure 5.

Note 1 to entry: This note applies to the French language only.

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

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

See: Figure 5.

Note 1 to entry: This note applies to the French language only.

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

Note 1 to entry: This note applies to the French language only.

3.14**residual voltage of an arrester**

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

[SOURCE: IEC 60099-4:2004, 3.36]

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

Note 1 to entry: This note applies to the French language only.

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

Note 1 to entry: This note applies to the French language only.

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

Note 1 to entry: This note applies to the French language only.

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**thyristor valve protective firing**

method of protecting the individual thyristors from excessive forward voltage stresses across individual thyristors, by firing them

3.19**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 60815-1: 2008, 3.1.5]

3.20

unified specific creepage distance

USCD

creepage distance of an insulator divided by the r.m.s. value of the highest operating voltage across the insulator

Note 1 to entry: This definition differs from that of specific creepage distance where the line-to-line value of the highest voltage for the equipment is used.

Note 2 to entry: For ' U_m ' see IEC 60050-604:1987, 604-03-01 [5]¹.

Note 3 to entry: It is generally expressed in mm/kV and usually expressed as a minimum.

Note 4 to entry: This note applies to the French language only.

[SOURCE: IEC/TS 60815-1:2008, 3.1.6]

3.21

separation distance

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

4 Symbols and abbreviations

4.1 General

The list covers only the most frequently used symbols and abbreviations, some of which are illustrated graphically in the single-line diagram of Figure 1 and Table 2. 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_{di0}	ideal no-load direct voltage (IEC 60633)

¹ Numbers in square brackets refer to the Bibliography.

U_{di0m}	maximum value of U_{di0} taking into account a.c. voltage measuring tolerances, and transformer tap-changer offset by one step
U_s	highest voltage of an a.c. system (IEC 60071-1 and 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	standard withstand voltage
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)

4.4 Abbreviations

CCC	capacitor commutated converter
CSCC	controlled series compensated converter
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

5 Typical HVDC converter station schemes

Figure 1 shows the single line diagram of typical HVDC converter stations equipped with two 12-pulse converter bridges in series. It may be noted that Figure 1 shows possible arrester locations covered in this standard. Some of these arresters may 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, may change accordingly.

The a.c. and d.c. filter configurations could be more complex than those shown in these figures.

