Silicone coating of insulators: latest technical knowledge based on field performance and laboratory testing

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Following the rapid and successful expansion of RTV coated insulators in the overhead line market IEC has started working on a standard following the publication of a very extensive CIGRE brochure TB837 [1]. Sediver has largely contributed and probably introduced to the market more than 20 years ago the concept of “factory coated insulators” in partnership with TERNA, the Italian TSO [2]. Likewise, Sediver launched the concept of an undercoated insulator around 2010 with extensive test results in various pollution conditions [13]. This approach to substitute polymer insulators with hydrophobic surface over glass (but also porcelain) has substantially impacted the selection of insulators in polluted environments in which so far polymer insulators were used for their performance in contaminated environment.

Today many companies offer silicone coated insulators either glass or porcelain and coating is either being applied in factories or on site. The latter case can be divided in two different approaches either directly on the tower or in the direct vicinity of the line or in temporary “sheds” or “specialized containers” trying to duplicate the quality and consistency of factory-made products.

Some performances are still being debated among which adherence which will be discussed in this paper.

More interest also for HVDC applications. In fact, except for China which has already used extensively coated insulators next to polymers in DC there are very few DC lines in severely polluted environments around the world. This will be discussed as well in this contribution.

Finally, a relatively unique field experience will be discussed bringing some light to the far limits of performance of coated insulators in extreme conditions, far beyond the pollution classification from IEC TS60815 [3].

1. Adherence

Worldwide practice for checking adherence can be summarized through 2 test methods:

- Checking adherence through cuts in the coating.
- Checking adherence through a water boiling immersion test.

1.1 Adherence checks through cuts:

There are 2 standards offering a "cut" technique for testing:

ISO 2409:2020 [4] describes "Cross-cut test for paints and varnishes"

ISO 16276-2 [5] is about "Corrosion protection of steel structures by protective paint systems- Assessment of, and acceptance criteria for, the adhesion/cohesion (fracture strength) of a coating" with part 2: Cross cut testing and X-cross testing.

There have been lots of discussions on this test (refer to CIGRE TB 837 brochure [1]) because the standards mentioned above are applicable to varnish (not silicone) and limited to a maximum thickness of 250µm for ISO 2409 [4]. The X cross test method in ISO 16276 [5] does not give thickness limitations. The classification of adherence given in these standards are shown in figure 1. Nevertheless, the multiblade cross-cut test described in ISO 2409 [4] has been used and adopted by all manufacturers and users and proved to be effective. Class 0 and 1 are the usual accepted adherence levels.

ISO 2409:2020(E)

Table 1 — Classification of test results

Classification	Description	Appearance of surface of cross-cut area from which flaking has occurred[a] (Example for six parallel cuts)
0	The edges of the cuts are completely smooth; none of the squares of the lattice is detached.	
1	Detachment of small flakes of the coating at the intersections of the cuts. A cross-cut area not greater than 5 % is affected.	
2	The coating has flaked along the edges and/or at the intersections of the cuts. A cross-cut area greater than 5 %, but not greater than 15 %, is affected.	
3	The coating has flaked along the edges of the cuts partly or wholly in large ribbons, and/or it has flaked partly or wholly on different parts of the squares. A cross-cut area greater than 15 %, but not greater than 35 %, is affected.	
4	The coating has flaked along the edges of the cuts in large ribbons and/or some squares have detached partly or wholly. A cross-cut area greater than 35 %, but not greater than 65 %, is affected.	
5	Any degree of flaking that cannot even be classified by classification 4.	—

[a] The figures are examples for a cross-cut within each step of the classification. The percentages stated are based on the visual impression given by the pictures and the same percentages will not necessarily be reproduced with digital imaging.

