SEDIVER
Sediver Research Center

EDM
reliability & innovation

INTERNATIONAL CONFERENCE ON OVERHEAD LINES
April 15-18, 2024
Fort Collins, Colorado U.S.A

Pollution of overhead line insulators : update on standards and insulators performance under severe contamination for AC and DC lines

JM George
Sediver

Abstract:

Coastal conditions or airborne dust can easily disrupt overhead lines operations. Solving this problem requires a good understanding of the phenomenon involved, the basics of pollution interaction over insulation coordination but also the options available in the selection of the most appropriate solution.
IEC 60815 is a guide intended to assist engineers in the management of pollution and design of lines crossing contaminated environments. It is currently under revision. Other IEC standards are also being drafted to provide solutions and facilitate the evaluation of the performance of insulators in such conditions.
After a review of the fundamental aspects of pollution definition and evaluation methods, this paper will give an update of the ongoing standardization work in IEC in this field.
A second part of this paper will present an update on the performance of different insulator designs in various pollution conditions including silicone coated glass insulators.
Finally, and because pollution accumulation on insulators is different in AC and DC, a special focus will be made on HVDC insulation options and pollution mitigation methods.

1. Basics on pollution

Pollution considerations for overhead lines are mostly related to the surface conductivity of insulators which is the result of moisture and wetting conditions, different from rain but capable to increase the conductivity along the leakage path. These conditions are usually met in coastal environments where salt is present or dusty environments which will bring airborne dust on the insulators. This dusty crust will absorb moisture which will dissolve the salts contained in the pollutant and subsequently generate leakage currents.

To better understand pollution some definitions are good to remember:

Leakage distance; the shortest distance along the surface of the insulator between the conductive ends of the insulator. Another word for the same dimension is creepage distance.

USCD: Unified Specific Creepage Distance. It is the leakage distance of an insulator or insulator string divided by the maximum voltage of the line phase to ground.

ESDD: the amount of sodium chloride in an artificial deposit on a given surface of the insulator (metal parts and assembling materials are not to be included in this surface) divided by the area of this surface.

NSDD: amount of non-soluble residue removed from a given surface of the insulator, divided by the area of this surface.

To make the assessment of the pollution level in a given environment it is a common practice to measure the ESDD and NSDD by cleaning the surface of the insulator (typically at the end of the dry season before natural washing takes place). Once these numbers are known they can be plotted on a graph which can be found in IEC 60815 part 1 as shown in figure 1 designed for such “dusty” environments also called “type A” pollution.

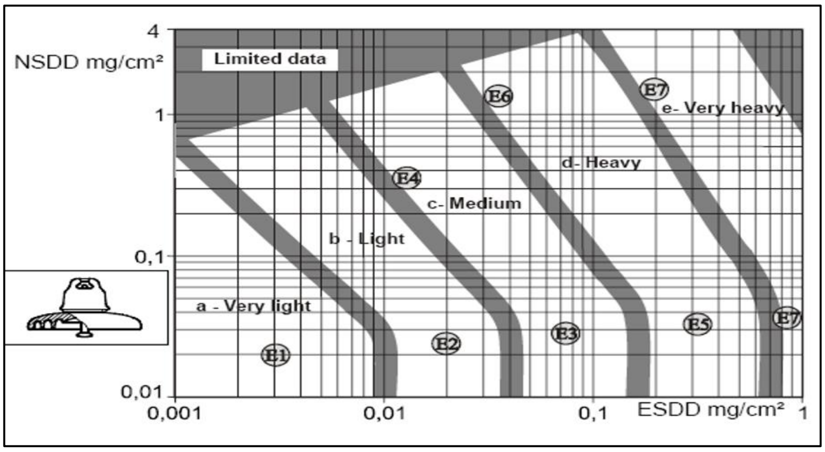


Figure 1 : IEC 60815 [1] classification of pollution type A as a function of ESDD and NSDD

In coastal areas the pollution events are usually less linked to dust deposit and even if there is a low NSDD and some ESDD the dominant factor is salt fog events which leave not much on the surface. The dry band activity is therefore generated during the fog event and the classification is based on surface conductivity which by itself can be challenging to establish unless there is a conductivity gage installed on a tower on reference insulators or a leakage current monitoring device on site. It is customary to define a type B classification (figure 2) based on the equivalent salt fog density measured in kg/m3 in order to perform a salt fog test for verification. The salinity for the test is based on the conductivity expected on the surface of an insulator in such an environment.

