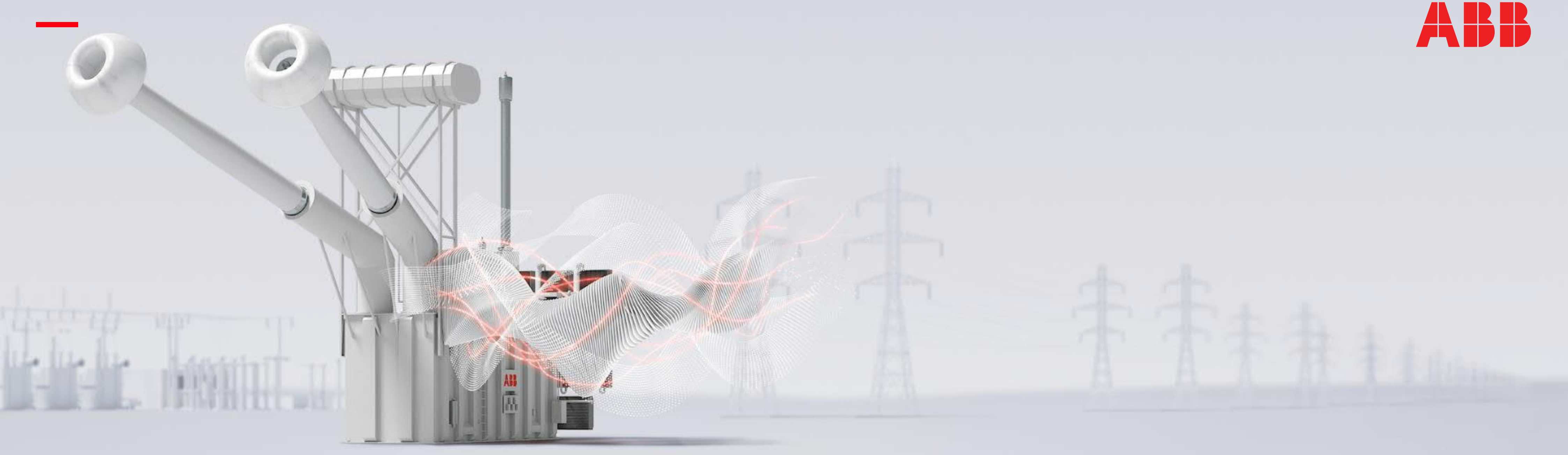
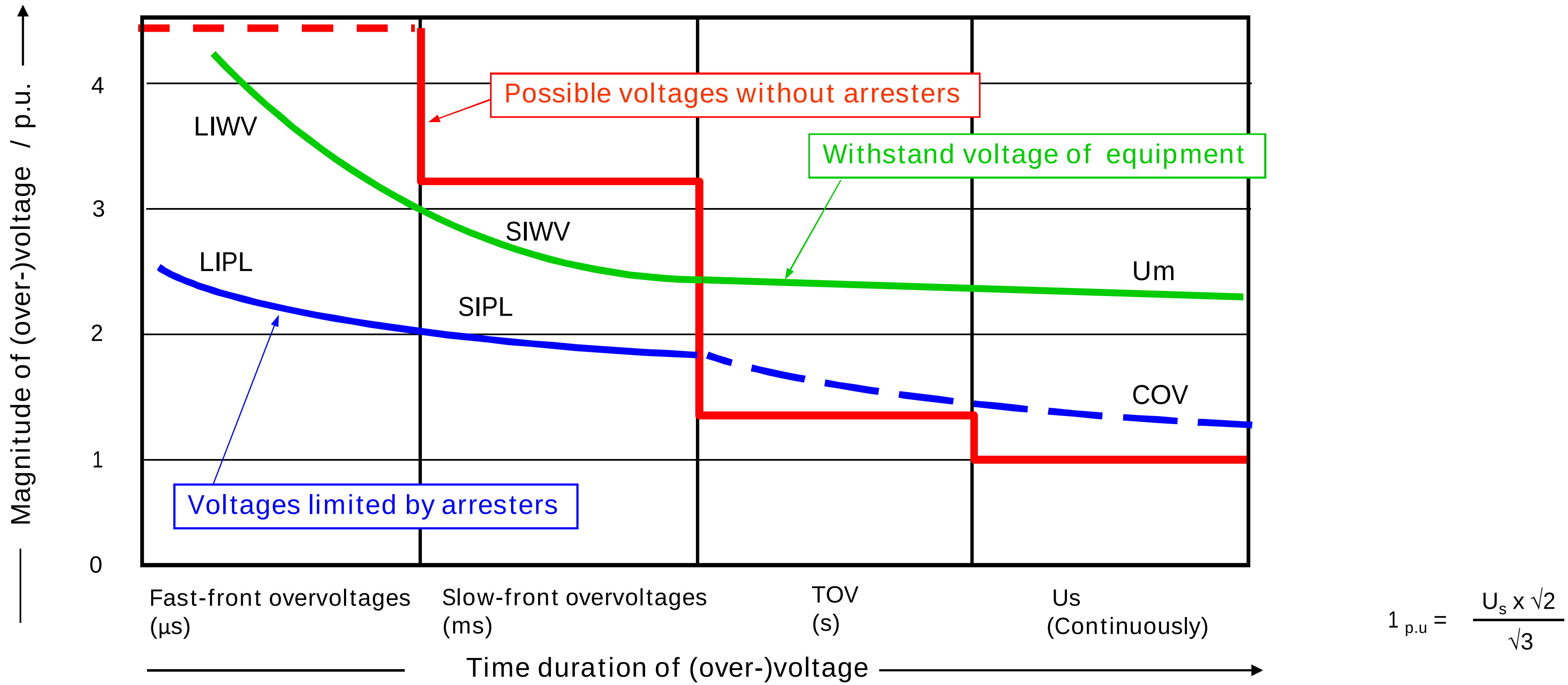


