KEY PARAMETERS FOR HVDC OVERHEAD LINES INSULATORS

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Abstract

In the recent years, large DC projects have been designed and/or built and several interesting comments should be made when it comes to insulators. Except for China, polymer DC applications remain marginal compared to traditional porcelain and toughened glass insulators. Material performance is still under evaluation for designing a long awaited standard for DC composite overhead line insulators, and some field observations raise questions when it comes to DC polymer insulators versus ageing and service conditions.

In the meantime in North America, South America and Africa, thousands of kilometers of DC lines just got completed or are being built without polymers, and in quite a number of cases composite insulators were not even allowed to bid. At the same time, DC field experience and results from tests on samples removed from old lines show excellent performance of toughened glass insulators with more than 40 years of service already demonstrated.

This paper will review the key requirements and specific parameters which define the technical aspects of a DC insulator for overhead transmission lines. Field performance in various environments will be presented. Questions related to contamination management and design of DC strings of insulators in a polluted environment will also be addressed.

1. Materials

1.1 Dielectrics

For ceramic insulators all the technical aspects related to DC are defined in IEC 61325. Body resistance being the main specificity for DC cap and pin insulators, manufacturers came up decades ago with dielectrics having a resistivity designed for the ionic effects of the unidirectional currents typical of a DC line (figure 1).

For silicone rubber the question remains under discussion and CIGRE as well as manufacturers are still engaged in the design of tests intended to establish a performance level for silicone rubber under erosion stress conditions. So far there is no international standard to back up the technical choices for using a polymer insulator in DC.

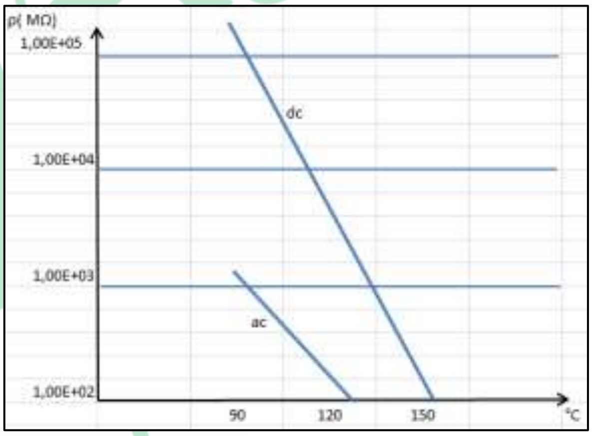
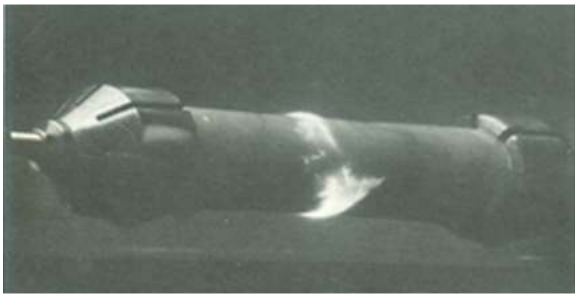


Figure 1: typical body resistance of toughened glass insulators in DC as per IEC 61325 versus AC

To help approaching this question, SEDIVER has designed a test where the silicone sample is not a slab (as in the traditional inclined plan) but a cylinder. This may offer perhaps a more accurate simulation of actual silicone core geometry of an insulator. The results (figure 2) show a much higher erosion level in DC than with AC similar conditions.



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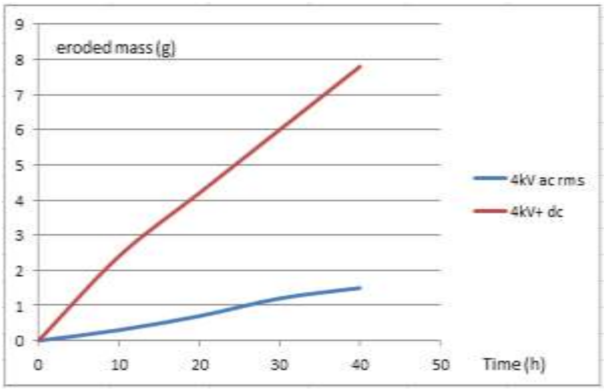


Figure 2: Erosion test in DC on silicone cylinders to duplicate the degradation on a core section of composite insulator and results.