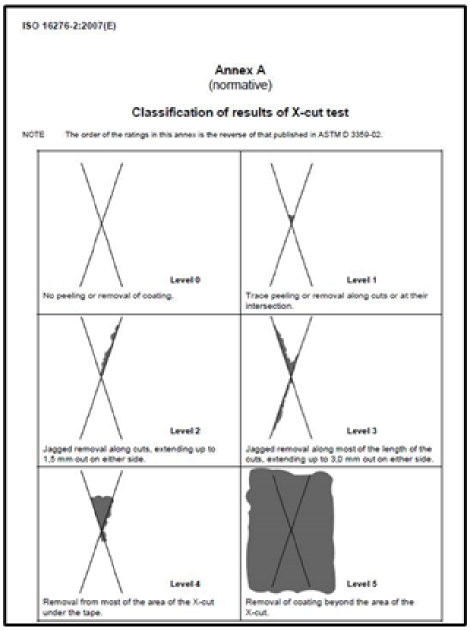


Figure 1: Classification of adherence for the 2 standards

Sediver is performing this test on a very regular basis and accumulated large data using the multiblade technique with blades distant of 3mm as per ISO 2409 [4] and benchmarked in multiple circumstances this method against the X cut described in ISO 16276-2 [5] including insulators with low adherence. It appeared clearly that the multiblade technique can detect insulators which coatings are questionable while the X cut does not necessarily point out these weaknesses as shown in figure 2,3 and 4. The multiblade test seems therefore preferable and more accurate.

Figure 2: Satisfactory adherence tested with X cut method (left) and Cross cut methods (right)

Figure 3: X cut (left) classifies the adherence as Level 1 or 2 whereas Cross cut (right) classifies adherence as class 3 or 4

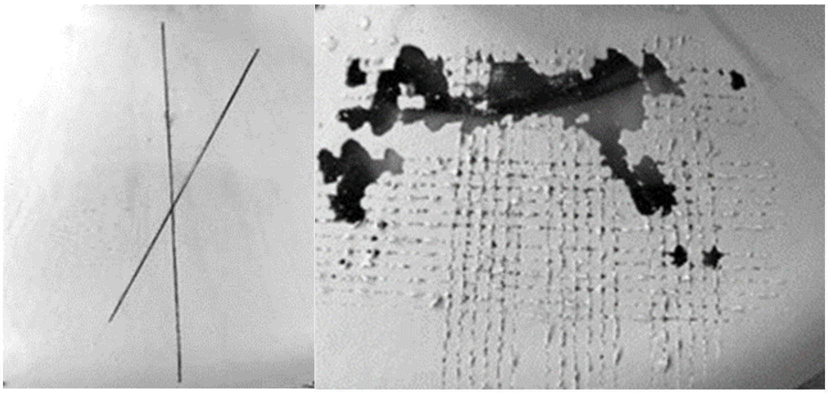


Figure 4: X cut (left) classifies the adherence as level 0 whereas Cross cut (right) classifies adherence as class 5

1.2 Adherence test using boiling water

This test described in IEEE 1503 [6] has been largely discussed in CIGRE TB 837. Questions were raised about the representativeness of the test especially with respect to the thickness of coating compared to polymer housing of composite insulators for which this test was originally designed for. More work is needed as stated in CIGRE TB 837 [1].

Beyond the technical aspects of this test, while benchmark of various brands and manufacturers show fluctuations in the results of this test [7] it can also be noted that it is not easy to consider this test as a sample test given its duration. Shorter durations, including immersion in water at ambient temperature might be considered to replace the current test procedure.

Adherence testing using the crosscut method as per [4] is by far the most appropriate testing technique for sample tests.

2. Silicone coating for HVDC

Many utilities are currently looking at the future challenges that will be faced by their grid. The integration of renewable energy is a critical aspect and, in many cases, those renewable energies sources are remote from the consummation centre and in order to limit the loss of power during the energy transport over long distance, HVDC is a technology of choice. More and more such lines are crossing relatively polluted environments and therefore string designs are more challenging, especially with consideration to longevity, resiliency and ease of maintenance which favours the use of glass insulators. In such cases, silicone coated glass insulators are gaining popularity in DC.

DC glass insulators have special features mainly high purity, high resistivity glass chemistry and appropriate fittings but also special profiles which will produce higher pollution performances [14]. But as far as the silicone coating there is still less experience and knowledge than for AC application.

Knowing the particularity of DC stresses to be able to catch any dielectric discontinuity, adherence is an absolute “must” with a requirement of upmost cleanliness and application control. Therefore, factory coating is even more important than for AC. Besides this, all the elements constitutive of the Sediver specification remain true. One question which is unique to DC is the ageing property.

Erosion tests such as the inclined plan test as per IEC 60587 [8] only give a partial view of the material performance in AC and is not applicable to coatings. The same test is still being under study for DC but far from being conclusive and still in discussion in CIGRE D1 72. These tests do not take into consideration the particularity of the shape of the insulators and in DC this aspect matters even more than in AC. Ageing in DC should be evaluated on DC shape fog type insulators and not slabs of silicone or any “non-DC insulator”.