JORGE MONROY, MARKET DEVELOPMENT MANAGER

High Voltage Surge Arresters

Insulation withstand and altitude

Fundamentals of insulation coordination

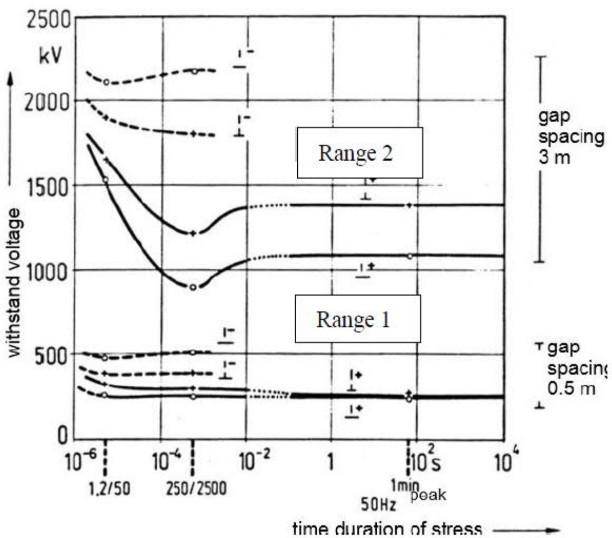


Standardized insulation withstand and clearances (IEC 60071)

Highest voltage for equipment (U_m) kV (r.m.s. value)	Standard rated short-duration power-frequency withstand voltage kV (r.m.s. value)	Standard rated lightning impulse withstand voltage kV (peak value)
3,6	10	20
		40
7,2	20	40
		60
12	28	60
		75
		95
17,5 [a]	38	75
		95
24	50	95
		125
		145
36	70	145
		170
52 [a]	95	250
72,5	140	325
100 [b]	(150)	(380)
	185	450
123	(185)	(450)
	230	550
145	(185)	(450)
	230	550
	275	650
170 [a]	(230)	(550)
	275	650
	325	750
245	(275)	(650)
	(325)	(750)
	360	850
	395	950
	460	1050

