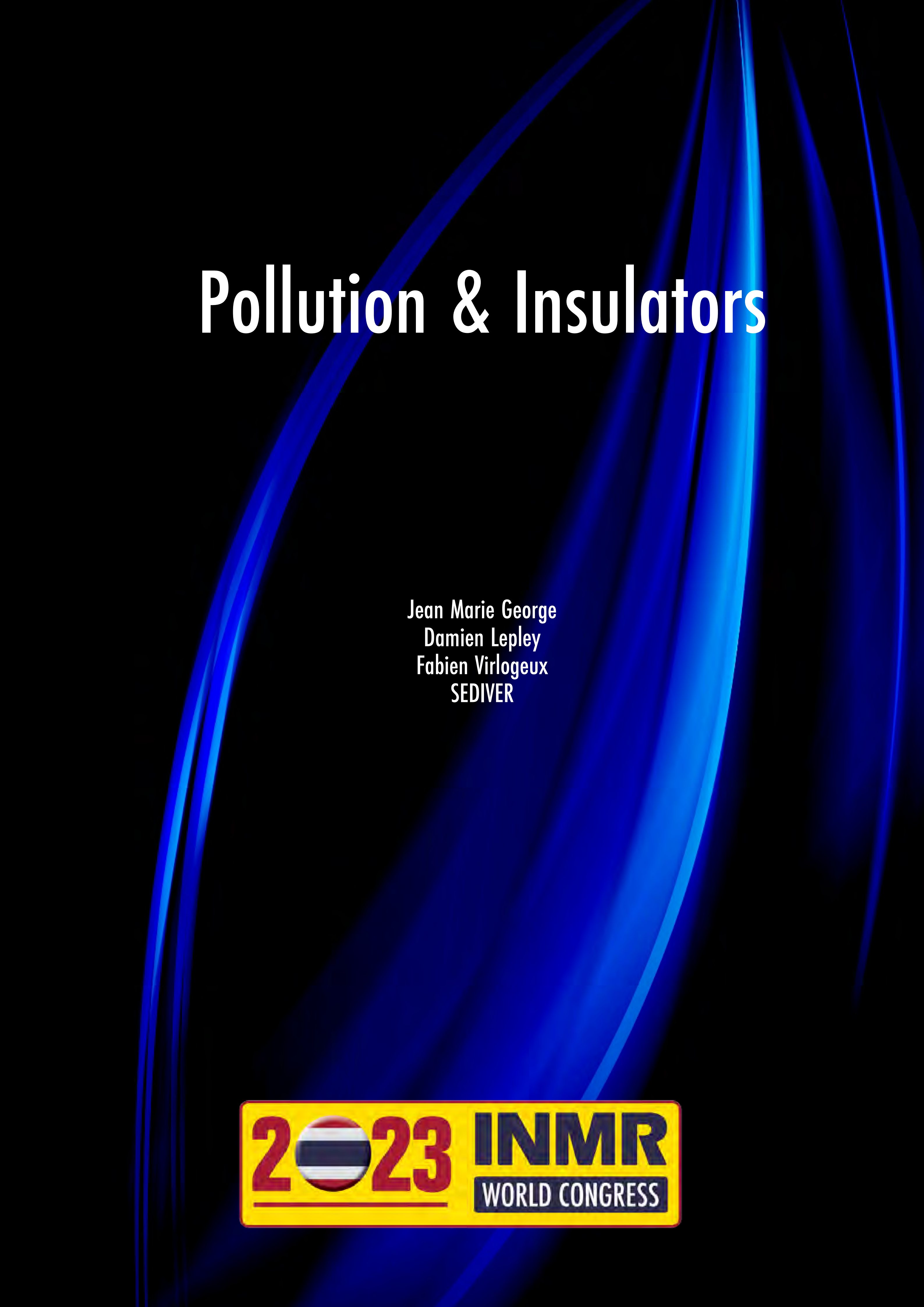

Pollution & Insulators

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Pollution of insulators is one of the most critical parameters in the continuity of operation of overhead lines in many countries either because of industrial, coastal or airborne dusty environments. While dielectric strength characteristics of insulator strings are vary basically defined by air gaps for lightning and switching, it is a much deeper technical question involving shape of insulators as well as material and surface properties when it comes to contamination.