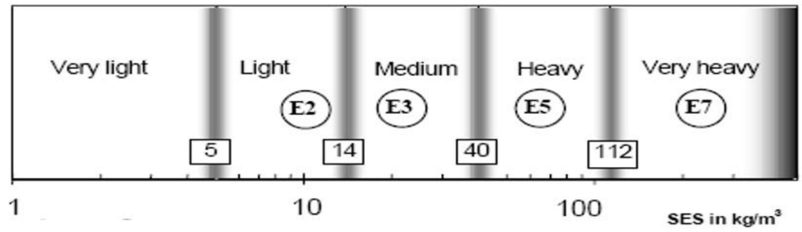


Figure 2: IEC 60815 [1]: classification of pollution severity type B

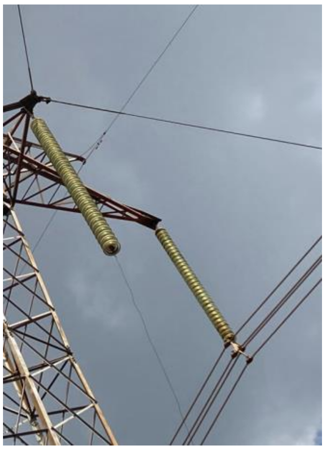
Artificial testing of insulators under pollution exists therefore in two distinct methods. For pollution type A the insulators are covered with a slurry which is made up with salt and kaolin in order to produce the ESDD and NSDD levels of interest. Usually as a standard practice such tests are performed with NSDD=0.1mg/cm^2 but other values are possible. The insulators are then introduced in a test chamber and tested with a clean fog generated as per IEC 60507 [2]. Type B pollution is tested according to the same standard but this time the fog is loaded with the appropriate level of salt to generate a salt fog. For type B the insulators are clean since the pollution is generated by the ambient fog and not a pre-deposited layer of contaminants.

2. Pollution assessment methods

It is possible to proceed to pollution measurements without taking insulators down from service. Among those we can mention three possibilities.

a. Dummy insulators: there are conditions where the evaluation of type A pollution requires more than a one-year typical weather cycle. In this case insulators can be placed in a tower to collect dust but without being energized. This works only in AC since under DC the polarized environment will attract dust. As a consequence, for DC non energized insulators would show a pollution level below the expected real condition with an energized line. Figure 3 shows an example of such experiment. A unit from a dummy string can be removed periodically to determine the evolution over a few years of the deposit.

b. DDDG boxes: in some cases, a set of tubes with a hole collecting dust can be used (figure 3). This device (Directional Dust Deposit Gage) works best it is installed at the same elevation as the insulators, sometimes on the ground but the difficulty is the representativeness of the collection of airborne dust which is strongly impacted by the air flow itself which can be different where the DDDG is installed.



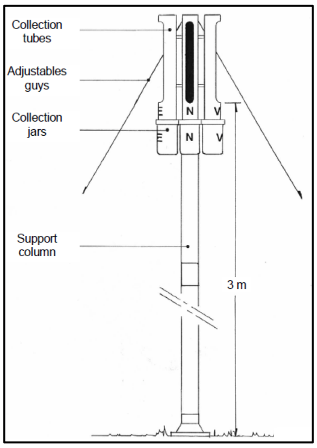


Figure 3 : Left: dummy string.   Right: example of a DDDG installation.

c. Direct measure of the leakage current: this recent technique is now available and will measure in real time the leakage current resulting from the pollution and local weather conditions. The concept is based on the collection of the leakage current flowing on the insulators surface by using a device connected generally to the cap of one of the insulators of a string (the ground end unit). This current being a function of the weather, it is fundamental to associate the current to the temperature and humidity. The leakage current will typically exist when the surface is humid which correspond to a relative humidity in the range of 70% and above. Two main families of devices have been developed so far. One is using a Rogowski coil technique where the current is established by induction in a coil. It does not work in DC and the limitations in AC are linked to the precision of the connection with the cap the insulator, which is made of a casted cast iron, therefore not very precise in dimensions. A second type of sensors is developed and patented by Sediver where the cap has an integrated current collector at the base of the cap (figure 4 and 5). This technique is progressively gaining attraction and the associated software which analyses the data (including weather conditions) shows an ability to provide a diagnostic which can help in the predictive maintenance like for example defining the most appropriate time for washing the insulators. Figure 5 gives an example where a warning was sent approximately 2 weeks prior to a flashover event. This technique is not directly measuring the pollution but measures the consequences for the operation and maintenance of a line.

