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Sizing and testing of HVDC disconnectors from the dielectric point of view

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SUMMARY

Disconnectors for HVDC application shall comply with DC constraints and requirements. General DC specifications are given in the DC insulation coordination Guide (IEC60071-5 [1]), presently under revision [2] [3] within IEC TC 99 taking into account DC VSC-LCC system evolution and future multiterminal applications. Standardization of design and testing of DC disconnectors is in progress within TC 17/SC 17A/WG 66. The target of the working group is to compile technical specification for disconnectors (IEC TS 62271-314 [4]) as a part of IEC TS 62271-5 "Common specification of High-voltage switchgear and control gear in HVDC" [5]. The present paper intends to contribute to the standardization work, with special attention to design and testing of disconnector under continuous voltage and overvoltages. The paper deals only with air insulated disconnectors, with special focus to the EHV-UHV range (250-1000 kV range) .

The need of voltage values standardization is firstly pointed out. The Lightning Impulse (LI), switching impulse (SI) and DC withstand voltages values proposed and under discussion within IEC TC 99 and IEC TC 17 WGs are analysed, at the light of values adopted in 37 worldwide projects. The proposed values of Rated Switching Impulse Withstand Voltage RSIWV and Rated Lightning Impulse Withstand Voltage RLIWV is very (too) large. The need of univocal definition of the Highest System Voltage Um and of a limited number of rated voltage is pointed out from the point of view of equipment design and interchangeability.
As far as the performance of the disconnector open gap, the necessity to clearly define the cases where a DC voltage is to be foreseen at the terminal opposed to the impulsed one is pointed out, to avoid useless general prescriptions, leading to complex "bias" tests.

Starting from the proposed voltage rating and from the applicable insulation performance, the required phase to ground and longitudinal insulation clearances are derived for system voltage up to the UHV range. The evaluation is performed considering disconnectors for indoor and outdoor use and application of ceramic and composite solutions for the phase to ground insulations. Examples of UHVDC disconnector solutions developed on the basis of the above approach are reported.

Indications about the minimum disconnector sizing are given based on tests carried out by GE, results of previous tests and calculation approaches set up within CIGRE WGs.
The minimum phase to ground clearances to satisfy SI requirements are given. Within the voltage range considered (250-1000 kV) they also satisfy LI requirements., thus determining the design for the disconnector for indoor applications. For outdoor applications pollution generally dominates the design. Indications about the insulator size to comply with pollution requirements are given, indicating that for very heavy contamination extreme insulator lengths would be necessary, at the limit of feasibility.

Finally, indications about the minimum necessary open gap clearances are given considering both the case of the opposite terminal earthed and the presence of a DC voltage on the opposite terminal. Again, SI requirements result determinant, suggesting that LI tests would be not necessary to verify the design adequacy.

KEYWORDS

HVDC – EHV DC – UHV DC – DISCONNECTOR –SWITCHING IMPULSE – LIGHTNING IMPULSE – POLLUTION – DESIGN– TESTING – OPEN GAP

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1 INTRODUCTION

Disconnectors for HVDC application shall comply with DC constraints and requirements. General DC specifications are given in the DC insulation coordination Guide (IEC60071-5 [1]), presently under revision [2] [3] within IEC TC 99 taking into account DC VSC-LCC system evolution and future multiterminal applications. Standardization of design and testing of DC disconnectors is in progress within TC 17/SC 17A/WG 66. The target of the working group is to compile technical specification for disconnectors (IEC TS 62271-314 [4]) as a part of IEC TS 62271-5 “Common specification of High-voltage switchgear and control gear in HVDC” [5]. The present paper intends to contribute to the standardization work, with special attention to design and testing of disconnector under continuous voltage and overvoltages.

The paper will deal only with air insulated disconnectors, with special attention to the EHV-UHV range (250-1000 kV range) .

2 HVDC DISCONNECTOR OVERVIEW

In a DC system, various types of disconnectors may be identified such as HVDC Line Disconnectors, HVDC Earthing Switch, By-Pass Disconnector, Transfer Bus Disconnectors, HVDC Filter Disconnector and Valve Hall Earthing Switch.

Disconnectors for HVDC applications are designed with reference to the specific constraints and requirements typical for DC applications, quite different from those for AC applications.

Different disconnector technical solutions are available, e.g., knee type, centre break and vertical break solutions. Knee type disconnectors consist of one articulated arm which, by moving “horizontally” on the plane of the insulators, closes the circuit on a fixed contact located on the side insulator. Centre break disconnectors consist of two arms, with breaking at the centre. Vertical break disconnector is not widely used for DC. Examples of DC adopted solutions are reported in Figure 1. A double arm knee type solution, Figure 1 b, was adopted to guarantee the necessary reliability of the disconnector for UHV application, implying very large open gap.