This paper gives several directions, options and results helping line design engineers to cope with this question. Shape, HTM properties (hydrophobicity of the surface of the insulator) and other considerations are discussed including for HVDC applications based on latest test results and standard evolutions.

1. Artificial Pollution Test with Solid Layer

Whenever a solid layer deposit is required to produce an artificial pollution test the difficulty resides in the method used to duplicate the actual deposit on an insulator. In the field pollution is a progressive, usually relatively slow process while in the laboratory the pollution is applied at once building a layer which can differ from reality in its morphology. Dipping an insulator in a slurry, as it is done usually does not reproduce the actual layer from the real world and this can alter the test results.

As already mentioned in an earlier publication [1] Sediver has developed another option in which the deposit is applied through an airborne dust deposit (method called SDAM, Spray Deposit Airborne Method, figure 1). Recent study in Sediver Research Center shows that with this technique the deposit is more consistent with the actual surface condition of an insulator (see figure 2). Thus, standards should reconsider this possibility as an option even if past trials were not successful.

Among the benefits of this method, it is possible to produce an uneven deposit between top and bottom surface (CUR) with less deposit on the top than the bottom as it is the case in the field where wind and rain keep the upper surface cleaner. This can eliminate the need for a correction factor when testing an insulator at a CUR=1 and be very useful in HVDC testing.

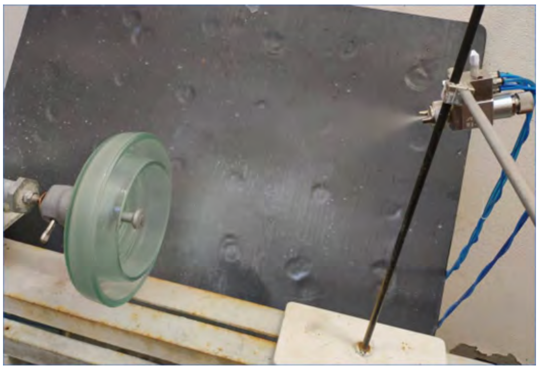


Figure 1: SDAM technique producing consistent pollution layers with possible different CUR levels

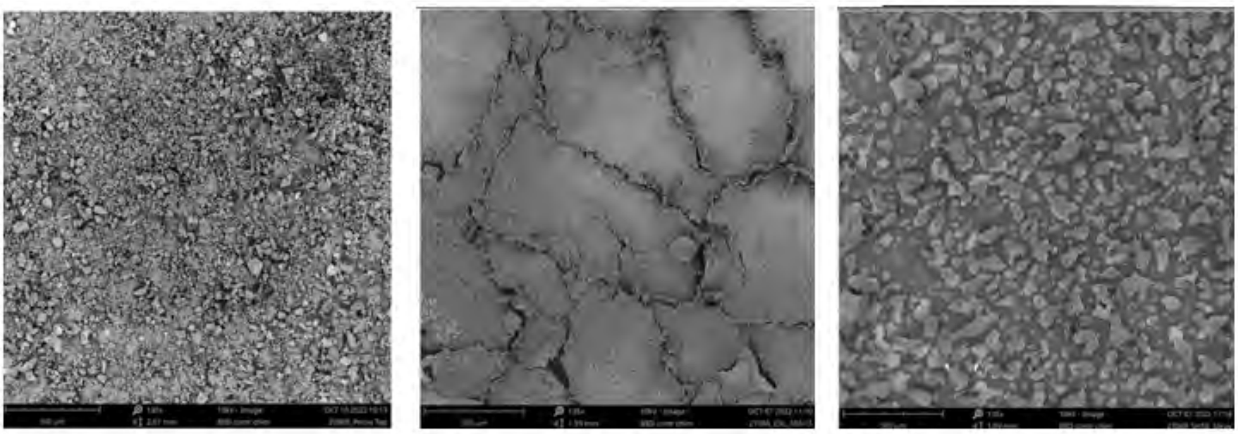


Figure 2 : Morphology of deposits of pollutants observations with SEM. Left: very heavy level as found on an insulator returned from service. Center: layer of pollutant using overspray or dipping of a slurry (Heavy class). Right: SDAM deposit classified "Heavy" with a similar ESDD/NSDD as the picture in the center and same magnification..