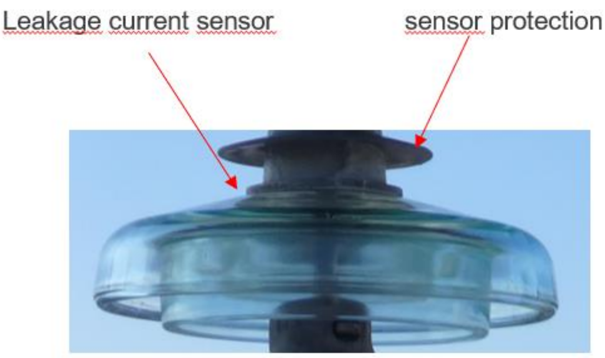


Figure 4: Sediver Smart insulator

Figure 5: Examples of Sediver Smart insulators field installations (Left: 500kVDC, Right 500kVAC) for real time leakage current monitoring and diagnostics.

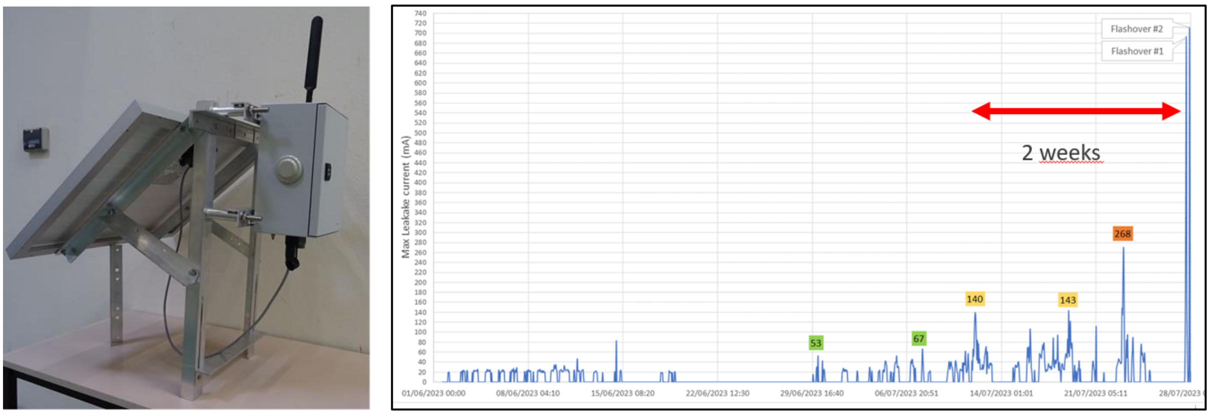


Figure 6 : example of records showing a 2 week notice prior to a flashover event with the lates V5 generation of Smart insulators with a direct GSM communication system.

3. Influence of the shape of the insulators in a defined pollution environment

Finally, but more expensive, physical test stations installed in strategic locations can be used to evaluate the evolution of the pollution levels on different shapes of insulators. Sediver has largely worked with large test station with ESKOM at Koeberg test station in South Africa and EDF at Martigues test station in France [4] Also in the Middle East working in a test station in the Arabic peninsula on dust collection comparisons between two shapes have provided very interesting data as shown in figure 7.

.

As a matter of fact, it is critical to understand that leakage distance is not the only criteria when designing a string of insulators in a contaminated environment. While standard shapes are the most popular in relatively clean conditions coastal conditions will require a longer leakage distance but also a shape capable to manage in an optimum condition the dry band arcing generated by the fog itself. This is why fog types have longer ribs than standard shapes beyond simply having more leakage distance.