Highest voltage for equipment U_m kV (r.m.s. value)	Standard rated switching impulse withstand voltage: Longitudinal insulation [a] kV (peak value)	Phase-to-earth kV (peak value)	Phase-to-phase (ratio to the phase-to-earth peak value)	Standard rated lightning impulse withstand voltage [b] kV (peak value)
300 [c]	750	750	1,50	850
				950
	750	850	1,50	950
				1 050
362	850	850	1,50	950
				1 050
	850	950	1,50	1 050
				1 175
420	850	850	1,60	1 050
				1 175
	950	950	1,50	1 175
				1 300
	950	1050	1,50	1 300
				1 425
550	950	950	1,70	1 175
				1 300
	950	1 050	1,60	1 300
				1 425
	950 1 050	1 175	1,50	1 425
				1 550
800	1 175	1 300	1,70	1 675
				1 800
	1 175	1 425	1,70	1 800
				1 950
	1 175 1 300	1 550	1,60	1 950
				2 100
1 100	–	1 425 [d]	–	1 950
				2 100
	1 425	1 550	1,70	2 100
				2 250
	1 550	1 675	1,65	2 250
				2 400
	1 675	1 800	1,6	2 400
				2 550

Range 1: Above 1 kV to 245 kV included
Range 2: Above 245 kV



1.2/50 µs wave shape can be of interest at all voltage levels. Switching surges is used instead of power-frequency withstand for Us >245 kV, because the 250/2500 µs wave shape results in the lowest withstand capability of an insulator in Range 2 system voltages.

ABB

Standardized insulation withstand and clearances (IEC 60071)

Table A.1 – Correlation between standard rated lightning impulse withstand voltages and minimum air clearances

Standard rated lightning impulse withstand voltage kV	Minimum clearance mm	
	Rod-structure	Conductor-structure
20	60	
40	60	
60	90	
75	120	
95	160	
125	220	
145	270	
170	320	
200	380	
250	480	
325	630	
380	750	
450	900	
550	1 100	
650	1 300	
750	1 500	
850	1 700	1 600
950	1 900	1 700
1 050	2 100	1 900
1 175	2 350	2 200
1 300	2 600	2 400
1 425	2 850	2 600
1 550	3 100	2 900
1 675	3 350	3 100
1 800	3 600	3 300
1 950	3 900	3 600
2 100	4 200	3 900

NOTE The standard rated lightning impulse withstand voltages are applicable phase-to-phase and phase-to-earth.

For phase-to-earth, the minimum clearance for conductor-structure and rod-structure is applicable.

For phase-to-phase, the minimum clearance for rod-structure is applicable.

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

Standard rated switching impulse withstand voltage kV	Minimum phase-to-earth mm	
	Rod-structure	Conductor-structure
750	1 900	1 600
850	2 400	1 800
950	2 900	2 200
1 050	3 400	2 600
1 175	4 100	3 100
1 300	4 800	3 600
1 425	5 600	4 200
1 550	6 400	4 900

Surge arrester specifics

Arresters are self protecting and have less risk for flashover than other equipment, provided they are dimensioned correctly

- external insulation of arresters need not fulfil a certain standardized insulation class
- insulation requirements based on the arrester's protection levels with a reasonable safety margin added

Unnecessarily long arresters give less effective protection against steeper surges and undue mechanical stress

Clearance to other equipment generally according to IEC 60071 guidelines

- arrester characteristics also may permit reduced clearance distances in specific cases

Standardized withstand & clearances

NOT applicable to surge arresters as permitted by IEC 60071-1

5.5 Selection of the rated insulation level

"For surge arresters the required withstand voltages of the insulating housing are based on the protective levels *U*pl and *U*ps with suitable safety factors applied as per the apparatus standard IEC 60099-4. In general, therefore, the withstand voltages shall not be selected from the lists of 5.6 and 5.7"

60071-1 © IEC:2006+A1:2010 – 31 –

Annex A
(normative)

Clearances in air to assure a specified impulse withstand voltage installation

A.1 General

In complete installations (e.g. substations) which cannot be tested as a whole, it is necessary to ensure that the dielectric strength is adequate.

The switching and lightning impulse withstand voltages in air at standard reference atmospheric conditions shall be equal to, or greater than, the standard rated switching and lightning impulse withstand voltages as specified in this standard. Following this principle, minimum clearances have been determined for different electrode configurations. The minimum clearances specified are determined with a conservative approach, taking into account practical experience.