In AC it is well established that a polymer insulator will have less erosion if a shed is directly applied to the end fitting (CIGRE document 284 from B2.03, 2005) thus reducing current density and improving electric field. Degradations from water droplet corona have also been extensively described with good correlation between laboratory testing and actual service conditions). Field observations have shown a similar pattern in DC as described in figure 3 where erosion can be seen near the triple point of a DC silicone composite insulator installed in a coastal type of pollution for about 10 years.

Figure 3: erosion at the shank of a silicone insulator returned from a DC line

1.2 Corrosion of end fittings

Corrosion of DC cap and pin insulators has been found to be a problem in the past mostly with pin corrosion on porcelain discs (figure 4 right) which back then were not fitted with a zinc sleeve. SEDIVER toughened glass always had a zinc sleeve in DC (figure 4 left). IEC 61325 requires today a fully bonded zinc sleeve and adherence tests are well described.

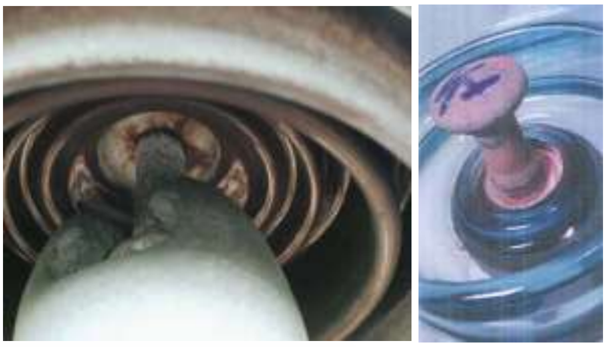


Figure 4:
Left: porcelain DC insulator without zinc sleeve.
Right: SEDIVER early zinc pin protection (BPA early 1980s)

To prevent cap corrosion SEDIVER was the first manufacturer to introduce (patent ref. EP0226474 from 1986) also a zinc collar at the cap (figure 5).
While it is not a mechanical concern this feature will avoid having an additional source of contamination on the surface of the insulator as can be seen in figure 6.
For Sediver toughened glass insulator this aspect was solved in the mid-1980s.
For porcelain it might be a more important question since the activity resulting from rust at the base of the cap can degrade the glaze which once gone can lead to cracks in the porcelain body as can be seen in figure 6.
The contact between the dielectric and the cap, more difficult to achieve with porcelain adds more risks of activity in this part of the insulator.

Figure 5: current zinc sleeve at the bottom of the cap of Sediver DC insulators

SEDIVER standard for the cap collar is to provide at least 100g of zinc at the base of the cap (figure 5) and more for specific cases.

Figure 6:
Left: first generation DC toughened glass insulators with corrosion at the base of the cap
Right: similar problem on porcelain insulators from an 800kVdc line in China.
Bottom: crack at the base of the cap in the porcelain body below the damaged glaze.

Composite insulators, on the other side, only have two fittings, and this is often presented as an advantage for polymers. In fact, reality is more brutal and severe corrosion of the fitting at the triple point has been observed in certain cases with destruction of the seal and severe erosion of the silicone rubber at this location (figure 7).

Figure 7: degradation at the triple point of a DC silicone composite insulator with corrosion of the fitting, disappearance of the seal and erosion of the rubber.

SEDIVER above mentioned patent was also referring to a zinc collar on DC polymer insulator fittings to provide electrolytic corrosion protection. This however only works if the zinc collar is directly in contact with the silicone housing, all bonded together with the zinc fully adherent to the rest of the fitting. This is impossible to do for all designs using a seal at the triple point.

2. Geometrical design of DC lines

It is generally accepted that DC string design is driven by contamination more than dielectric properties of the insulators as such. CIGRE C4-3 TB518 and IEC 60815-4 are providing guidance to determine such parameters. Considered strictly from this angle and disregarding erosion risks possible from excessive compaction of the profile or reduction of hydrophobicity over time, it is possible to have shorter vertical strings, which most likely will be double strings for polymers for safety reasons when single strings are commonly used with toughened glass insulators. Other considerations such as clearances to the tower and maintenance crews' protection have also to be included to the design parameters. The following example for a V string from a designers desk is made for a contaminated level (ESDD=0,034mg/cm², NSDD = 0,044 mg/cm² CUR=5) estimated at the border line between light and medium (figure 8).