2. Pollution Testing of Hydrophobic Surfaces

A standard for testing HTM surfaces is currently being drafted by IEC. One of the big questions is the time required between the application of the slurry and the time for the electric test knowing that it can take "some time" to regenerate "some" hydrophobicity. This is a complex question especially for heavy and very heavy pollution class for which in the real world, as stated before, the deposit accumulates progressively providing time for some continuity in the hydrophobicity transfer unlike for an artificial test where the slurry is applied at once.

Figure 3 shows the time to transfer some level of hydrophobicity for these extreme conditions. While a rest time of 48 h prior to test seems reasonable for the lower pollution classes, it appears that it is not compatible with the higher classes of pollution (above medium class or above a NSDD of 0,2mg/cm²) and therefore caution should be exercised when looking at results of such tests.

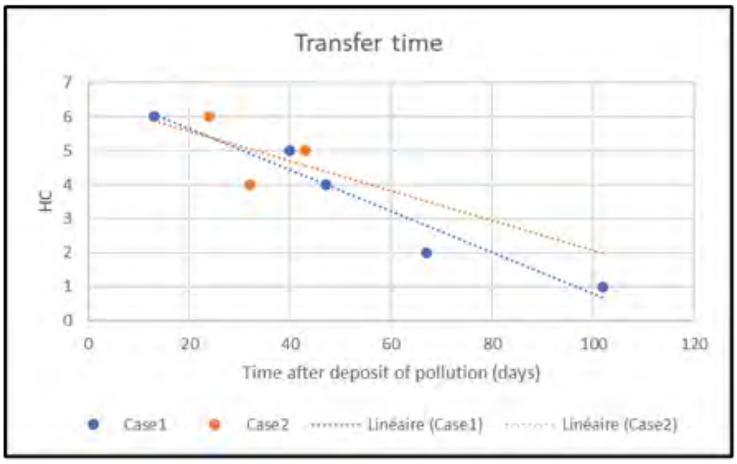


Figure 3: Transfer time for heavy and very heavy pollution layers on a silicone surface (Case 1 for NSDD=0.2mg/cm² and Case 2 for NSDD=1mg/cm²).

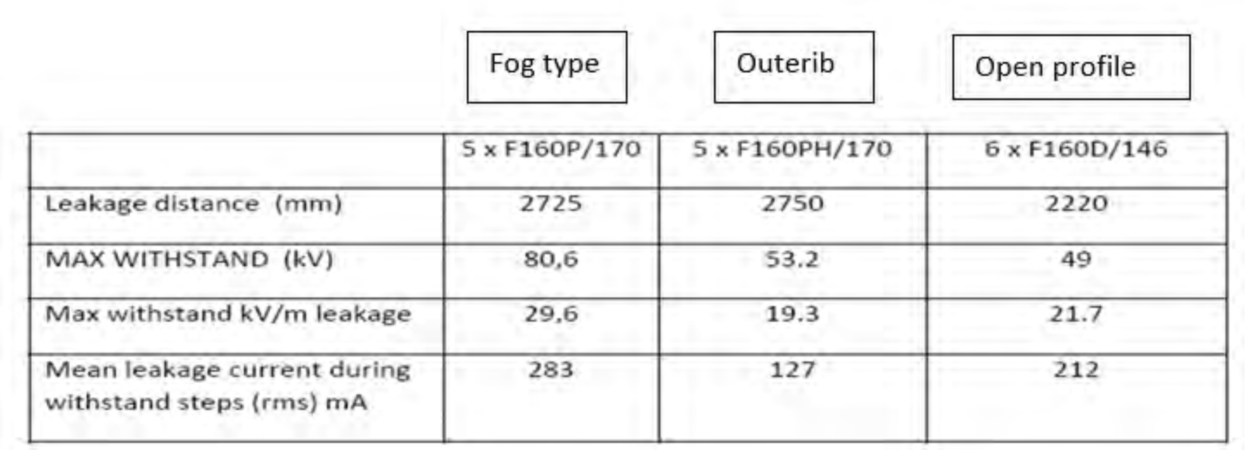
3. Shapes of Insulators

The recent revision of IEC 60305 [2 h]as introduced a shape so far mostly used in China. The “Outerib” insulators, as shown in figure 4 was initially designed for dusty environments. It combines typically the leakage distance of a fog type insulator with an open aerodynamic shape which will favor self-cleaning with wind.