The paper will concentrate on the performance of type disconnectors with horizontal insulating gap.

a) Single arm knee type disconnector for 800 kV

b) Double arm knee type disconnector for 800 kV in altitude

Figure 1 Examples of disconnectors for DC applications

3 BASIC INSULATION COORDINATION

The "highest DC voltage" Um that is the 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, Um depends on the nominal voltage of the Scheme, normally dictated by the customer requirements. It is determined by steady-state studies considering the DC Power Flow, harmonics present due to the operation of the converter and voltage drops depending on the location of each disconnector. This voltage may contain a superposition of AC and DC components. The peak of that superposition is considered as Um.

A minimum ratio between the Switching Impulse Protective Level (SIPL) of the surge arrester and Um of around 1.7 is assumed in order to avoid the risk of overheating of the surge arresters. Once the SIPL is determined on that base, the Lightning Impulse Protective Level (LIPL) is determined considering typical surge arrester curves. Safety margins according to the IEC-60071-5 standard or customer specifications are applied to determine the minimum requirement for withstand levels.

The energy of the surge arresters is determined by time-domain studies, simulating events that produce switching impulses. Multiple surge arrester columns may be required to ensure that the Switching Impulse Protective Levels are not exceeded at any point of the scheme under any of the conditions simulated.

The withstand level required across the open disconnector is determined considering the worst combination of the overvoltage in one side of the disconnector and of the DC voltage the on the other side. This is applicable to disconnectors that may be energised at both terminals in continuous operation, for example, a DC Busbar Disconnector (number 2 in the Figure 2) or Transfer Bus Disconnector (number 3 in the Figure 2) in VSC Bipole Schemes. For disconnectors that have only one end energised in continuous operation, for example the DC Line Disconnector (number 1 in the Figure 2) a 10% of the nominal voltage is considered in the de-energised terminal to account for remanent voltage in the HVDC cable.

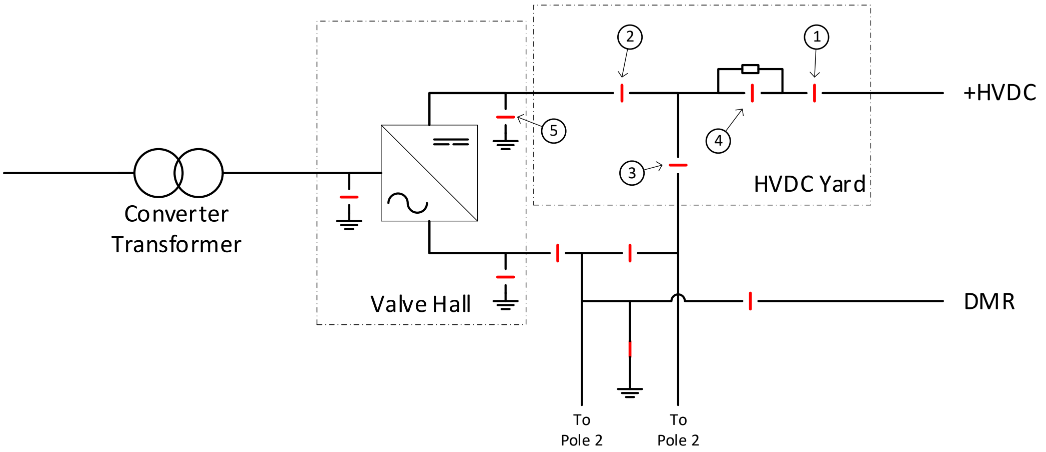


Figure 2. Simplified diagram of a HVDC VSC Bipole

4 STRESSES

DC insulation coordination is presently under the responsibility of IEC TC 99. The last working document [2] defines

- the "nominal DC voltage" as the mean value of the DC voltage required to transmit nominal power at nominal current, Un
- the "highest DC voltage" as the 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, Um

Furthermore, reports tables with "typical DC voltage values" and related Rated Switching Impulse Withstand Voltage RSIW and Rated Lightning Impulse Withstand Voltage RLIWI values. The document does not specify if the "typical DC voltage" is to be intended as "nominal DC voltage" Un

or “highest DC voltage” Um. The “typical” RSIW and RLIWI values from [2] are reported in Figure 3. The same Figure reports the RSIWV values reported in [6], based on “nominal voltage of some HVDC projects worldwide”. Field experience [6] seems to confirm that RSIWV value in the range 1.9-2.1 p.u. generally represents system needs, against the large spread of values suggested in [2], ranging from 1,8 to more than 2,5. A correct definition of the RSIWV is very important in the EHV and UHV range, since insulations designed for SI also comply with LI requirements,
The number of RLI WV levels proposed in [2] is even larger with a larger spread, ranging from 1,8 to 2,9. as shown in Figure 4.