Very interesting work was done jointly with TERNA and RSE leading to a publication in CIGRE [9] showing the good performance of silicone coating in DC. Additionally, Sediver has studied more in detail an adaptation of the existing 2000h multi-stress test largely used in AC (figure 5) but with a DC voltage applied to the insulators. A benchmark between 2 different chemistries of silicone coating has been carried out using these parameters. The stress was set at 45mm/kV (-DC) which is representative of DC requirements in relatively common cases.

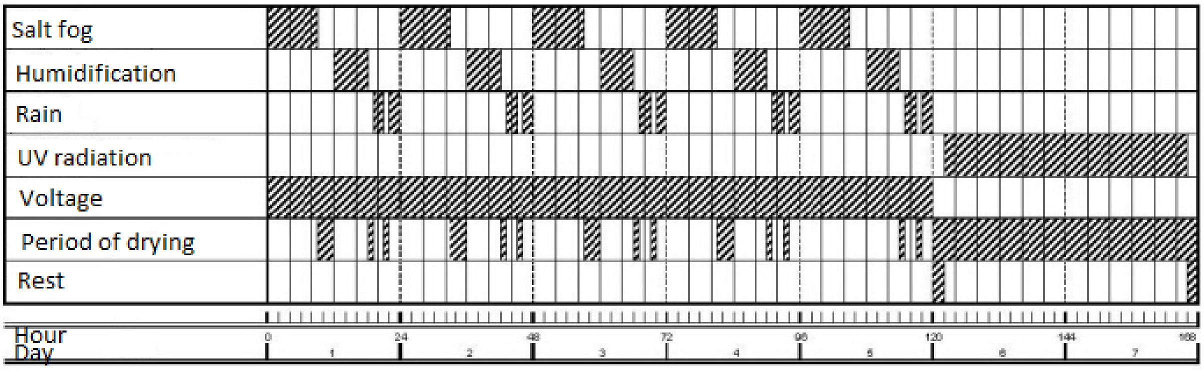


Figure 5: 2000h multi-stress cycle

In this test 4 strings were tested using 2 different coatings and for each case a vertical and a horizontal string as shown in figure 6.

Figure 6: Set up of the double string configuration in the 2000h DC multi-stress test

Both coatings have a chemistry using ATH (Alumina Tri Hydrate) which is a fire-retardant filler (commonly used to reduce erosion in electrical applications). The findings in this test can be summarized as follow:

a. The 2 different coatings do not perform identically one being more eroded (figure 7) while the second coating formulation remains intact (figure 8).

b. Coating n°1 led to several flashovers after 1500h. It shows (figure 9) a substantial reduction in hydrophobicity (HC5 to HC6) at the end of the test.

c. Coating n°2 did not flashover, no erosion and full hydrophobicity retained over the entire time of the test (figure 10)

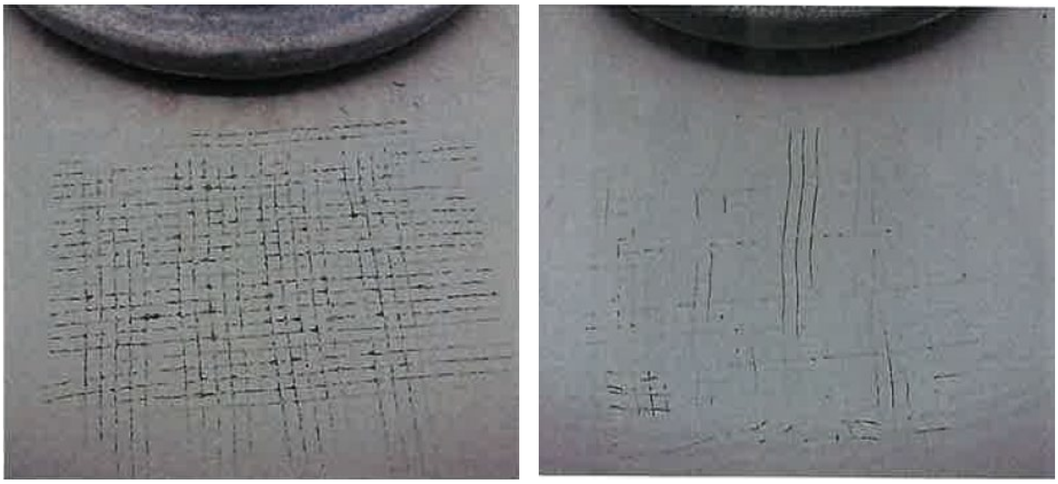
d. At the end of the test both coatings tested well the adherence test as per ISO 2409 [4] using the cross- cut method (figure 11)