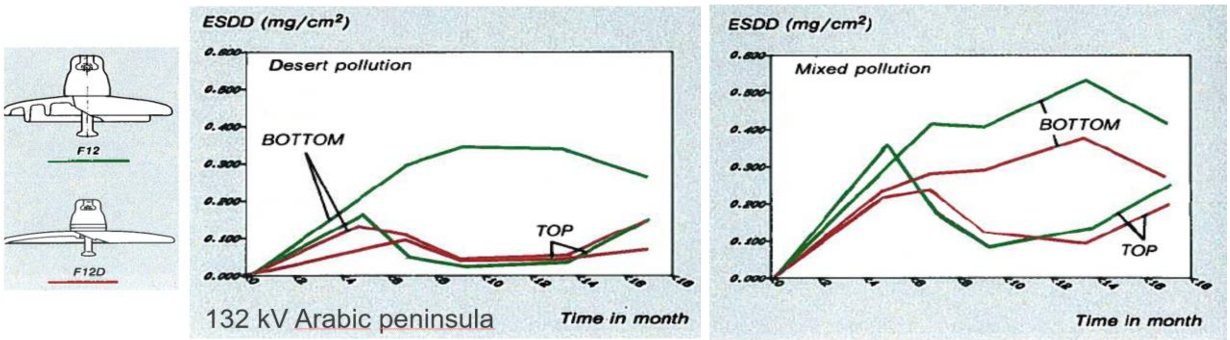


Figure 7: ESDD levels on top and bottom surface of standard and open profile shapes in desertic and mixed pollution conditions from a test station in the Arabic Peninsula

One parameter to take into consideration when dealing with very dusty conditions is the risk of dust accumulation between the ribs. To this extend open profiles are being used especially in desertic climates where humidity is low, dust levels high but with a good self-cleaning effect provided by the wind. These insulators have a shorter leakage distance since they have no ribs and still need to remain in a reasonable diameter. For conditions where semi desertic conditions require simultaneously a high leakage distance and a good self-cleaning effect outerib shapes are now being introduced in standards such as IEC 60305 [3] and IEC 60815 [1]; These insulators have ribs located outside and in a horizontal position offering an easy self-cleaning capability. Typical shapes of such insulators are shown in figure 8 below.

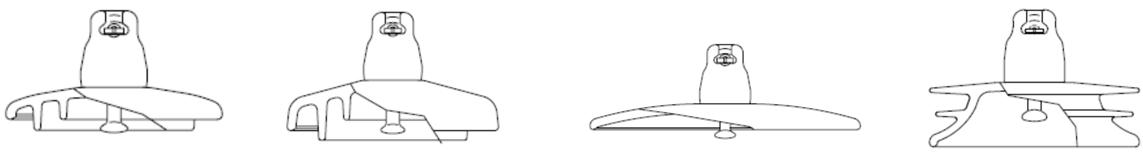


Figure 8 : typical shapes of suspension discs for different environmental conditions. Left to right: Standard, fog type, open profile and outerib.

To illustrate the fact that the shape can take a dominant role in the pollution performance of a string of insulators a salt fog test was performed with standard shape, fog type and open profile. The results are shown in figure 9 for short strings of 5 to 6 units with similar leakage distances. The bad performance of outeribs in coastal conditions is confirmed in figure 10 on long strings up to 18 units per string but in figure 11 the very good performance of outeribs in dusty deposit conditions. These results show that for the same leakage distance and the same pollution deposits outeribs outperform fog types. What is behind this difference is the dynamic arcing discharge activity which is different between the two shapes. Keeping in mind that an outerib will actually collect less dust than a fog type it increases furthermore the potential performance of this insulator in dusty conditions.

	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 9: salt fog test results at 80g/l between strings of similar leakage distance but different shapes.

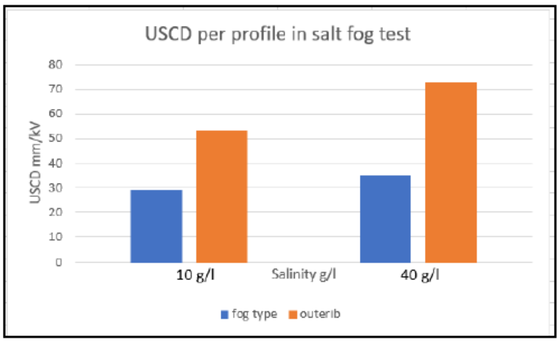


Figure10: salt fog test on long strings of fog type and outerib insulators

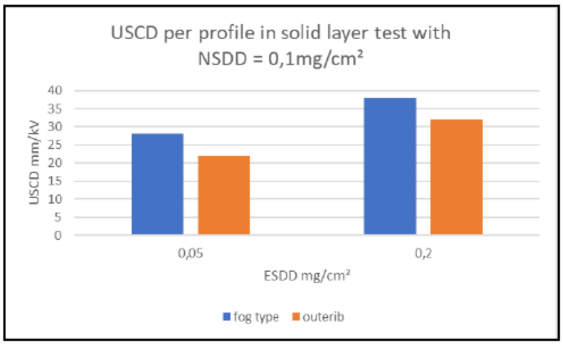


Figure 11: solid layer pollution test on long stings of fog type and outeribs

The use of silicone coating on glass or porcelain insulators has become a solution no longer as a remedial situation to fix a problem on an existing line but more and more a solution selected from the design stage in replacement of polymer insulators especially with glass which offers unique benefits in terms of resiliency, inspection and lively ne work.