These clearances are intended solely to address insulation co-ordination requirements. Safety requirements may result in substantially larger clearances.

Tables A.1, A.2 and A.3 are suitable for general application, as they provide minimum clearances ensuring the specified insulation level.

These clearances may be lower if it has been proven by tests on actual or similar configurations that the standard impulse withstand voltages are met, taking into account all relevant environmental conditions which can create irregularities on the surface of electrodes, for example rain, pollution. These distances are therefore not applicable to equipment which has an mandatory impulse type test included in the specification, since a mandatory minimal clearance might hamper the design of equipment, increase its cost and impede progress.

The clearances may also be lower, where it has been confirmed by operating experience that the overvoltages are lower than those expected in the selection of the standard rated withstand voltages or that the gap configuration is more favourable than that assumed for the recommended clearances.

Standardized withstand & clearances

NOT applicable to surge arresters
as permitted by IEC 60099-5 (Clause 5.2.2.2)

For surge arrester housings in general (i.e. not limited to porcelain), the requirements on dielectric strength are different from those of all other equipment in electrical power systems. Note that the standard insulation levels of the insulation coordination standard IEC 60071-1:2010 (Tables 2 and 3) are not relevant, but lower values shall be applied instead as an arrester housing represents the best protected insulation in a power system. In order to avoid any flashover under impulse residual voltage stress during arrester operation, the minimum requirements for surge arrester housings, according to IEC 60099-4, are (abbreviations in line with IEC 60071):

– LIWV = 1,3 times the lightning impulse protection level (U_{pl}) of the arrester
– SIWV = 1,1 × $e^{m \times 1\,000/8\,150}$ times the switching impulse protection level (U_{ps}) of the arrester for substation class arresters for use in systems of $U_s > 245$ kV, where m = 1 in case of 245 kV $< U_s \leq 800$ kV, and in case of $U_s > 800$ kV m is taken from IEC 60071-2:1996, Figure 9, phase-to-earth insulation, with the value on the abscissa being 1,1 times the switching impulse protection level (U_{ps}) of the arrester
– PFWV (peak value) = 1,06 times the switching impulse protection level (U_{ps}) of the arrester for substation class arresters for use in systems of $U_s \leq 245$ kV
– PFWV (peak value) = 0,88 times the lightning impulse protection level (U_{pl}) of the arrester for distribution class arresters.

Often users are not aware of this special situation for surge arresters and would require the standard values of IEC 60071-1:2010 (Tables 2 and 3). This leads to unnecessarily tall arrester housings, which is not only a problem of geometrical dimensions but also results in an adverse axial voltage distribution and possibly in a more critical performance under polluted conditions. There may be special situations, such as extreme environmental conditions, that require higher impulse withstand ratings, but in general only the requirements of IEC 60099-4 should be applied.

Surge arrester withstand & clearances

The correction factor (Ka) is based on the dependence of the atmospheric pressure at the altitude.

$$K_a = e^{m\left(\frac{H}{8150}\right)}$$

where
H is the altitude above sea level (in metres) and the value of m is

Lightning m = 1,0

Switching
$\leq$ 800kV m = 1,0
> 800 kV m according to fig 9 IEC 60071-2

As per IEC 60099-4, up to 1000masl for $\leq$ 800kV

LIWV (dry) $\geq$ 1.3 x Upl

obtained from 1.15 x $e^{(1000/8150)}$

which reflects a 15% co-ordination factor to take into account discharge currents higher than nominal and the statistical nature of the withstand voltage of the insulation, and a 13% margin to account for variation in air pressure from sea level up to normal service altitudes not exceeding 1 000 m and discharge currents higher than nominal.