Figure 4: Outerib shape of insulators

Laboratory test results are indicating that this shape is clearly well fitted for dusty environments since it takes less pollution. Figure 6a shows a comparison between fog type and outerib tested under the same conditions and the outerib shows already better results for a similar pollution level. In reality, it is expected to see outeribs taking approximately 30% less pollution than a fog type, which means that the pollution performance will be even better. The comparison between the two shapes need to take in parallel for the same environment the results of an outerib having less pollution than a fog type in the same environment. But this it is not the case for coastal conditions as shown in figure 6b. In such conditions since the initiation of the discharge around the pin will not be blocked by any rib it is expected to see the arc propagation flowing easily along the surface when subjected to wet fog conditions.

Short string test comparisons between open profile fog type and outeribs have shown this phenomenon as already published previously [3] and shown in figure 5. This has been confirmed in long string tests at 10g/l and 40g/l of salinity as per IEC 60507 [4] on strings made of 10 to 18 units per string with fog types having a leakage distance of 545mm and outeribs with 550mm of leakage distance. The results are shown in figure 6 and we see that under salt fog conditions the outerib needs between 1.8 and 2 times more leakage distance (USCD, Unified Specific Creepage Distance).



	Fog type	Outerib	Open profile
	5 x F160P/170	5 x F160PH/170	6 x F160D/146
Leakage distance (mm)	2725	2750	2220
MAX WITHSTAND (kV)	80,6	53.2	49
Max withstand kV/m leakage	29,6	19.3	21.7
Mean leakage current during withstand steps (rms) mA	283	127	212

Figure 5: Short string test results comparing different profiles in salt fog conditions

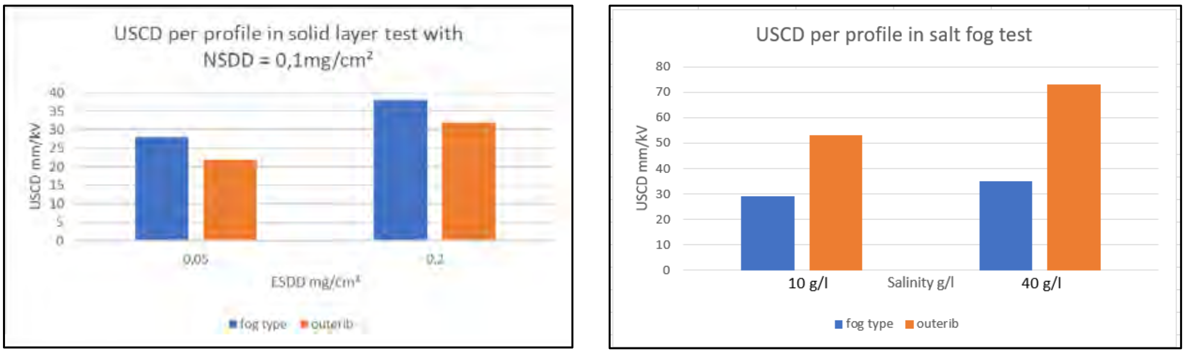
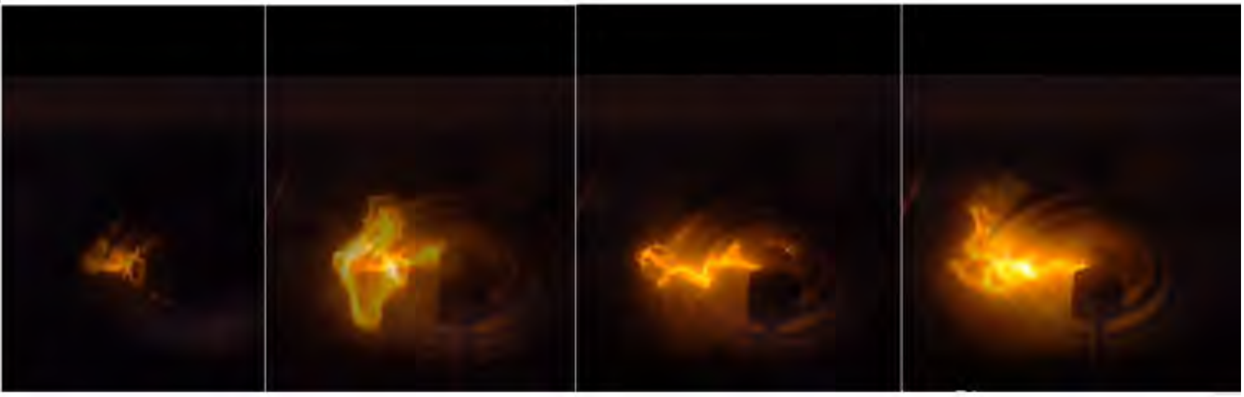