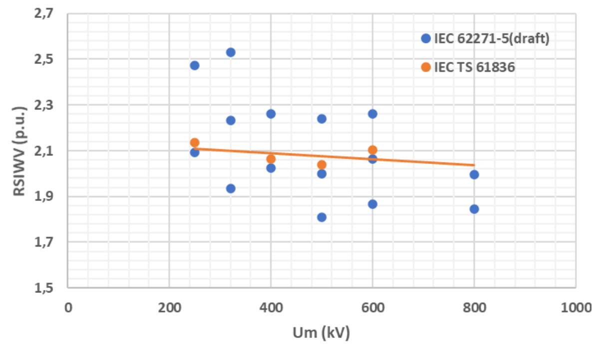


Figure 3 RSIWV values proposed in [2], [5], [6]

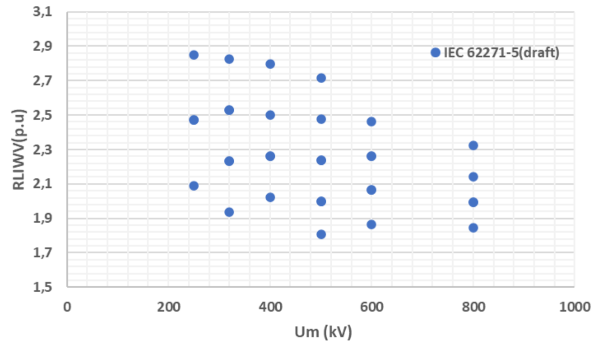


Figure 4 RLIWV values proposed in [2], [5]

As a support to define the required insulation levels, analysis of the values of RSIWV, RLIWV adopted for various projects in the world has been made, considering a larger number of cases than those considered in [6] : the analysis concerned 23 line commutated converter LCC projects and 14 voltage source converter VSC projects, made by different companies in different times. A summary of the values obtained is reported in Table 1.

Table 1 Summary of the values adopted in 37 projects worldwide

	RSWV avg (min-max) [p.u.]		RLIW avg (min-max) [p.u.]	
	LCC	VSC	LCC	VSC
V < 500kV	**2.32(2.11-2.53)**	**2.15(1.55-2.91)**	**2.72(2.61-2.83)**	**2.59(1.79-3.6)**
500kV < =V <= 600kV	**2.08(1.84-2.31)**	**1.90(1.73-2.04)**	**2.53(2.04-2.83)**	**2.30(2.09-2.63)**
V > 600kV	**2.04(1.95-2.15)**	**-**	**2.47(2.20-2.75)**	**-**
Total project n°	23	14	23	14

The analysis has confirmed that the adopted insulation levels for the different projects are very spread, as indicated in [2], reflecting the different design approaches of the different companies and data of old projects and of more updated new projects. Furthermore, the data confirm a trend to use lower values for VSC than for LCC and decreasing values for higher Um values.
The conclusion is that the approach in [2] gives a picture of all the solutions adopted in the world, without a critical and rationalising approach. A more rational approach which could facilitate equipment standardization. would be to analyse the experience in more detail, considering the applicable values based on the most recent knowledge and design evolution and the needs for the different project types (e.g., LCC or VSC), with the aim to reduce the number of insulation levels.

Insulation coordination of high voltage switchgear and control gear (including disconnectors) are presently under the responsibility of IEC TC 17. The last working documents [4] [5] take as a basis the same tables in [2], but:

- Assuming that the “typical values” in [2] , representing just a picture of the many choices made in the world, can be directly proposed as standardised values, without any rationalisation.

- Making the additional assumption that the “typical” DC system voltages in [2] are the nominal DC voltages.
- Defining a new parameter, the “rated DC voltage” Urd (which would have practically the role of Um for equipment). According to [4] [5] “the rated DC voltage Urd is typically 105 % of the nominal DC voltage of the system. Depending of the configuration of the DC System, other percentages might be reasonable, i.e., higher values like 110 % or lower values like 102 %”.

The absence of a univocal Um definition [4] [5] would make problematic the standardization and interchangeability of the equipment. A rational standardization of DC equipment necessitates to define univocally the reference highest voltage for equipment, Um, as for AC [7] [8]. Then, as in AC, the system nominal voltage Un may be taken lower than Um, differing by 5% or more as required by specific projects, taking into account the considerations in [9]. Reference to Um allows the disconnector manufacturers to propose the same products independently of the selected nominal voltage of the system, which could vary project by project.

The above analysis refers to values which are to be withstood by the disconnector both in closed and open conditions. Furthermore, for the open condition the possibility of the presence of a DC voltage on the other terminal may need to be considered, as mentioned in [4] [5]. In particular for multiterminal HVDC transmission systems, the LI and SI overvoltage may occur with the other terminal fully energized with DC voltage. For two-terminal HVDC transmission systems marginal DC voltages on the other terminal (e.g., 10 % of rated DC voltage) may need to be taken into consideration, depending on the disconnector function. The disconnector applications needing bias tests should to be clearly identified, to avoid unnecessary tests and again to rationalise the standardisation.

5 DISCONNECTOR SIZING

Indications about the minimum disconnector sizing will be given based on tests carried out by GE (see examples of configurations representative of UHV solutions in Figure 5) , results of previous tests [10] [11], [12] and calculation approaches set up within CIGRE WGs [13].