The pollution performance of silicone coated insulators benefits from the same hydrophobic properties than a polymer insulator, but the shape can provide some additional performance (as shown for example in section 5 for DC. Silicone coated glass insulators are used today either fully coated or coated only underneath which is where dry bands would be forming under a humid pollution event. The advantage of having only the underside coated is in the ease of handling and installation. Figure 12 shows the difference in performance of coated insulators compared to non-coated units.

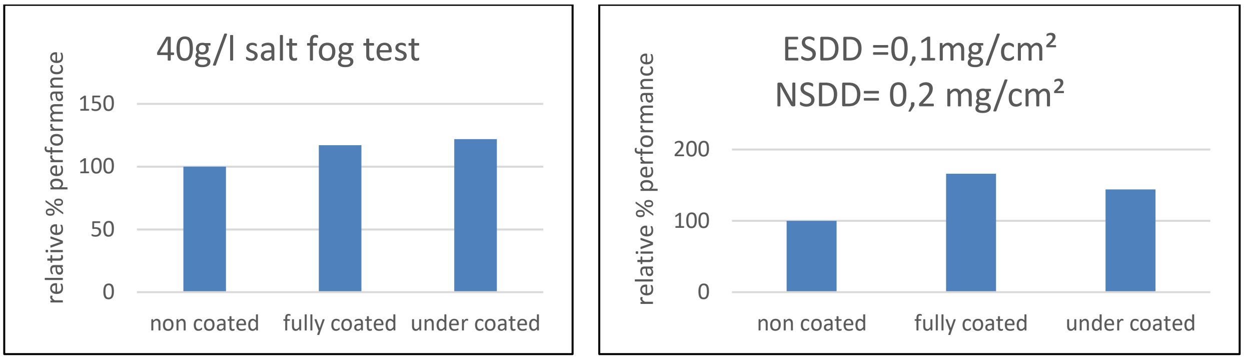


Figure 12: Comparative performance of coated and non-coated insulators in salt fog and solid layer pollution test conditions

4. Evolution of standards around pollution related matters

As already mentioned earlier, and IEC being the main standardization body in this field several documents have been or are being updated as we speak, others being created to cope with new needs.

a. IEC 60305 has just been published with a new revision which includes the outerib shape
b. IEC TS 60815 series 1, 2 and 3 are currently being revised. Among the changes an additional pollution class is added for extreme cases.
c. IECTS60815 part 4 [5] specialized on HVDC will be revised in the coming years with possible major changes especially in the expected performances of different insulator types (see section 5 below)
d. Following expert considerations on the difficulty to test hydrophobic surfaces [6] IEC has opened a new working group to determine artificial pollution test methods for insulators which surface hydrophobicity can fluctuate because of the time needed for the transfer of hydrophobicity across the pollution layer. The upcoming standard will define a so called “rest time” between the time the slurry of pollutant is applied on the insulator surface and the testing time. This document will be referred as IEC 63414. It covers both type A and type B pollution.

5. The DC case

The particularity of DC polarized environment generates a higher pollution level through ionized airborne dust attracted by the line. Under those conditions and because higher NSDD are expected on a DC line than an AC line built in the same area there is a need for a higher USCD in DC. But beyond this simple adjustment the shape matters even more than for an AC line.

The reasons for this can be found in the development process of partial arcing along the surface of an insulator. Figure 13 describes the fact that in DC the arc will try to bridge the leakage distance between two consecutive ribs leading in some cases to much lower flashover values under critical conditions of pollution.

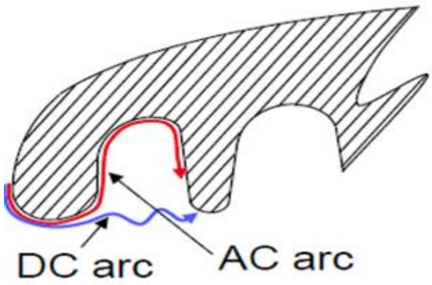


Figure 13: difference in arc development between AC and DC

To illustrate this point figure 14 shows the difference in arc bridging the profile of insulators as a function of the shape under a DC voltage. The efficiency of the leakage distance is a direct consequence of this phenomenon.