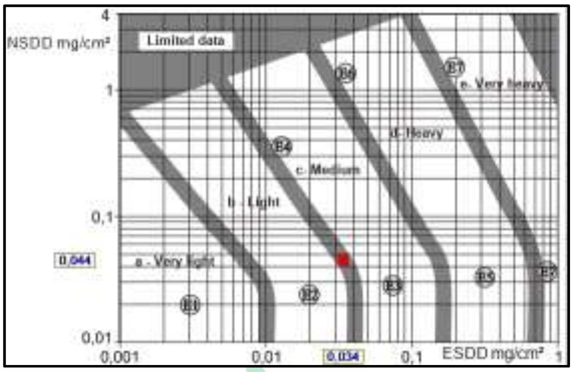


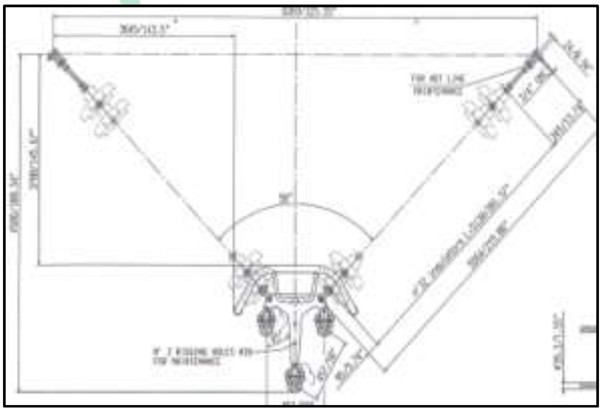
Figure 8: contamination hypotheses for the example

A first theoretical selection of insulators disregarding the need for polymer to reduce grading stress and avoiding excessively packed creepage profiles leads to the table below:

	Spacing	Leakage distance
Silicone polymer	3,9m	15700mm
Ceramic	32x 170 = 5,4m	32x620=19840mm

When designing the V string, the insulator has to fit in a given geometrical structure design, and a minimum clearance is required to the cross arm and to the side of the pole or tower higher than the spacing of the insulator itself. In this case, vertical clearance requirement is defined at 3,7m approximately.

Figure 9 shows the string configuration using toughened glass insulators with this minimum clearance requirement.
No extra length is required compared to what would be the string with a polymer insulator since extension links would be required to match the minimum clearance.
In the end, this project could be built with glass or composite insulators with identical tower designs.



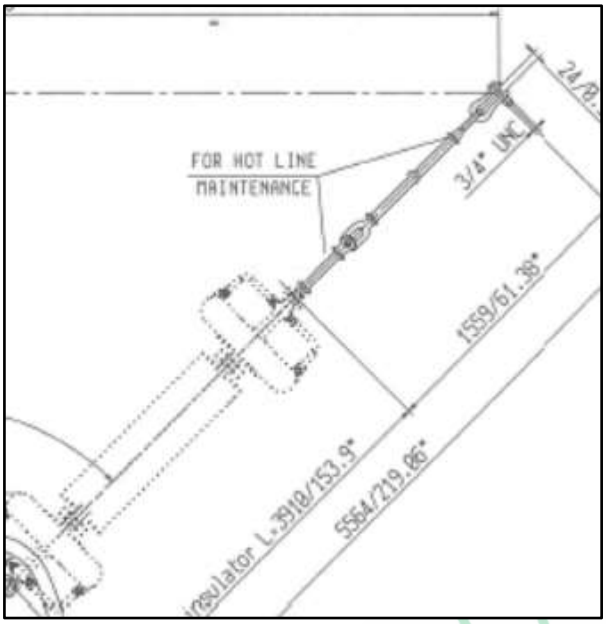


Figure 9:
Left: V string using glass.
Right: detail of the extension link required to meet the minimum clearance when using a polymer. Same overall string dimensions.