Mock-up of 800 kV disconnector. Tests at Graz University laboratory

Mock-up of 1000 kV disconnector. Tests at FGH (CESI) Laboratory

Figure 5 Examples of disconnector mock-up under test

The following most critical stress conditions, determining the disconnectors design, are considered:

- withstand under negative continuous DC voltage (more critical than positive) under pollution conditions
- withstand under impulses of positive polarity (more critical than negative) for the assessment of the necessary arcing distance

In the following reference to the disconnector scheme in Figure 6 will be made. Where

- Hs is the clearance to ground
- Hg is the height of the supporting structure
- H is the total height (Hg+Hs)
- D is the isolating distance between terminals

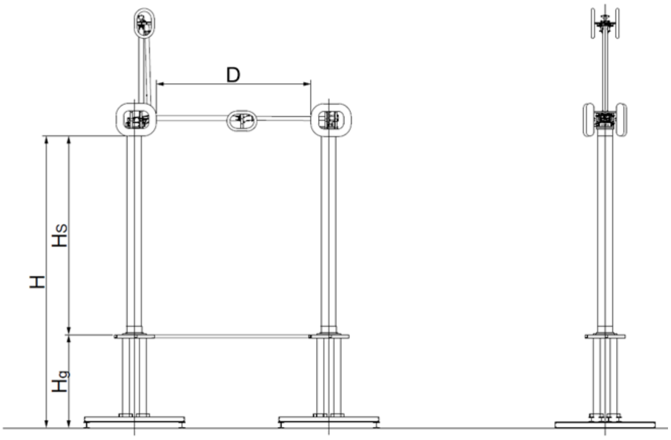


Figure 6 Disconnector scheme

5.1 *Phase to ground sizing*

SI and LI overvoltages are superimposed to DC voltage, however, as for AC, the impulse performance is not significantly influenced by the DC pre-stress [13] , [14]. Thus, reference only to the impulse voltage value will be made in the following, as in AC.

5.1.1 Switching impulse performance

The 50% flashover voltage phase to ground value U50 under standard Switching Impulses (SI) in dry conditions may be evaluated according to the equation:
$U_{50}= 500*D^{0,6}*Kg$ (1)
With $Kg= 1+0,6*Hg/H$ (2)
The withstand voltage U_w is evaluated as:
$U_w=U50*(1-1,3\sigma)$ with $\sigma=6\%$ for SI. (3)
The comparison between experimental Uw values [10] and calculation results , is shown in Figure 7 , confirming the accuracy of the formula.
The experimental SI withstand values obtained with different actual disconnectors, characterized by different Hg values, is reported in Figure 8 as a function of the arcing distance (insulator length). Due to the different Hg values, the actual experimental gap factors values range from 1.1 to 1,4. The same Figure reports the Uw value evaluated with a gap factor of 1,1, as suggested in [7].

The evaluation with a gap factor of 1.1 leads to conservative results, taking into account aspects as the possible reduction of the withstand voltage under rain for outdoor disconnectors.
For DC disconnectors for indoor applications, where the space constraint is important, design optimisation is recommended, considering the actual applicable gap factors.
As an example, Figure 9 reports the required Hs values for the different RSIWV, assuming two height values of the basement.

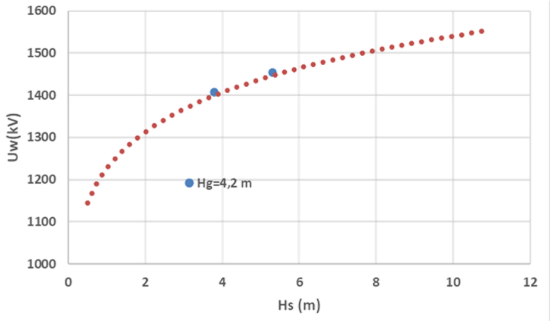


Figure 7 SI. Comparison between computed and experimental data (mock up in Figure 5)

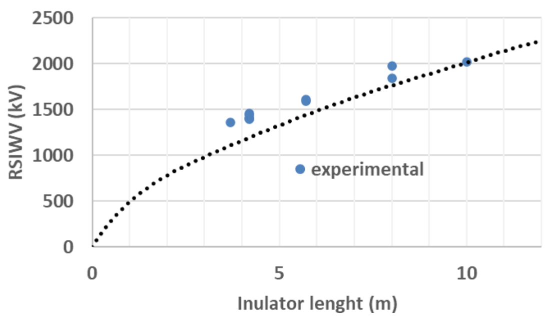
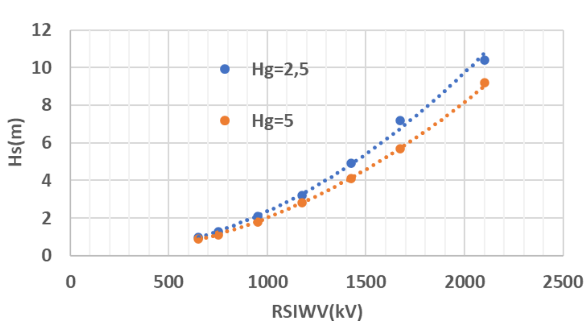


Figure 8 SI Comparison between experimental data and computations, assuming a conservative gap factor of 1.1



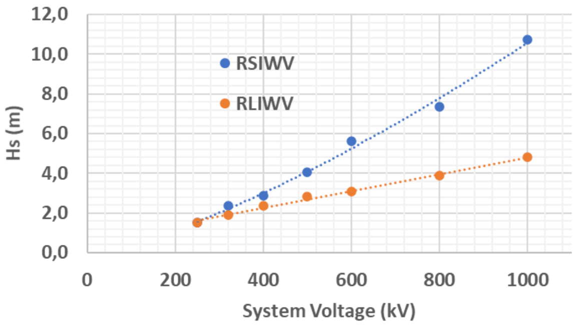


Figure 9 Required insulator length with different values of Hg.