Figure 6: left: Solid layer artificial pollution and right: salt fog tests on long strings. Comparisons between fog type and outerib shapes. Tests performed at same pollution levels.

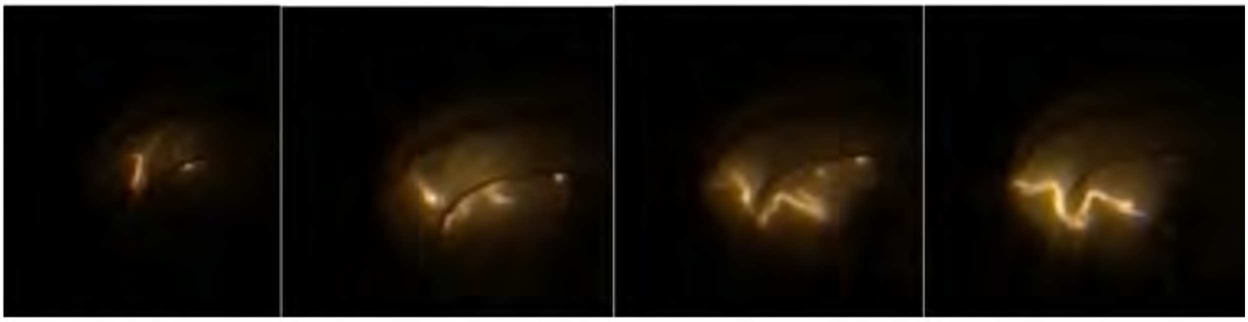
4. The DC Case

Pollution for HVDC overhead lines is more complex than for AC given the intrinsic fact that DC lines are attracting airborne dust. IEC 60815 part 4 [5] is providing guidance for the selection of the most appropriate USCD but is often underestimating the actual performance of DC insulators which differ in shape from AC insulators.

Figure 7 shows the arc development for different shapes of insulators tested in salt fog under DC voltage. The dry band arcing activity in DC is different from what happens in AC and therefore real DC insulators (the only one to take into consideration for describing their pollution performance in DC) are designed with large inter rib distances and at least one long rib (figure 8) to mitigate arc development as shown in the still pictures from the observation with a high-speed camera shown in figure7. It can be noted also that the making of a glass insulator allows for a better profile than porcelain (longer ribs and typically one rib less than porcelain for an identical leakage distance) which is also shown in figure 8.



Arc development in DC over a glass insulator not specifically designed for a DC application. The arc is bridging the ribs eliminating largely the benefit of the leakage distance



Arc development in DC over a DC shape glass insulator. The arc follows better the profile taking a real benefit of the leakage distance.

Figure 7 comparison of the development of arcing activity in DC between a regular AC type insulator and a real DC glass insulator

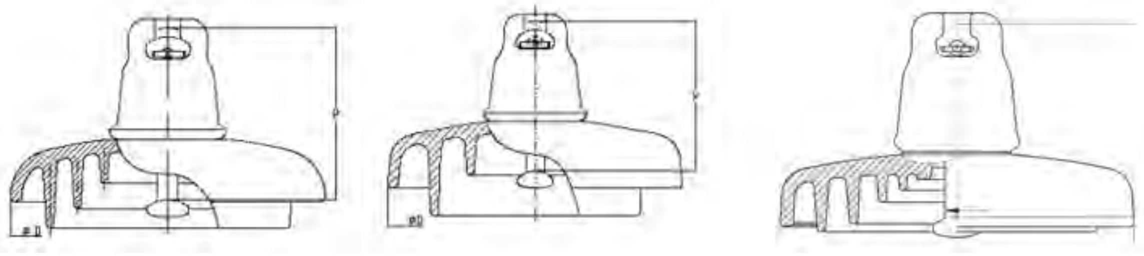


Figure 8: Typical sketch of a DC glass profile (left and center) and profile not adapted to DC (right)

Using the correct shape for DC applications would clearly generate better results than those who led to the performance curves in IEC 60815 part 4.