3. Field experience

In previous documents (CIGRE Calgary 2007, INMR Rio 2007) we had already mentioned the non-ageing of DC toughened glass insulators (BPA 500kVdc, Great River 500kVdc, Itaipu Furnas 600kVdc) for which old insulators had been taken down for evaluation. Additional results are now available since in Brazil a new sequence of tests was performed on Itaipu 600kVdc insulators after about 28 years and Manitoba Hydro bipole 1 and 2 in Canada (Results for Manitoba Hydro have been published in CIGRE Winnipeg in August 2015) after 40 years of service.
All these results show excellent service performances with an overall condition comparable to new insulators. Contamination conditions of these lines are described in figure 10. (note: Itaipu samples had been found with a very high CUR ratio).

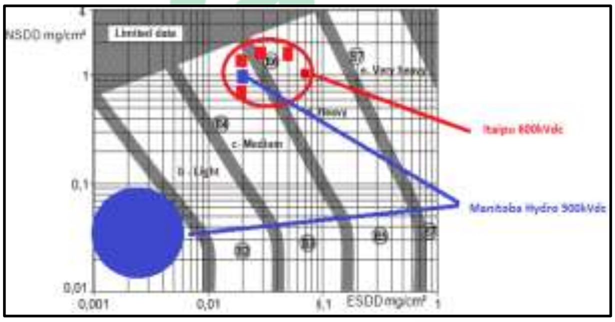


Figure 10: contamination levels measured on samples tested from Itaipu and Manitoba Hydro.

4. Current trends

In the last twenty years, millions of Sediver toughened glass insulators have been installed on DC lines worldwide under the largest possible diversity of climatic and environmental conditions. In the last 5 years, and in North America only, almost a million toughened glass insulators have been or are being installed, which represents about 80% of all the insulators used for these DC projects. Polymers were not even accepted as candidates. In South America for the DC projects Rio Madeira 600kVdc and Belo Monte 800kVdc toughened glass is being used exclusively.

4.1 Handling very harsh contamination conditions

For very harsh conditions, silicone coated toughened glass insulators are emerging and are considered by more and more utilities as the most attractive solution for very high contamination levels, including in China. Among the benefits and features perceived by utilities for using silicone coated toughened glass insulators, the key element is the combination of the hydrophobic property of silicone with the inherent properties of toughened glass (non-ageing, no line separation resulting from internal punctures in porcelain or brittle fractures, or decay fractures in polymers, easy inspection, safe live line work…). Field experience in extreme conditions with almost five years of service in Italy has shown very strong interest in DC. Figure 11 describes the contamination level measured on site for this 200kVdc line in Italy, pointing out conditions which are by far above most if not all the DC lines where polymers had been introduced.

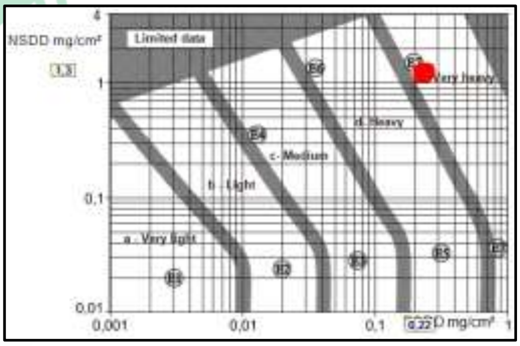


Figure 11: Contamination level of the 200kVdc line in Italy

The results of the periodic monitoring of this line indicate good performance, stable condition of the coating, and a complete elimination of washing or flashovers. To support this field information, salt fog tests were performed in the Sediver R&D center with similar strings of silicone coated toughened glass compared with silicone polymer insulators. The test procedure was a salt fog of 80g/l using the rapid flashover method with steps of 5%. The table below and figure 12 describe the test and the results, showing a superior performance of the silicone coated glass insulators.