SIWV (wet) $\geq$ ~1.25 x Ups

obtained from 1.1 x $e^{(1000/8150)}$

which reflects a 10% co-ordination factor to take into account discharge currents higher than normal and the statistical nature of the withstand voltage of the insulation, and a 13% margin to account for variation in air pressure from sea level up to normal service altitudes not exceeding 1 000 m

PFWV (wet) $\geq$ 1.06 x Ups (as peak value), 1 minute withstand

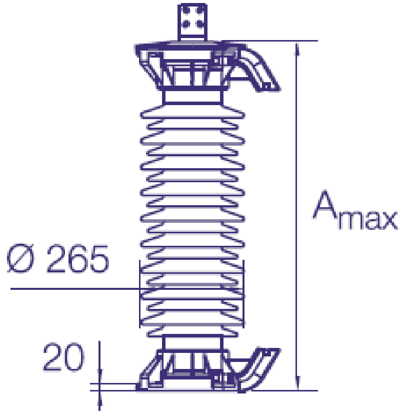
The factor of 1,06 takes into account a safety margin of 1,1 for higher switching impulse currents, an altitude correction factor of 1,13 for 1000 m installation altitude, and a test conversion factor of 0,6×√2 according to Table 2 of IEC 60071-2.

Surge arrester withstand & clearances

Example

Altitude Correction acc. IEC
Adjusted Protection Level
Required Clearance Distances

Arrester Type				**EXLIM Q098-EH123**			
Rated Voltage				**96**	kV		
Creepage distance				**3685**	mm		
Flashover Distance			F	**1268**	mm		
Lightning Impulse Protection Level			Upl	**226**	kV		
Switching Impulse Protection Level			Ups	**185**	kV		
Altitude above sea level			H	**1000**	m		
Corrected Protection Level							
Lightning Impulse (Uplcorr)	Upl x 1.15 x e^(H/8150)			**294**	kV		
Switching Impulse (Upscorr)	Ups x 1.10 x e^(H/8150)			**230**	kV		
Is IEC tested Insulation Withstand of Housing > Corrected Value ?							
LIWL		537	Corrected Value =	1.3 * Uplcorr =	294	kV peak	**YES**
SWIL	Um > 200kV		Corrected Value =	1.25 * Upscorr =	230	kV peak	**YES**
PF	Um < 200kV	287	Corrected Value =	1.06 * Upscorr /√2 =	138	kV rms	**YES**
Conclusion:							
The surge arrester type	EXLIM Q098-EH123		is suitable for use at the altitude of		1000	m asl	



Surge arrester withstand & clearances

Example

Altitude Correction acc. IEC
Adjusted Protection Level
Required Clearance Distances

LIWL=550

Arrester Type					**EXLIM Q098-EH123**			
Rated Voltage					**96**	kV		
Creepage distance					**3685**	mm		
Flashover Distance				F	**1268**	mm		
Lightning Impulse Protection Level					**226**	kV		
Switching Impulse Protection Level					**185**	kV		
Altitude above sea level					**1000**	m		
Corrected Protection Level								
Lightning Impulse (Uplcorr)		Upl x 1.15 x e^(H/8150)			**294**	kV		
Switching Impulse (Upscorr)		Ups x 1.10 x e^(H/8150)			**230**	kV		
Is IEC tested Insulation Withstand of Housing > Corrected Value ?								
LIWL		537	Corrected Value =		1.3 * Uplcorr =	294	kV peak	**YES**
SWIL	Um > 200kV		Corrected Value =		1.25 * Upscorr =	230	kV peak	**YES**
PF	Um < 200kV	287	Corrected Value =		1.06 * Upscorr /√2 =	138	kV rms	**YES**
Conclusion:								
	The surge arrester type	EXLIM Q098-EH123		is suitable for use at the altitude of			1000	m asl