Figure 7: Erosion (class 3 to 4 as per [10]) on coating n°1 after the 2000h DC test

Figure 8: Typical aspect of coating n°2 after the 2000h DC test

Figure 9: Coating n°1: hydrophobicity HC5-HC6 after the 2000h DC test

Figure 10: Coating n°2 hydrophobicity HC1-HC2 after the 2000h DC test



Coating n°1 Coating n°2

Figure 11: Both coatings are showing good adherence (class 1) as per ISO 2409 after the 2000h DC test

This test overall appears to be very interesting for the discrimination between various coatings for use in HVDC applications. While the acceleration factor remains, like for all ageing tests, this test is clearly pointing out the benefits of using coating n°2 in DC since no flashovers nor any degradation occurred over the course of the test. It must be noted that both coatings pass successfully the classical 2000h AC multi-stress test. It demonstrates once more the higher severity of DC stress conditions which requires more care in the selection of insulators and more generally housing materials or coatings.

3. Silicone coated glass insulators in very extreme conditions

With millions of insulators in service for now more than 20 years there are silicone coated insulators used in the most various environmental conditions. Sometimes the pollution conditions go beyond anything described in IEC TS60815 [3]. For example, in Peru ESDD/NSDD levels are far beyond the very heavy class as shown in figure 12 and figure 13 crossing dry deserts with salt mixed with sand and sometimes very close to the coast.

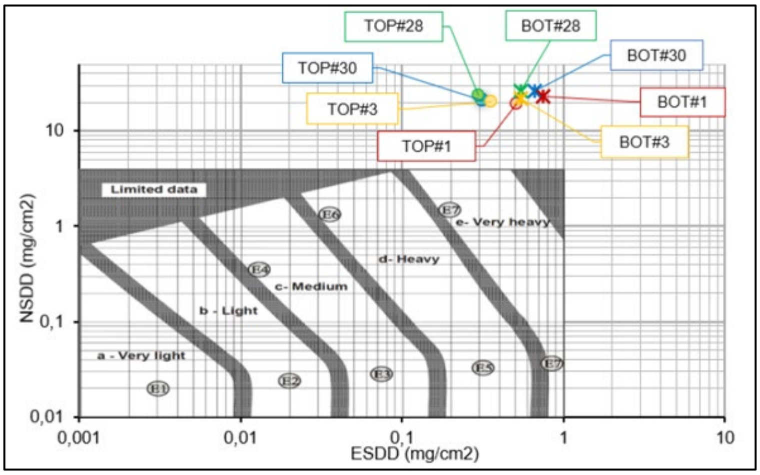


Figure 12 Pollution levels measured on site in Peru

Figure 13: Overall view of typical environment where some 500kV lines are in service (Chilca Feniz 500kV)

The string design in these regions follows local specifications with USCD values which can be considered as very low in comparison to the extreme pollution levels. The strings are made with values of USCD around 55mm/kV.

Despite the benefits of silicone coatings or silicone housing (for polymers) the amount of pollution and environment conditions has shown that over time dry band arcing can become strong (figure 14) degrading the insulator surface as shown in figure 15 and already described in various occasions in test stations [11].

Figure 14: Electric activity on a string of glass silicone coated insulators on the 500kV Chilca Feniz line

Figure 15: Erosion of the coating of a glass insulator (left). Polymer insulator failure (right) [12]

Under these extreme conditions it is possible to see glass insulators shatter (figure 16) once the coating is severely eroded around the pin.