An extensive test program was initiated in the Sediver DC pollution laboratory in Bazet, France, with various solid layer pollution levels. Figure 9 shows the gap between the actual performance of a typical fog type glass insulator versus the USCD curve in IEC (dotted line), confirming earlier statements already made several times in previous publications showing the need to be addressed in a future revision of IEC TS60815-4.

In fact, a performance curve should be associated to a proper l/d factor and creepage factor CF. IEC 60815-4 makes recommendations for a creepage factor CF< 3 and never above 3,75. The lower CF and l/d the better the performance but experience shows that more detailed design aspects are needed. Figure 10 describes key parameters to take into consideration for an optimum performance in DC.

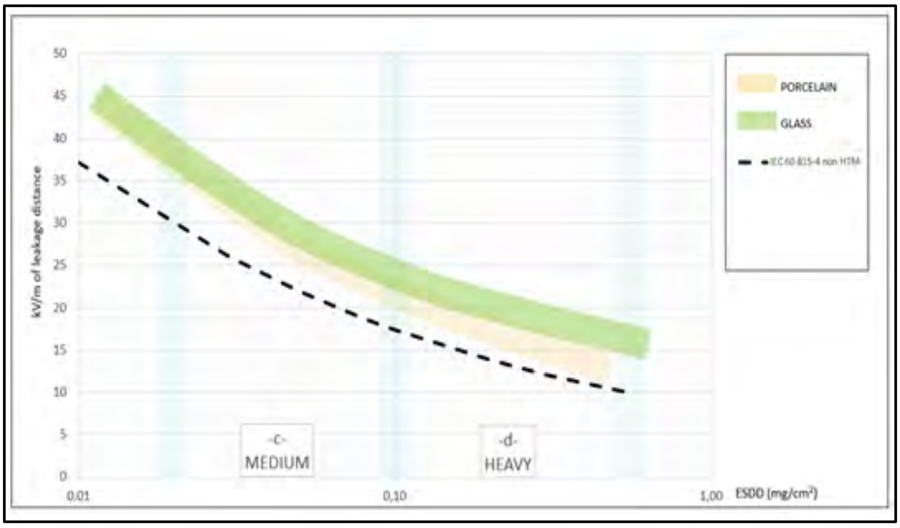
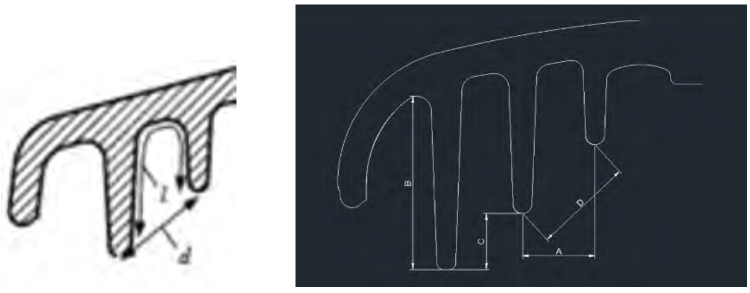


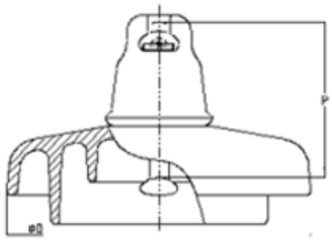
Figure 9: Actual pollution performance in DC solid layer conditions of Sediver DC insulators (greenà compared to current IEC 60815-4 (dotted line)



parameter	value
(D/2)/N	≥ 60
Average A	≥ 30
Average B	≥ 50
C	> 20
D	> 35

Figure10: Key geometric parameters in the design of HVDC insulators (N being the number of ribs excluding the outer skirt and inner corona rib around the cement area)

As a practical example for a 600kV DC application, in a project estimated to cross a region with a ESDD=0.02mg/cm² (normalized at NSDD=0.1mg/cm²) and spots at 0.04mg/cm² the string design can be seriously optimized as shown in figure 11 below and based on actual test data. It is therefore highly recommended to check actual performance of DC insulators prior to designing towers which cost would be seriously inflated if designed with IEC 60815 part 4 recommendations.