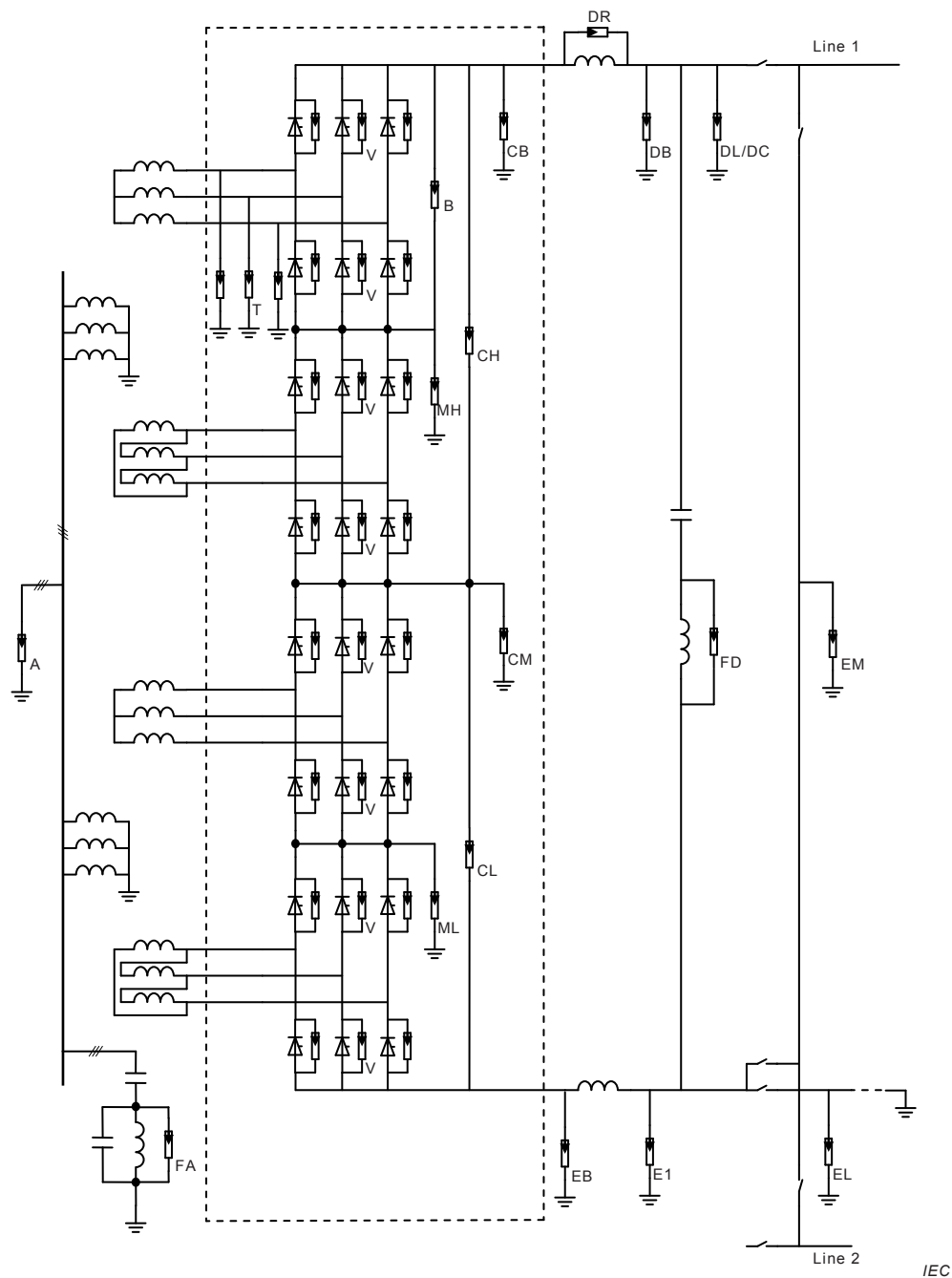
Table 2 presents the graphical symbols used in this standard.

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 may be considered at 800 kV and above to lower the insulation levels especially to the top valve group.

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

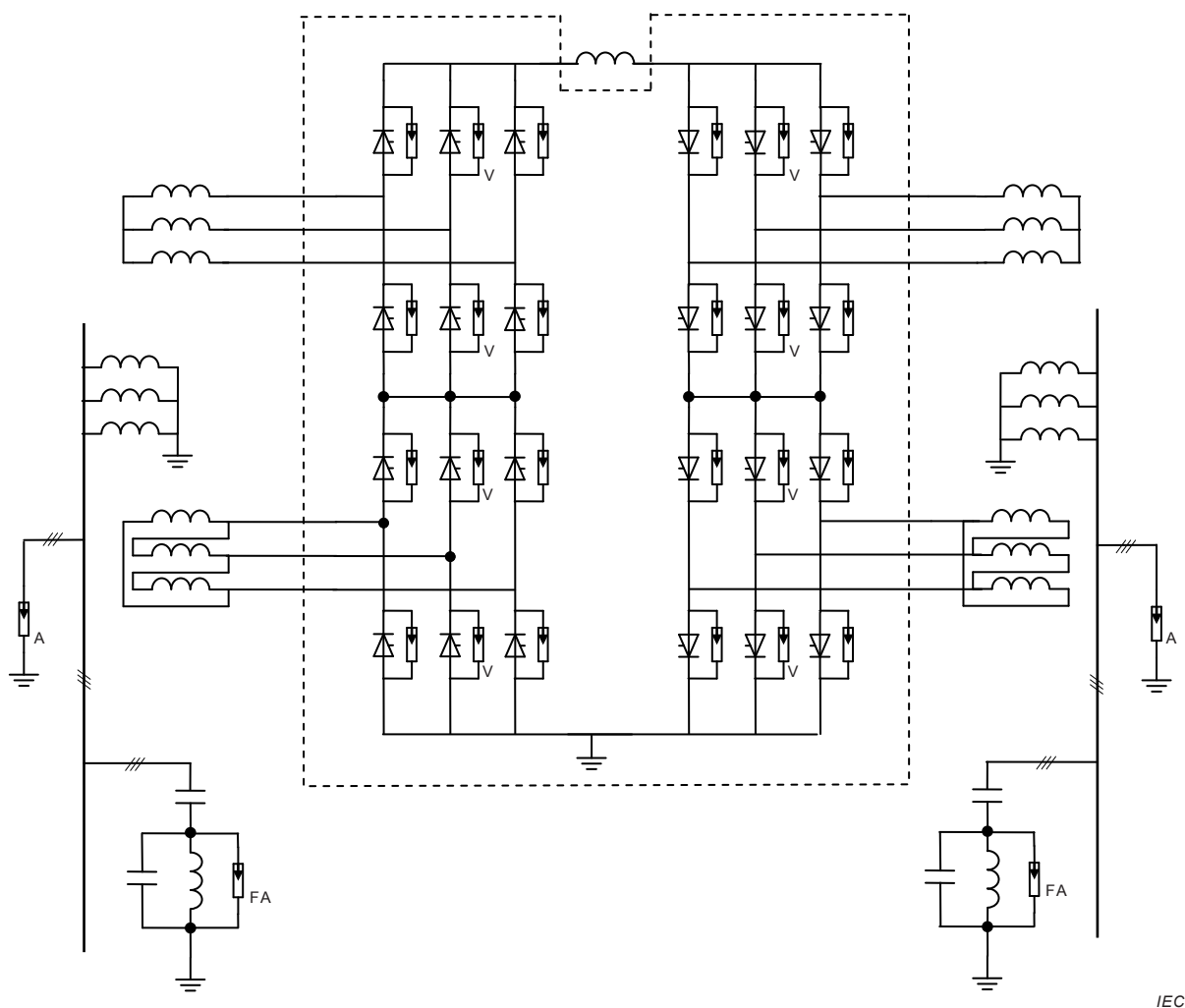
Arrester designations and details on their design and specific roles are presented in Clause 8.