	Arcing distance (mm)	Leakage distance (mm)	Result (kV)
Silicone coated glass	715	2088	Withstand -90 kV
Silicone polymer	775	2774	Withstand - 54kV/ flash at - 70kV

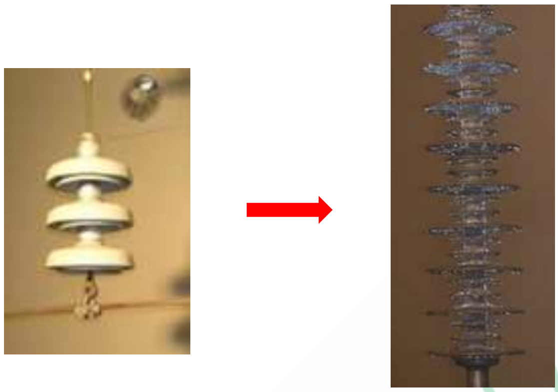


Figure 12: DC salt fog test on a silicone coated toughened glass short string and an equivalent silicone DC polymer insulator.

5. String dimensioning

Pollution deposits on the surface of an insulator are classified between ESDD (Equivalent Salt Deposit Density) and NSDD (Non Soluble Deposit Density). Both are important and while the ESDD contributes to a higher conductivity of the water on the surface of the insulator and subsequently increase leakage currents, the NSDD works like a sponge sucking moisture at morning dew phases or during fog events providing water to the leakage current and dry band arcing mechanism. Additionally, contamination deposits in the field are usually non homogeneous with the bottom of an insulator being more polluted than the top surface. CUR is a parameter describing this property and defined as the ratio bottom to top ESDD levels. In laboratory testing, CUR is often set at 1 for practical reasons, thus it provides more severe conditions than with a higher CUR.
The specific creepage distance is determined to avoid flashovers of the string of insulators under the given contamination conditions. One important element in this discussion is RUSC (Reference Unified Specific Creepage distance which is the minimum USCD calculated as per IEC 60815-4. Many examples are now available with field experience after many years in service (see Insucon 2017 article by Sediver).

Figure 13 gives an idea of the magnitude of the margin of error in the theoretical evaluation of the RUSCD versus laboratory or field performance. This graph needs to be further adjusted by more test results to fine tune the reference to a RUSC.

The type of errors possible with a mathematical model can lead to a possible overdesign of 20% to 30% or more. The consequence in cost is huge and can make a line design become unacceptable to the utility. Large campaigns of pollution tests in DC are required to better document the actual performances.

Likewise, most if not all laboratories produce tests only with a CUR=1 while in reality CUR varies often between 3 and 5 or 7. There is a necessity to define new contamination deposit methods to be able to duplicate with consistency such variable CUR levels in the tests. This will help to better simulate actual field conditions without relying on theoretical correction factors.

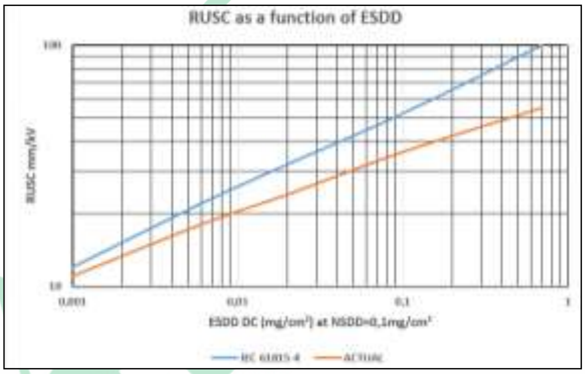


Figure 13: specific creepage distance as IEC 60815-4 versus test data and field experience gathered over the last years (in blue the current curve versus red the estimated true performance)

Conclusion

DC lines are highly strategic assets given their role in the stability of a grid and the amount of bulk power transferred over long distances. The questions of reliability, inspection and maintenance, the possibility of live line work are all taking their place in the decision process of the selection of the proper insulator system, probably even more than for AC transmission lines.

A lot of experience is available today worldwide with toughened glass in DC, and Sediver has the largest and longest experience being uniquely positioned to clearly establish a performance record, with evolutions over the last 50 years, mainly on the dielectric resistivity and corrosion management of the end fittings.

While quantities of DC polymer insulators installed are too low and/or too recent to establish a similar approach, similarities to AC in the degradation process of polymers are already showing up, and the lack of standard does not provide guidance or assistance in the liability of a line designer who would select composite insulators for a DC application.

Whenever a DC line has to cross very heavy contaminated environments Sediver silicone coated toughened glass insulators are an innovative and safe alternative to composite insulators, keeping all the benefits of toughened glass from a maintenance, and live line work prospective