For NSDD=0.1	Nb of insulators		String length (m)	
ESDD	0.02	0.04	0.02	0.04
IEC 60815-4	40	51	6.8	8.7
SEDIVER	31	36	5.2	6.1
SEDCO coating	25	28	4.5	5

Figure 11: Sediver DC insulator ref PP/PS leakage distance 550mm, spacing 170mm. Estimation made with a CUR=1. IEC results based on IEC 60815 part 4. Sediver results based on actual test data. SEDCO estimation for Sediver silicone coated insulators

An additional topic of interest in DC is the performance under salt fog conditions, and surprisingly there are very few DC lines near the coast. This second type of pollution compared to inland dusty conditions was investigated in the Sediver HV pollution laboratory and a comparison between coated glass and polymer was made with a salt fog of 20g/l. Strings of similar leakage distance were compared both having the benefits of a hydrophobic surface. The purpose of the test was to check for a withstand at -200kV DC. The polymer insulator held for less than an hour and flashed over while the string of silicone coated glass withstood 6h with almost no leakage current as shown in figure 12.

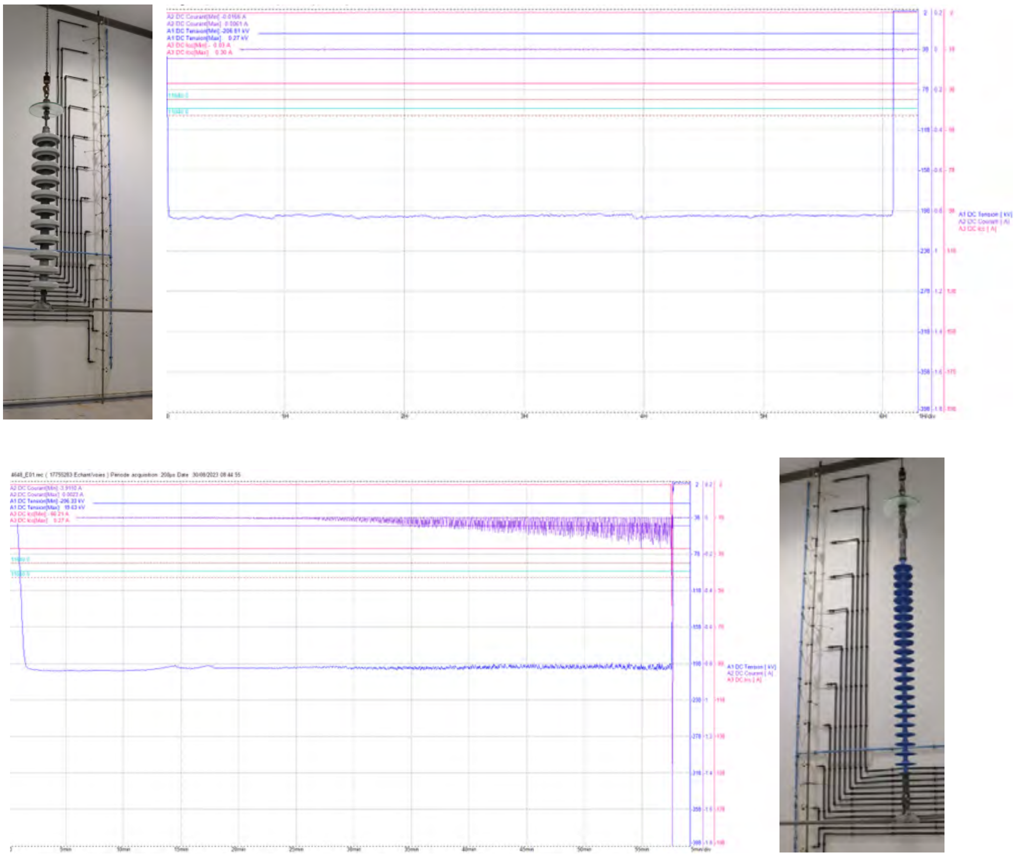


Figure 12: DC comparision between a string of silicone coated glass and a polymer in salt fog

These results demonstrate once again the benefits of the shape of the insulators which in most cases have been under estimated compared to pure leakage distance considerations. It is consistent with another test performed on much smaller test objects as shown figure 13 where leakage current was peaking on the polymer sample while no activity whatsoever could be seen on the DC silicone coated glass insulator.