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 d.c. 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
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 1 – Possible arrester locations in a pole with two 12-pulse converters in series

**Key**

A: AC bus arrester

FA: AC filter arrester

V: Valve arrester

Figure 2 – Possible arrester locations for a back-to-back converter station**Table 2 – Symbol description**

Symbol	Description
	Valve (commutation group)
	Valve (one arm)
	Arrester
	Reactor
	Capacitor
	Transformer with two windings
	Earth

6 Principles of insulation co-ordination

6.1 General

The primary objectives of insulation co-ordination are:

- to establish 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.

6.2 Essential differences between a.c. and d.c. systems

The insulation co-ordination applied to an HVDC converter station is basically the same in principle as that of an a.c. 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 (see also 8.3.5.4);
- c) the presence of reactive power sources and harmonic filters on both the a.c. and d.c. 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 d.c. side;
- e) the presence of converter transformers with the valve side not directly connected to earth potential, and a d.c. 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 d.c. stress which, by attracting greater contaminants to the d.c. insulation because of constant polarity, lead to greater creepage and clearance requirements and to worse pollution and flashover performance compared with a.c. insulation under the same environment;
- j) interaction between the a.c. and d.c. systems, particularly where the a.c. system is relatively weak;
- k) the various operating modes of the converter such as monopolar, bipolar, parallel or multi-terminal;
- l) no standard insulation levels exist in the case of d.c. systems.

6.3 Insulation co-ordination procedure

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

- a) selection of the d.c. circuit configuration, for example location of the d.c. smoothing reactors, location of the d.c. side earthing, converter transformer valve winding connection (star or delta) to the higher d.c. voltage terminal;
- b) selection of arrester arrangement according to the selected d.c. circuit configuration;

- c) evaluation of the characteristics of the a.c. system at the commutation bus and the d.c. 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.