Figure 10 Comparison of SI and LI requirements

5.1.2 Lightning impulse performance

Conservatively a withstand voltage of 500 kV per meter is assumed for standard lightning impulse, LI [7].The comparison between the SI/LI requirements for the different system voltages, with the maximum values RSIWV and RLIWV assumed in [5] is reported in Figure 10. It is evident that the phase to ground distance assessed under SI satisfies conservatively also LI requirements. Thus, in principle LI tests would not be necessary to verify the adequacy of the phase to ground clearance.

5.1.3 Pollution performance

Pollution classes are not defined for DC [15]. A class definition can start from [16], making however reference to measurements of equivalent salt deposit density ESDD and non-soluble deposit density NSDD on DC energized insulators.

In particular reference to Figure 11 from [16] is made.

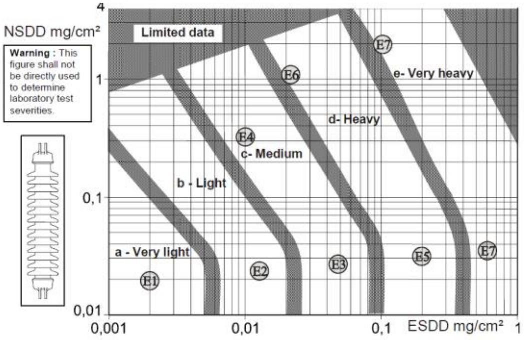


Figure 11 Relation between ESDD/NSDD and pollution class for rod type insulator [16]

To obtain the necessary RUSCD values reference to results of standardized test is to be made. In particular solid layer tests [17] are made vi variable values of SDD (salt deposit density) and fixed values of NSDD (corresponding to about NSDD=0,1 mg/cm^2). Thus, the classes should be "translated in terms of the laboratory parameter SDD: this is made assuming for each of the classes in Figure 11, SDD equal to the maximum ESDD for the condition of NSDD=0,1 mg/cm^2. The SDD values are reported in Table 2, together with the corresponding RUSCD value evaluated according to the formulas reported in [15], [18].

Table 2 Relation SDD/ pollution class and corresponding RUSCD

pollution class	SDD (mg/cm^2)	RUSCD ceramic (mm/kV)	RUSCD polymeric (mm/kV)
very light	0,002	14	14
light	0,01	24	21
medium	0,05	41	31
heavy	0,25	70	46
very heavy	1	110	65
extreme	>1	>110	>65

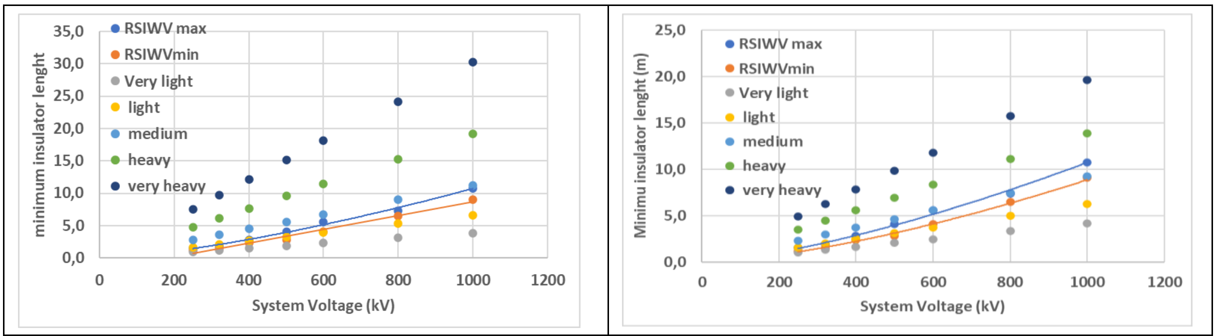
The necessary insulator length as a function of the system voltage for ceramic and polymeric insulators are reported in Figure 12 a) and Figure 12 b) respectively, assuming the use of insulators with average diameter lower than 300 mm and a creepage factor (ratio between creepage distance and insulator length) of 4. The evaluation is made with a USCD value equal to 1.1 RUSCD, taking into account the creepage factors influence.

In the same Figures the insulator length required by SI, based on the maximum and minimum RSIWV values in [4] [5] are reported.

Data for ceramic (porcelain and glass) indicate that for pollution classes equal to medium or above pollution dominates the design. Furthermore, the insulator lengths required for heavy and very heavy pollution are very high, limiting the apparatus feasibility at least in the upper voltage range.