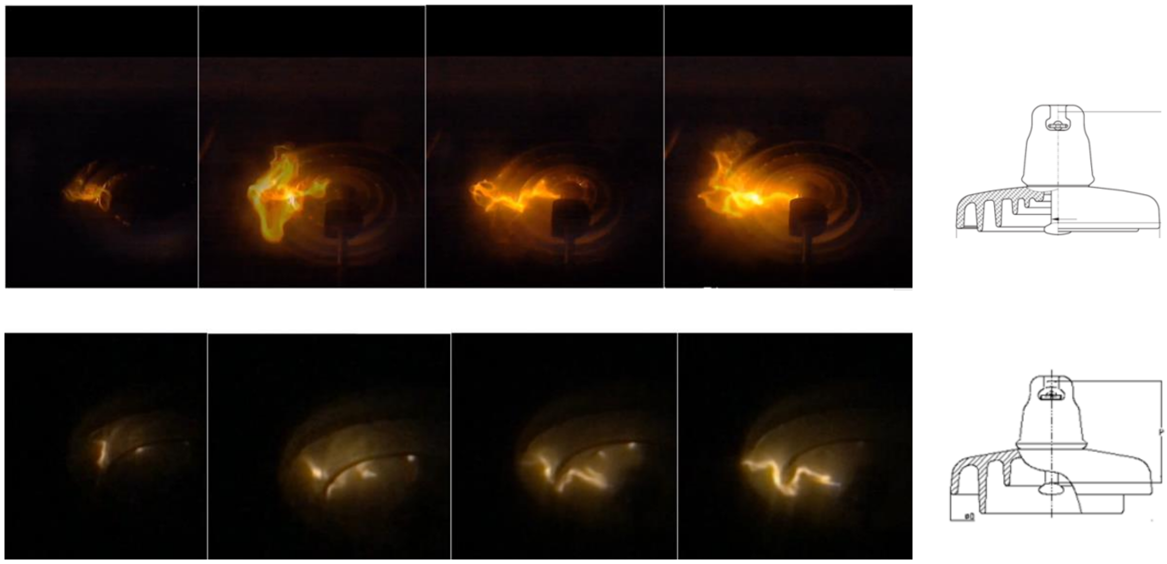


Figure 14: Top: arc development in salt fog conditions under a skirt of poorly designed insulator for a DC application. Bottom: arc development following more closely the profile for a well-designed shape adapted to DC application. (Tests performed with insulators having the same leakage distance).

The determination of the appropriate leakage distance for a string of insulators in a DC application was initially made through a large test program performed in the EPRI laboratory in Lenox, USA approximately 40 years [7] ago which consisted of clean fog with solid layer artificial pollution testing of a large variety of insulators which shapes either no longer exist or, for some of them are not used or were not even designed for DC at all (figure 9 illustrate the shapes which were considered during this test).
Additionally, these tests were not performed according to IEC 61245 [8] but rather through a customized procedure aimed at comparing glass, porcelain, and polymer insulators simultaneously in so called equivalent strings.

The data from the EPRI program was reused by IEC to plot the recommended USCD as a function of pollution but unfortunately this data contained results from insulators not at all aimed at a DC application and subsequently the curve from IEC 60815-4 is largely underestimating the real performance of real DC insulators as shown in the graph figure 15 where actual test data on real DC glass insulators is used with also data from porcelain DC insulators.