6.4 Comparison of withstand voltage selection in a.c. and d.c. systems

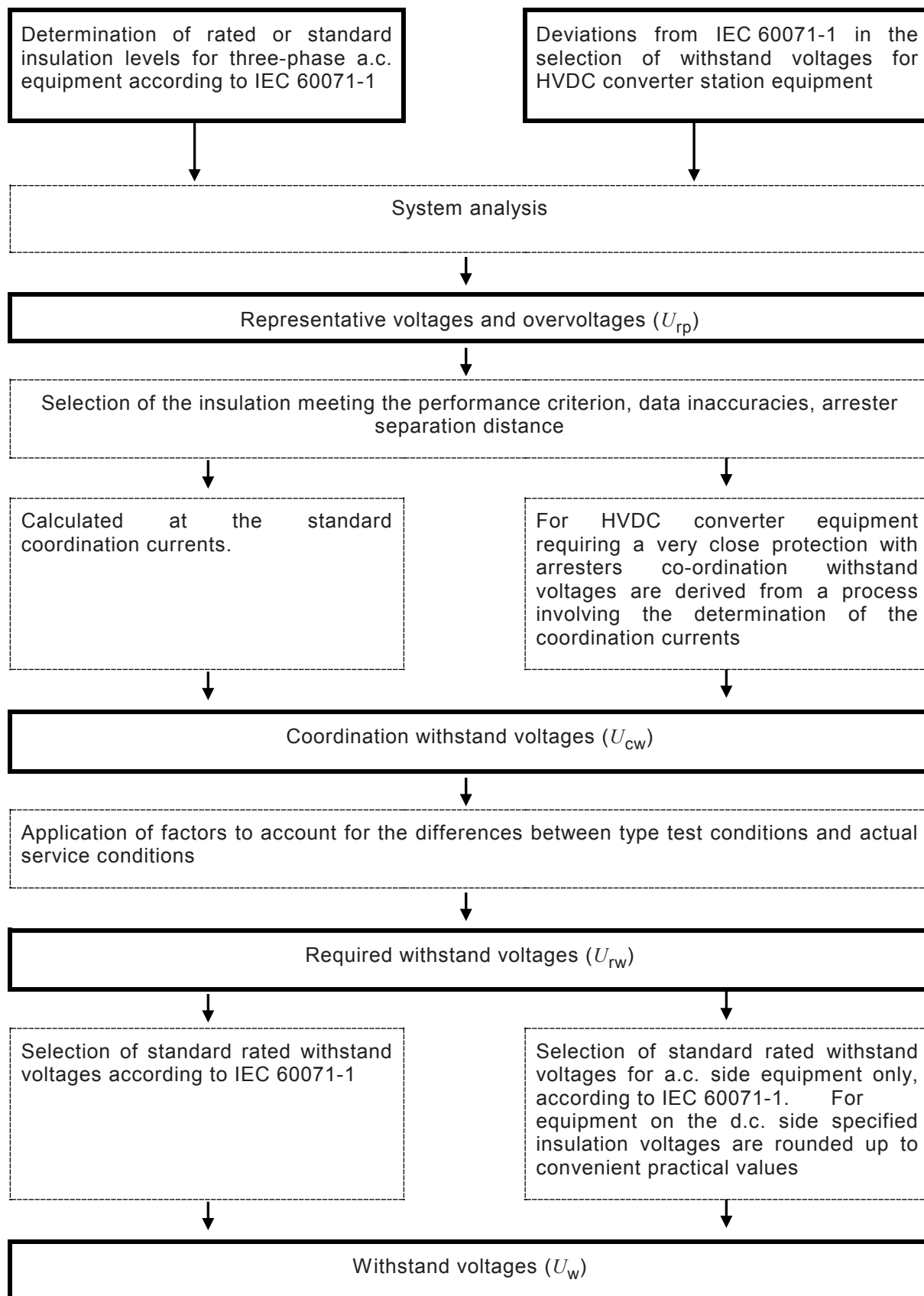
As described in IEC 60071-1 there are four main steps in the insulation coordination procedure which can be identified as below:

- 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 withstand voltages (U_w)

Table 3 is a flow chart showing the procedure in selecting the withstand voltages (U_w) in both a.c. (Figure 1 of IEC 60071-1:2006) and d.c. systems with the differences in the d.c. case being identified.

The individual steps involved in the selection process are detailed in IEC 60071-1 for the a.c. system application and in Clause 9 of this standard for the d.c. system.