For polymeric solutions pollution dominates the design only for heavy and very heavy conditions. Again, for very heavy pollution conditions the required insulator lengths are very high limiting apparatus feasibility for the upper voltage range.

In general, for heavy and very heavy conditions advantages and feasibility and convenience of alternative outdoor and indoor solutions may have to be examined.



a) Porcelain insulators

b) Polymeric insulators

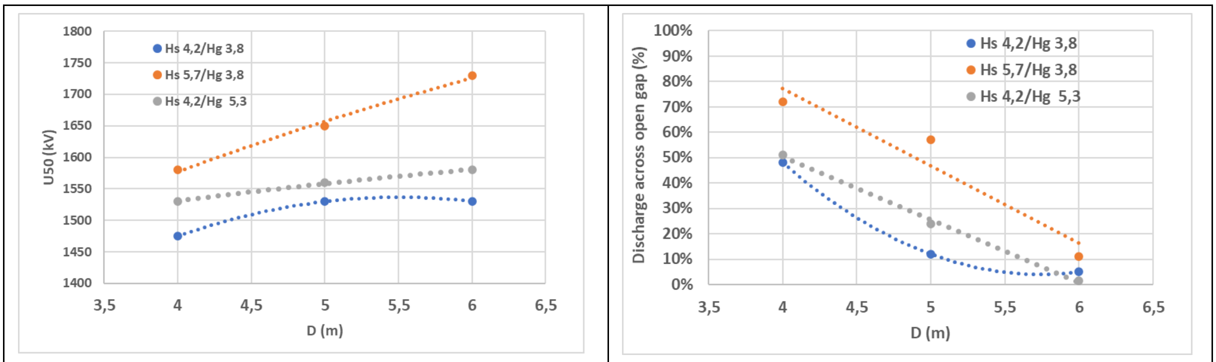
Figure 12 Minimum required Hs as a function of the system voltage. Comparison of SI and pollution requirements

5.2 *Open gap sizing with voltage applied to one terminal, the other earthed.*

As for phase to ground, reference will be made only to positive polarity impulses, being the most critical.

5.2.1 *SI performance*

Results of tests on the disconnector mock-up of Figure 6 at CESI laboratory [10] are reported in Figure 13. The flashover voltage depends not only on the parameter D but also on the parameter Hs and Hg. When D is larger than Hs (D=6 m case) most of the flashovers occurs phase to ground (at the stressed terminal) and the flashover voltage can be evaluated with equation (3). When D is lower than Hs, the percentage of flashovers across the open gap with respect to the total ones increases, becoming the majority when D is much lower than Hs.



a) 50% flashover voltage

b) Number of discharges across open gap in %

Figure 13 Results of SI tests on disconnector mock up

As indicated in [13] the 50% flashover voltage of the open gap under standard Switching Impulses (SI) for D<Hs may be evaluated according to the equation:
$U_{50}= 500*D^{0,6}*Kd$ (4)
With $Kd= 1,85- 0,1*Hg/H -D/H$ (5)
The withstand voltage U_w is evaluated as:
$U_w=U50*(1-1,3\sigma)$ with $\sigma=6\%$ for SI. (6)
Comparison between experimental U50 values and calculation is shown in Figure 14, confirming the accuracy of the formula, especially for D<<Hs,

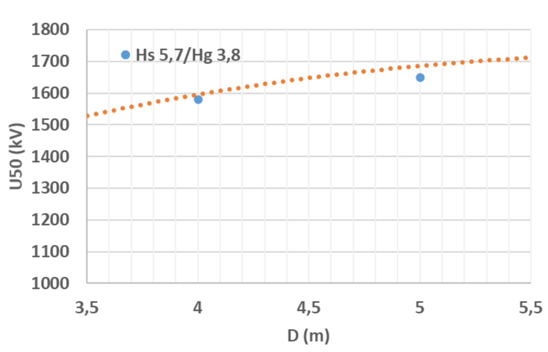


Figure 14 SI test results. Comparison calculation and experimental data for D<Hs

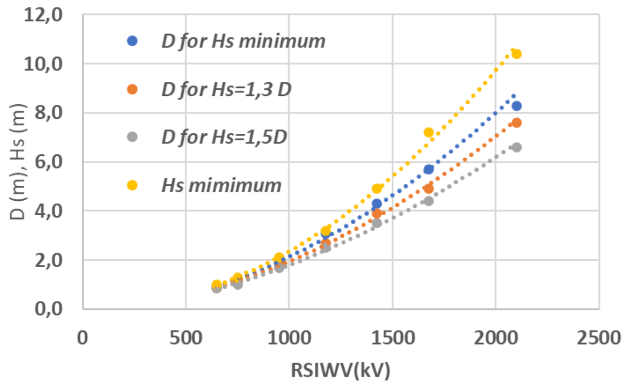


Figure 15 SI. Required D values for different Hs values (computed values)

The D value depends, among others, on the Hs values. As an example, the case of Hg=2.5 m is considered in Figure 15, reporting

- the minimum required Hs from the SI point of view
- and the necessary D value corresponding to the minimum Hs value and to higher HS values as required by pollution requirements.