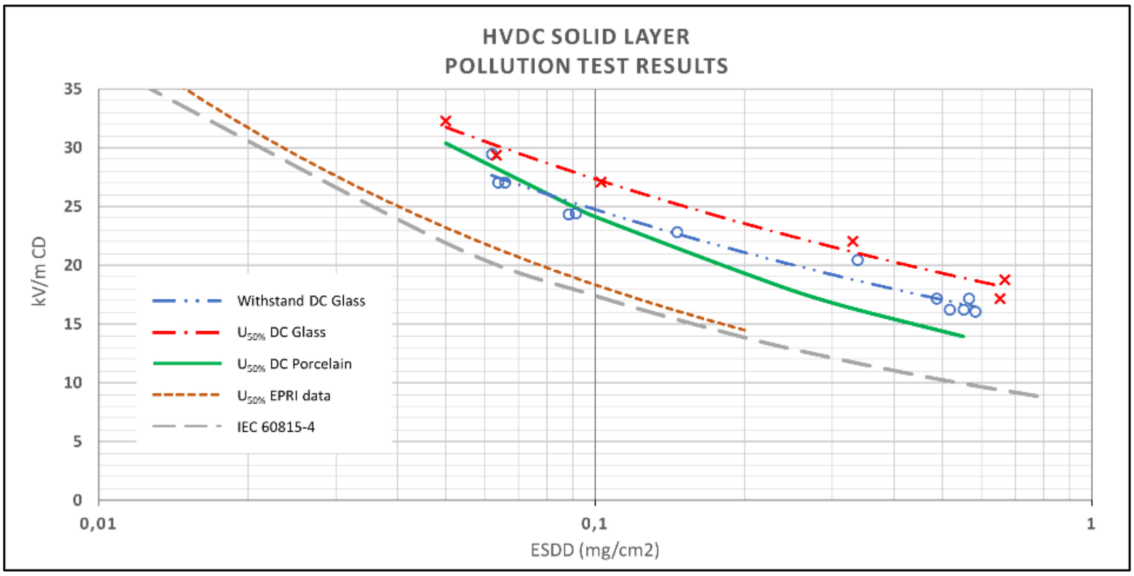
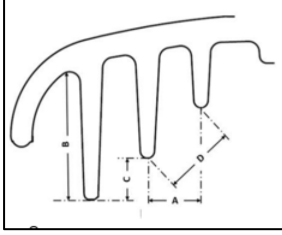


Figure 15: actual DC insulator performance compared to old EPRI data and IEC 60815-4

Field experience is confirming that strings built with the appropriate shape of DC insulators can be reduced substantially compared to what is suggested by the IEC guide provided shapes are in line with recommendations already described in previous publications [9] and as shown in figure 16, where the geometry is described with more details than in IEC 60815-4 where only creepage factor and l/d ratios are mentioned.



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

Figure 16: details of shape of DC insulators

Silicone coating is used as well in DC up to 800kV. While the hydrophobicity of silicone provides similar benefits than for polymers which are not yet fully described in standards, the advantage of the resiliency of glass makes this solution an extremely effective approach to pollution mitigation without the need for increasing the string length.

The performance of silicone coated glass insulators in pollution in DC is showing also a superior performance compared to polymers and mostly because of the shape of the discs. An example is shown in figure 17 in a salt fog test where a string of DC glass insulators was tested with the same leakage distance as a DC polymer insulator.