Table 3 – Comparison of the selection of withstand voltages for a.c. equipment with that for HVDC converter station equipment



7 Voltages and overvoltages in service

7.1 Continuous operating voltages at various locations in the converter station

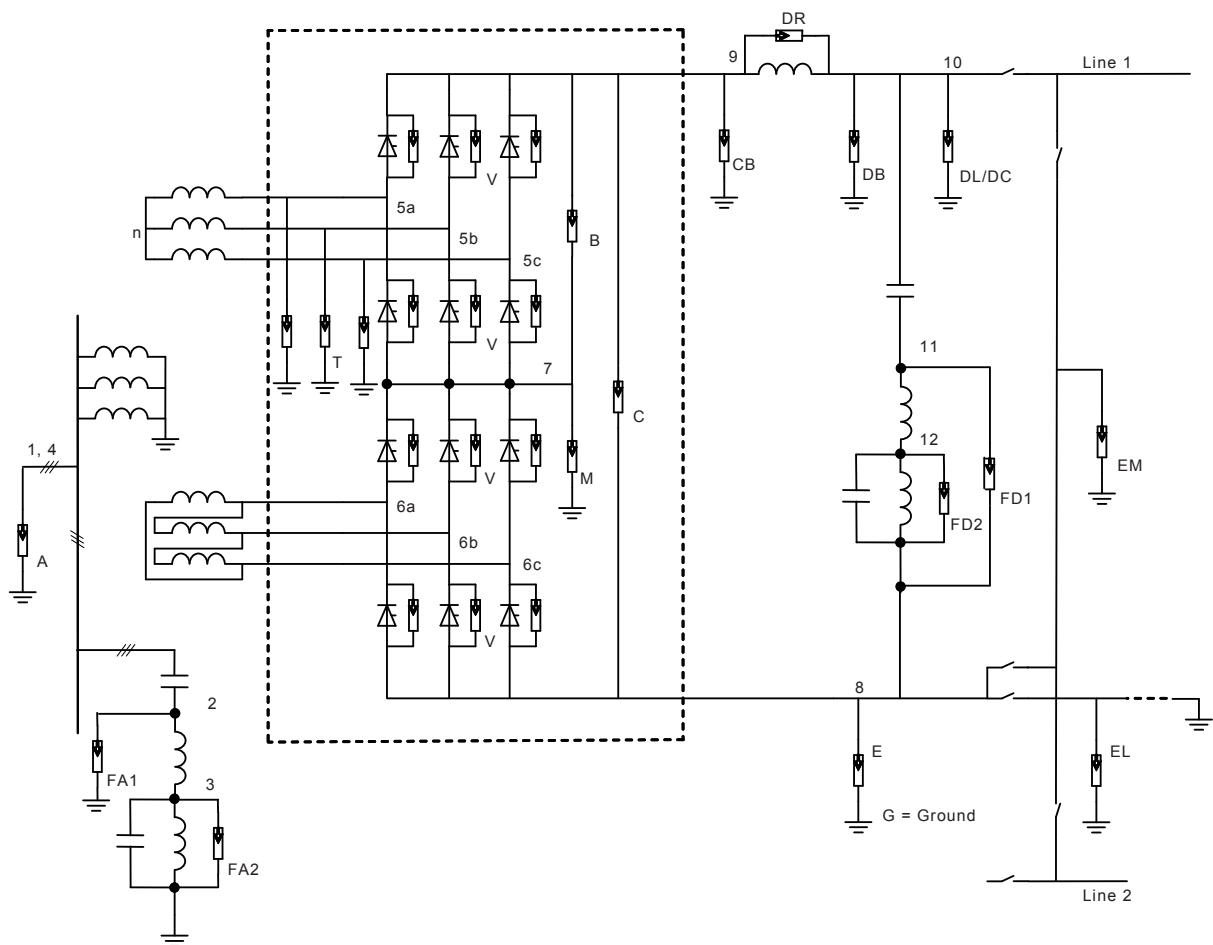
The continuous operating voltages at various locations in an HVDC converter station differ from the a.c. system in that they consist of not simply the fundamental frequency voltages. They could be a combination of direct voltage, fundamental frequency voltage, harmonic voltages, and high frequency transients,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

Figure 3 shows an HVDC converter station with one single 12-pulse converter per pole configuration. In general phase-earth arresters on the valve side of the converter transformer (T) are not provided for HVDC schemes up to 600 kV.