The data in the Figure indicate that D is always lower than the required Hs value. When Hs is increased, e.g., due to pollution requirements, the D value could be potentially decreased, while maintaining the withstand requirements.

5.2.2 LI performance

Only the case of LI of positive polarity will be examined, more critical than negative.
For LI a withstand voltage of 550 kV/m [13], higher than for the value assumed for the phase to ground evaluation in paragraph 5.1.2, is assumed. Thus, as for the phase to ground clearance, SI requirements determines the open gap sizing and tests to verify the LI performance are, in principle, not necessary.

5.3 Open gap sizing with impulse voltage applied to one terminal, the other terminal energized with DC voltage (Bias Tests).

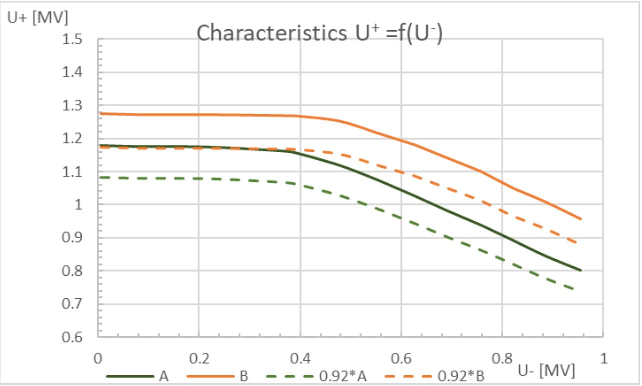
Reference will be made in the following only to the most critical condition (positive impulse on one terminal and negative DC on the other terminal).

5.3.1 Performance under positive SI and a negative DC

Results of tests performed on disconnector mock up applying Switching impulses of opposite polarity at the two terminals are reported in Figure 16, derived form [12] . The mock up geometrical characteristics and the test results are given in Table 3. It is assumed that the results can approximate also the expected results with SI+ DC-, since in the first part of the diagram, with U- much lower than U+, the discharge is governed by the positive impulse with the negative voltage just contributing to the electric field necessary for he discharge propagation [11].

The results with the other terminal earthed (U-=0), confirm the validity of the evaluation approach presented in par.6. At U-=0 nearly all the flashovers occur toward the earthed structure (percentage of flashovers toward the longitudinal insulation φ=0) being D> Hs.
When a DC voltage is applied on the other side the flashovers % on the air gap φ increases, with still a significant part on the impulsed terminal.

As an example, Object A results suitable for 400 kV system, with a RSIWV of 1050 kV and a full DC voltage of -400 kV (at U-=400 kV the SI withstand voltage results from Table 3 1058 kV). For Object B the SI withstand voltage equal to 1150 kV results at U-=500 kV applied at the other terminal, thus the solution is almost suitable for a 500 kV system with RSIWV of 1175 kV.



A: U_{50} withstand voltage ring-ring pedestals d=3m H=6m Hg=2.5m

B: U_{50} withstand voltage disconnector d=4m H=6,5 Hg=3m

$U_w=U_{10}^{sw}=0.92\times U_{50}^{sw}$

Figure 16 U50 and Uw (U50*0,92) at the positively stressed electrode as a function of the negative voltage applied at the other electrode.

Table 3 Bias Tests. Disconnector mock up geometrical characteristics and results from [12]

Test object	Laboratory	D	H	Hg	Hs	U50 (U-=0) exper.	U50(U-=0) Comp.	Uw(U-=0) exp.	U-	U50(at U-)	U50+U-	gap factor K	Uw (at U-)	(Uw)+U-
A	FGH	3	6	3,5	2,5	1180	1170	1086	400	1150	1550	1,6	1058	1458
B	CESI	4	6,5	3	3,5	1300	1354	1196	500	1270	1770	1,54	1150	1650

The equivalent experimental gap factor for the bias voltage results in the range 1,54-1,6.
The necessary clearances for the different system voltages by associating the DC voltage to the minimum value of SI as from [4] [5] (as expected for multi-terminal VSC systems) are reported in Table 4 where the necessary clearance has been evaluated assuming conservatively a gap factor of 1,4 as suggested in [13]. For more accurate and less conservative evaluation the calculation procedure suggested in [12] can be applied, allowing to draw curves like those in Figure 16.

Table 4 Conservative evaluation of the necessary clearance D in case of Bias tests

DC	SI	DC+SI	D
(kV)	(kV)	(kV)	(m)
250	550	800,0	1,44
320	650	970,0	1,98
400	850	1250,0	3,02

DC	SI	DC+SI	D
500	1050	1550,0	4,32
600	1175	1775,0	5,42
800	1550	2350,0	8,65
1000	2100	3100,0	13,72

The required clearances are lower than those being necessary when applying the total DC+ SI voltage value at one terminal with the other terminal earthed.

5.3.2 *Performance under positive LI and negative DC*

Bias tests performed with LI on one side and either SI or AC on the other side of a rod-rod configurations [11] have shown similar U50 results , confirming that for LI performance what is important is the resulting average gradient condition in the gap. The above conclusion is here assumed valid also in the case of LI-DC test.