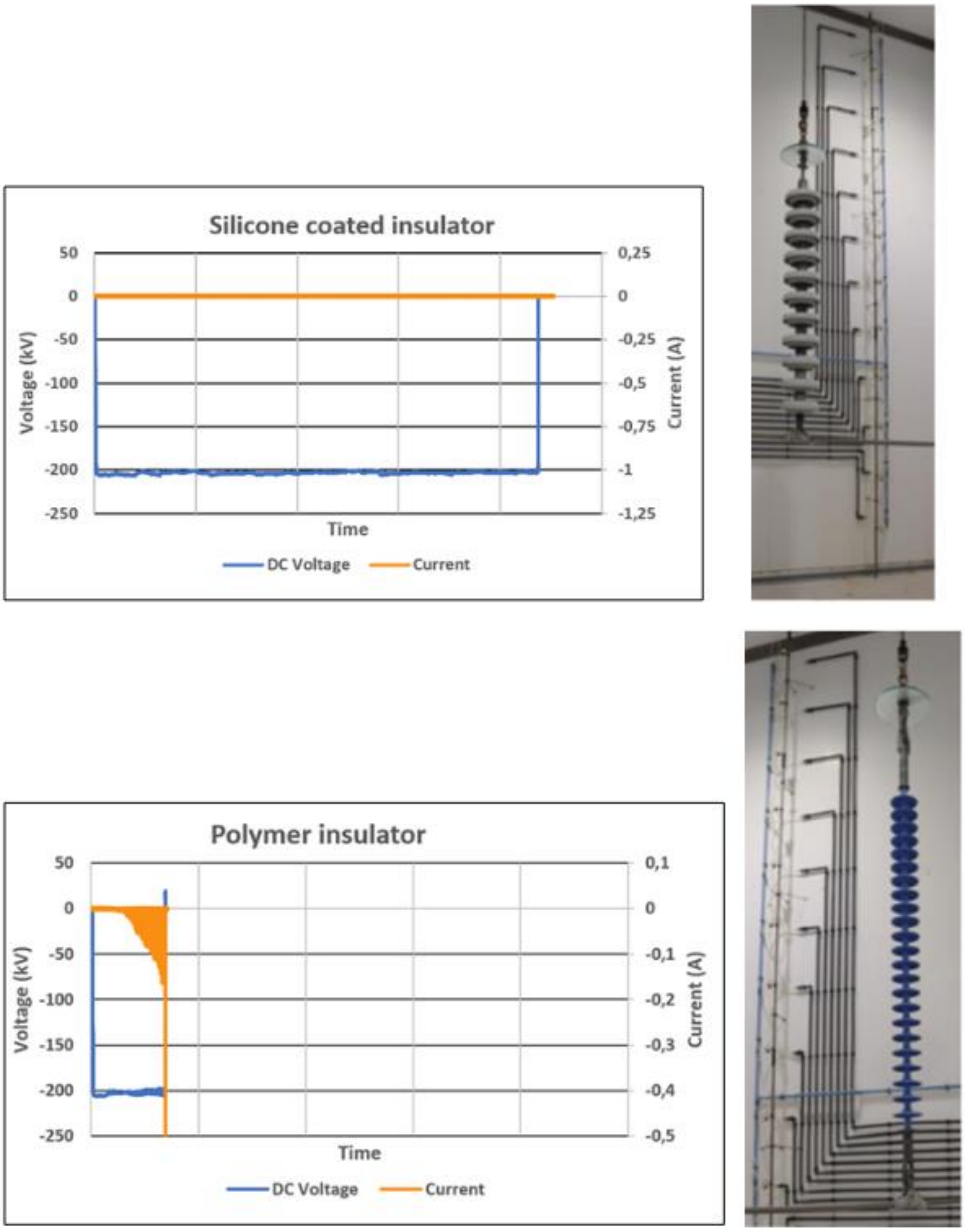


Figure 17: Top no leakage currents on silicone coated DC glass for the entire test duration. Bottom: high leakage current on the polymer sample leading to a flashover in within 1 hour of test

Test conditions were 20g/l with a USCD= 31mm/kV in a preconditioning test phase at -200kVDC. The polymer insulator flashed over after 1h while the coated glass string finished without any noticeable activity twice the 3h sequence. Silicone coated .DC glass insulators can allow string length reduction compared to polymer insulators while offering a unique resiliency .

References:

[1]: IEC 60815 Selection and dimensioning of high-voltage insulators intended for use in polluted conditions.part 1 and part 2
[2]: IEC Standard 60507, “Artificial pollution tests on high-voltage ceramic and glass insulators to be used on a.c. systems”, Edition 3.0, 2013-12
[3]:IEC 60305 Insulators for overhead lines with a nominal voltage above 1000V. Ceramic or glass insulator units for AC systems. Characteristics of isulator units of cap and pin type
[4]: Assessment of performance of insulators through leakage current monitoring under contaminated conditions. JM George, C. Pons, W. Vosloo. CIGRE 2022 B2 218
[5]: IEC 60815-4 Selection and dimensioning of high-voltage insulators intended for use in polluted conditions Part 4: Insulators for D.C. systems (IEC Standard, 2016)
[6]: State of the art of pollution test procedures for insulators with hydrophobic Transfer Materials. Gutman, et al. (CIGRE Science & Engineering, N°21, p.29, June 2021)
[7] Evaluation of the performance of 16 contaminated DC suspension insulators. Nigbor R (EPRI, 1983)
[8]: IEC 61245 Artificial pollution tests on high-voltage ceramic and glass insulators to be used on D.C. systems
[9]: Pollution and insulators, JM George, D. Lepley, F. Virlogeux. INMR Bangkok 2023

Author:

Jean Marie GEORGE, Scientific Director of Sediver. 38 years in the overhead line insulator industry, past experience in various management positions in Sediver including manufacturing and quality management. Currently responsible for R&D and Technical Assistance for Sediver Worldwide.
Author of numerous publications and patents, member of NEMA, ANSI C29, CSA 411, CIGRE B2, IEEE and chair of the French committee of IEC TC36.