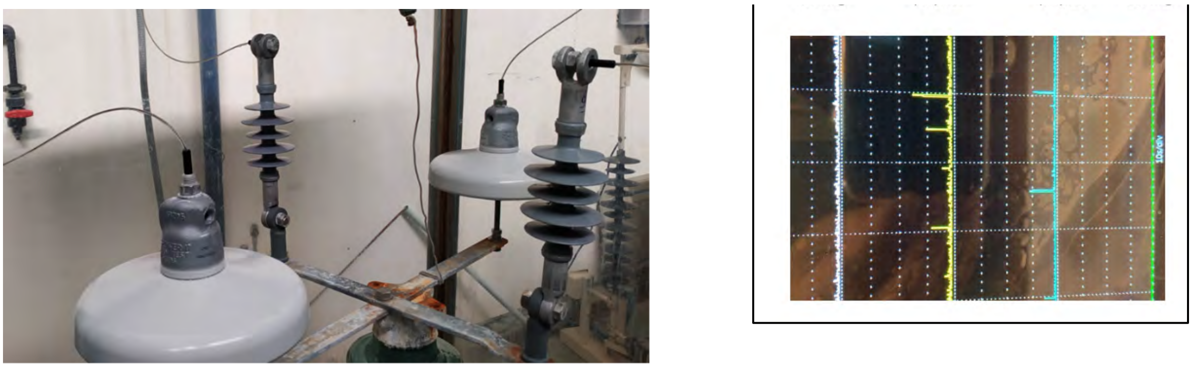


Figure 13: difference of leakage current between a silicone coated glass insulator and a DC polymer. 20g/l with samples at 30mm/kV. Applied voltage 15kV.

5. Real Time Monitoring of Pollution

As already mentioned in previous communications, SEDIVER had introduced a few years ago a Smart insulator concept which measures simultaneously and in real time temperature, humidity, and Leakage current, all three being key parameters to detect possible risks for flashovers but also a good device to build a pollution map going directly to the leakage current rather than measuring ESDD/NSDD.

This device is now in a version 4.5 (figure 14) going directly to GSM and using a patented software managing simultaneously the energy consumption of the device while screening the critical developments of current in frequency, magnitude and shape.

Figure14: Smart E leakage current monitoring system

These devices are evolving rapidly with the development of IOT technology, and it is interesting to see how they start contributing to a better possible forecast in predictive maintenance. Figure 15 shows the readings of the leakage current on a site where it was possible to give a 2 week notice prior to flashover. This recording of current was obtained in the EDF test station of Martigues where a string of glass insulators was set with a USCD just at the limits of the requirements for the local conditions, expecting some currents and flashovers to occur at some point in time.

Figure15: Records of the Smart E leakage current monitoring in Martigues test station providing a 2 week notice prior to flashover

These very interesting results demonstrate the benefits maintenance teams could have using such devices in polluted areas and save time and money while still staying ahead of needed maintenance operations.

References:

[1] J.M. George, D. Lepley, “AC and DC pollution testing methods: accuracy and limitations”, 2022 INMR World Congress, Oct 16 – 19, 2022, Berlin, Germany, pp. 1-8.

[2] IEC 60305, “Insulators for overhead lines with a nominal voltage above 1000 V - Ceramic or glass insulator units for AC systems - Characteristics of insulator units of the cap and pin type”, Edition 5.0, 2021-01.

[3] S. Prat, J.M. George and J.P. Lopez, “Performance evaluation method and optimum selection of overhead line insulators for contaminated environments”, INMR 2009 World Congress Crete, 2009, pp. 1-13.

[4] IEC 60507, “Artificial pollution tests on high-voltage ceramic and glass insulators to be used on a.c. systems”.

[5] IEC/TS 60815-4, “Selection and dimensioning of high-voltage insulators for polluted conditions – Part 4: Insulators for d.c. systems”, Edition 1.0, 2016-10.