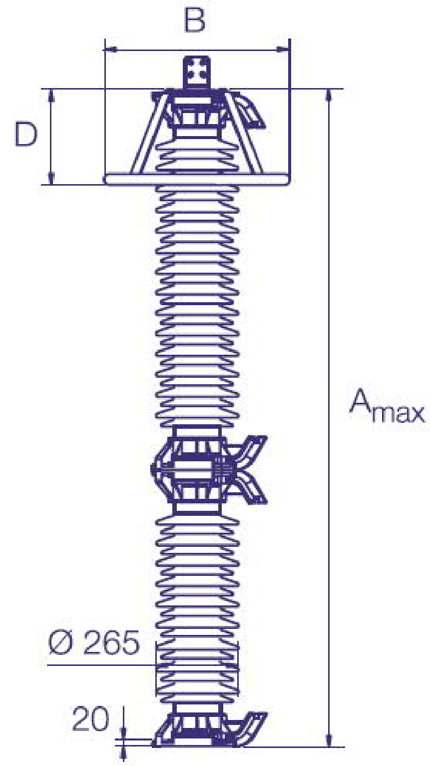


Figure 3

Insulation withstand and clearances

Recommendations available

1HSM 9543 16-01en Edition 1, 2012-06

Technical information

Insulation withstand and clearances with EXLIM and PEXLIM surge arresters

In order to reduce the risk of insulation failure to an economically and operationally acceptable level, the insulation withstand of substation equipment is selected with regard to expected over-voltages, taking into account the protective characteristics of the surge arresters. This technical information discusses the different aspects of insulation withstand and provides guidelines for positioning EXLIM and PEXLIM surge arresters in outdoor substations.

Altitude correction

- Statistical risk of an external flashover less than or equal to 10^{-3} (0.1 % per year) is considered acceptable by IEC 60071-2
  - Resultant factor between the arrester protective levels and the LIWV and SIWV of the arrester housing

- Normal installed altitude above sea level
  - IEC $\leq$ 1000 m
  - IEEE $\leq$ 1800 m (in process of changing to 1000 m)

- For higher altitudes, special consideration needs to be given on a case-by-case basis.
  - Altitude correction methods considering
    - arrester protection level
    - insulation withstand level required for altitude difference over 1000 masl
    - creepage distance

Air pressure

An altitude correction factor (Ka) based on the dependence of the atmospheric pressure on the altitude, can be calculated from

$$K_a = e^{m\left(\frac{H}{8150}\right)}$$

where H is the altitude above sea level (in metres) and with the coordination factor, m, conservatively taken to equal 1.0 for $U_s \leq 800$ kV.

- The normal value of air pressure at mean sea level is 101.3 kPa.
  - Depending on meteorological conditions, air pressure at sea-level may vary from approximately 91% to 107% of this value
  - In areas above sea-level air pressure is lower than at sea level and in areas below sea-level higher than at sea level.

Altitude H above sea level (m)	Air pressure (kPa)	Relative air pressure at altitude	Calculated Ka $= e^{(H/8150)}$
0	101.3	1	1
1000	89.9	1.13	1.13
2000	79.5	1.27	1.28
3000	70.1	1.45	1.44
4000	61.6	1.64	1.63
5000	54.0	1.88	1.85

Altitude correction

Preferred method

$$Protection\ level_{adjusted} = protection\ level \times coordination\ factor \times e^{\left(\frac{H}{8150}\right)}$$

LIWV (dry) $\geq$ Upl x 1.15 x $e^{(H/8150)}$

SIWV (wet) $\geq$ Ups x 1.1 x $e^{(H/8150)}$

PFWV (wet) $\geq$ Ups x 1.1 x $e^{(H/8150)}$ x 0.6 x $\sqrt{2}$ (as peak value)

ABB

Altitude correction

Non-supported methods

Based on altitude difference over 1000m

$$K_a = e^{m\left(\frac{H-1000}{8150}\right)}$$

- Standardized insulation withstand x Ka
- Presumes equipment is directly designed for use at 1000 masl
- Less conservative, but may be suitable / necessary in some cases

Based on creepage distance

$$Creepage_{\ corrected} = creepage\ distance \times e^{m\left(\frac{(H-1000)}{8150}\right)}$$

- Pollution withstand already catered for up to the design altitude; only the altitude above 1000 m needs to be corrected. Experience suggest m = 0.5 should be used for AC applications when correcting creepage distance.
- Method arguably warranted for hydrophilic surfaces, eg. porcelain, if they can become at risk of flashover due to dry-band related discharge activity taking place. Such an issue is less of a concern for hydrophobic transfer materials, eg. silicone, and the need to correct creepage distance on these insulators is doubtful.
- Intent should be to first determine the necessary creepage distance according to pollution conditions at the actual altitude and then correct only that value for altitude.

ABB