Furthermore, the results in [11] indicate that the flashover voltage on the isolating distance is independent, in the range of interest, of the ratio between U+ and U- (flat curve).
Furthermore, the U50 and Uw (0,95 U50) across the gap varies linearly with the gap clearance, with a withstand value of about 570 kV/m, as shown in Figure 18.

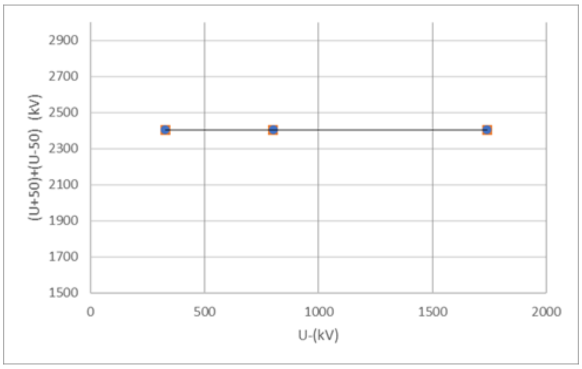


Figure 17- Rod-rod configuration. D=4 m. LI+ on one terminal and negative voltage on the other electrode. U50 flashover voltage across the air gap as a function of the negative voltage value

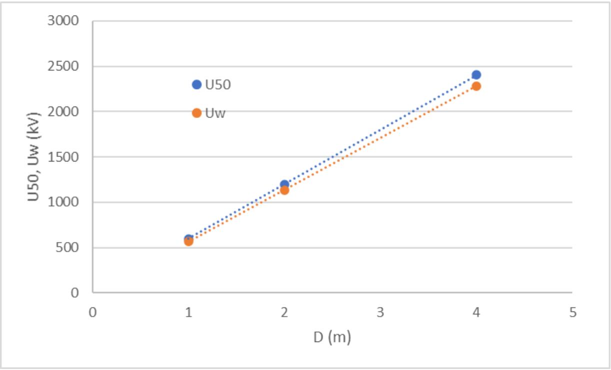


Figure 18 Rod-Rod. LI. U50 obtained in Bias Test versus gap clearance.

The comparison between the required SI and LI clearances (with SI lowest value among the range of [8] and LI the maximum associated value) is reported in Figure 19. The comparison indicates that also for Bias Tests the design is dominated by the SI performance and that LI tests are not necessary to prove the adequacy of the design.

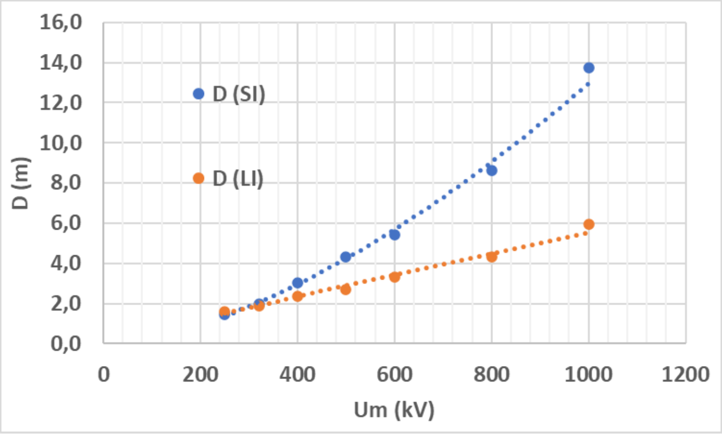


Figure 19 Bias tests. Comparison of SI and LI requirements

6 CONCLUSIONS

Many different DC system voltages Um have been used in the world, within the DC development phase, as confirmed by the review of 37 projects, with a wide range of Rated Switching Impulse and Lightning impulse withstand voltage, reflecting the different design approaches of the different companies and data of old projects and of more updated new projects . Nowadays, taking care of the greater DC maturity, a rationalization of Um and rated withstand values is recommended to allow rational equipment standardization and interchangeability.

Starting from the proposed voltage rating and from the applicable insulation performance, the required phase to ground and longitudinal insulation clearances are derived for system voltage up to the UHV range. The evaluation is performed considering disconnectors for indoor and outdoor use and application of ceramic and composite solutions for the phase to ground insulations.

Sizing of phase to ground insulation is determined by the SI performance for disconnectors for indoor application. For outdoor applications the sizing is determined in most of the cases by the need to comply with the pollution performance. For very heavy contamination pollution may require very long insulator sets, at the limit of feasibility, thus pushing toward the adoption of the indoor solution.

The size of the open disconnector gap is determined by the SI performance in the EHV UHV range, predominating on LI requirements. Thus, LI tests are not necessary to verify the adequacy of the open gap size. Larger open disconnector clearances are necessary when a DC values is foreseen on the opposite terminal. Considering the complexity of combined Impulse-DC tests (Bias tests), the Disconnector applications for which a DC voltage should be foreseen are to be clarified and delimited, limiting the need to generalize complex and costly combined impulse-DC tests (bias tests).

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