Figure 1 shows an HVDC scheme with two 12-pulse converters per pole configuration, which has been used for the early 600 kV scheme and some of the recent 800 kV schemes.

Figure 4 shows typical waveforms of continuous operating voltages excluding commutation overshoots at various locations in the 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 d.c. parameters.

Note that Figures 1, 2 and 3 show possible arrester locations, and some of them may be eliminated because of specific designs.

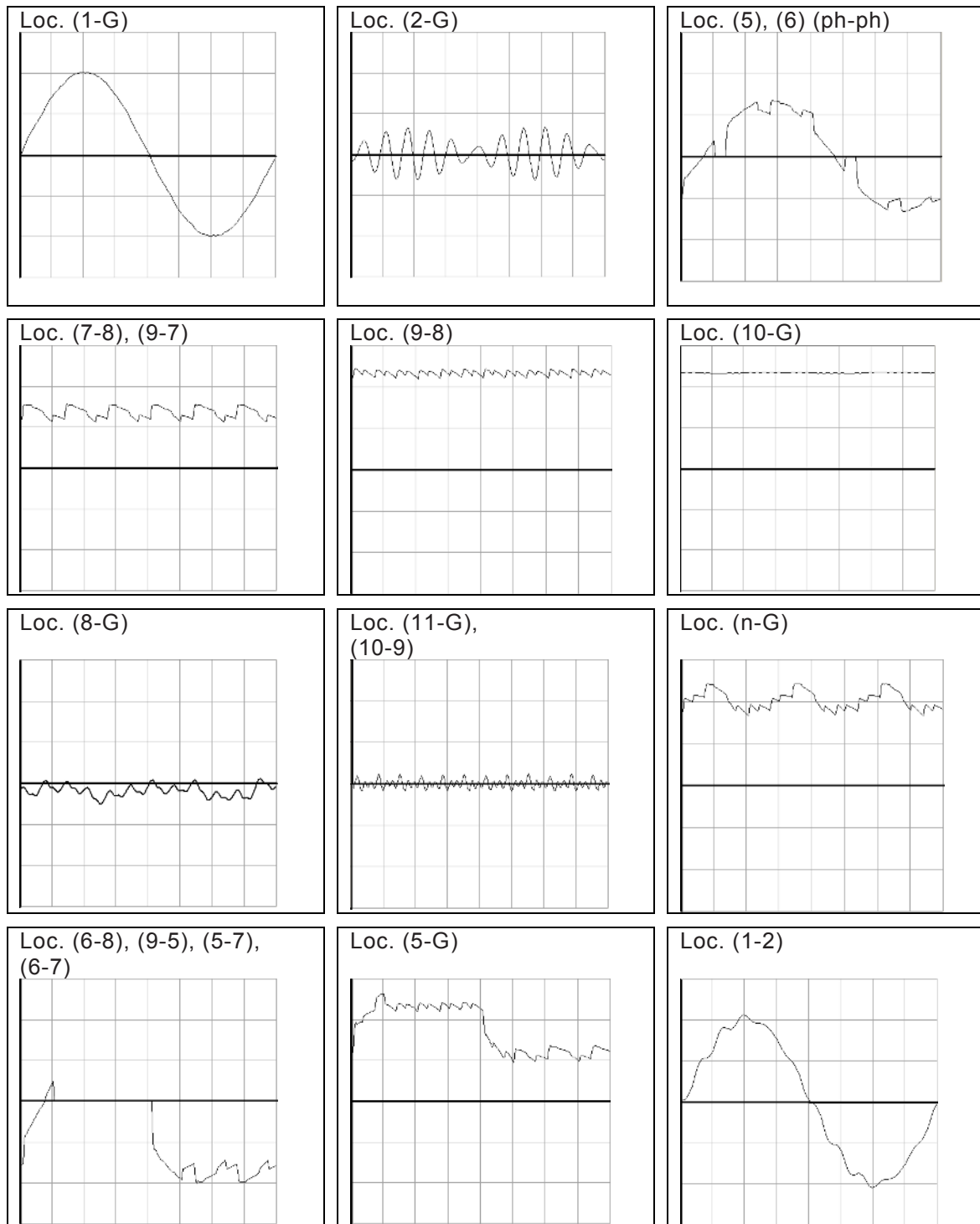


IEC

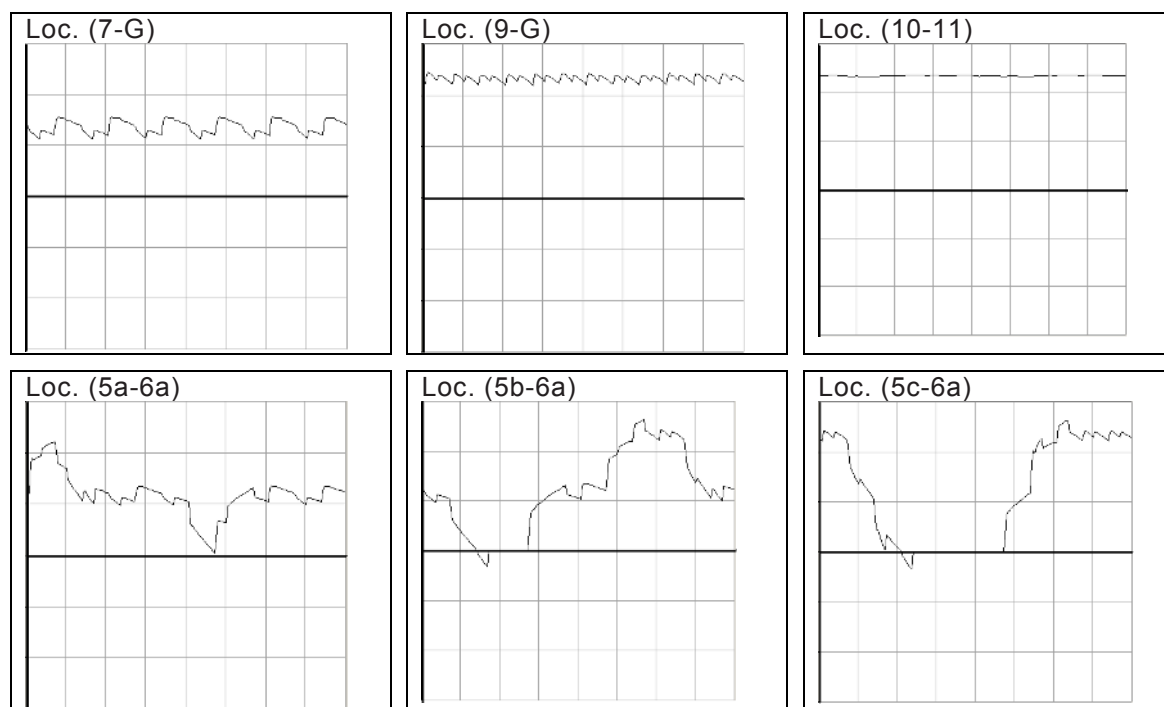
Key

A: AC bus arrester	EM: Metallic return arrester
M: Mid-point bridge arrester	EL: Electrode line arrester
E: DC neutral bus arrester	B: Bridge arrester (6-pulse)
V: Valve arrester	C: Converter unit arrester
T: Transformer valve winding arrester	DB: DC bus arrester
DR: Smoothing reactor arrester	DC: DC cable arrester
DL: DC line arrester	FD1, FD2: DC filter arresters
FA1, FA2: AC filter arresters	

Figure 3 – HVDC converter station with one 12-pulse converter bridge per pole



IEC



IEC

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

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

Voltage shape at (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 d.c. voltages across the bridges consisting of about 60° arcs of line-line a.c. voltages ($60^\circ - \mu$, 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 d.c. offset will be superimposed.

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

The voltage across the 12-pulse bridge 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 d.c. 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 d.c. offset especially during monopolar metallic return operation.

The voltage at location (n-G) has a d.c. 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.

7.2 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 recovered 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.

Special attention shall be paid to the commutation overshoots, including wave shape with respect to power dissipation in the valve arresters and other arresters on the d.c. side.

The continuous operating voltage waveform across the valve (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_{di0m} , and is given by:

$$CCOV = \frac{\pi}{3} \times U_{di0m} = \sqrt{2} \times U_{v0}$$

Refer to 4.3 for the definition of U_{di0m} 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.