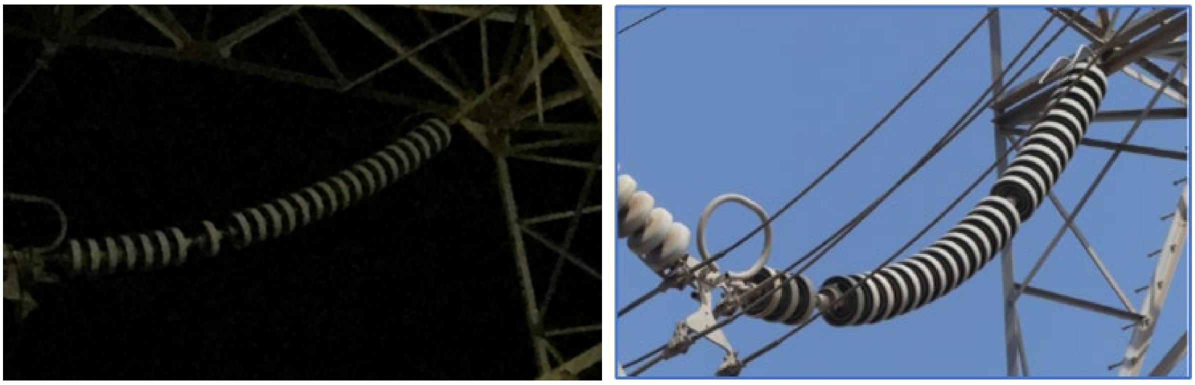


Figure 16: Stubs in a string of coated insulators subjected to extreme conditions (beyond the IEC TS 60815 class "very heavy") and severe under insulation (USCD=55mm/kV)

Even if some units are shattered and unlike for polymer insulators there is no risk of facing a line drop with a stub as it is the case with polymer insulators (figure 15 from Peru). Wisdom would therefore favour silicone coated glass with possible stubs rather than service interruption with catastrophic failures.

Another interesting field report comes from a recent line inspection in Peru as shown in figure 17.

Figure 17 : 500kVAC line Chilca Poroma USCD =54mm/kV

The insulators have been in service for 8 years in an area with dust, near the coast with no rain, and never washed. Some insulators were taken down for evaluation and pollution levels were established beyond "very heavy" as often in Peru (figure 18).

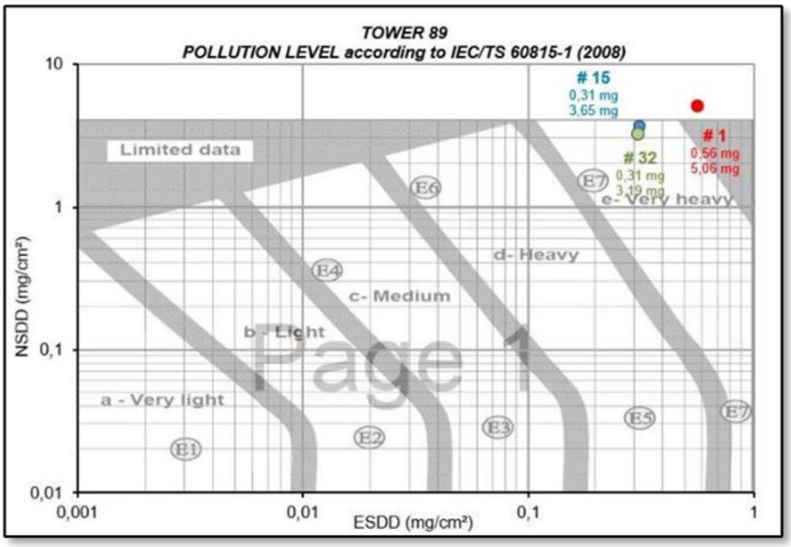


Figure 18: Example of ESDD/NSDD levels found during the inspection

Hydrophobicity was checked as shown in figure 19 with very good transfer property despite the harsh environment.

Other interesting findings shown in figure 20 demonstrate that despite hydrophilic deposits such as moss, lichens or heavy bird droppings, overall, the performance of the strings remain excellent.

TOP SURFACE **BOTTOM SURFACE**

Figure 19: Hydrophobicity checks showing HC1 and HC 2 levels despite the extreme pollution deposits

Figure 20: Left: lichens and moss on the coating. Center and Right: heavy bird dropping

Conclusion

Silicone coated glass insulators are gaining more and more attraction either in AC or DC. In all cases several points of importance need to be considered in specifying coating and coating application. CIGRE TB 837 [1] gives good recommendation. A few more specifics have been discussed in this paper:

- Adherence test is better established using ISO 2409 [4] multi-blade cross-cut method which is more severe than ISO 1627662 [5] with the X cross technique

- HVDC is more challenging than HVAC for coating (like for any type of insulator). Special care should be exercised when selecting a coated insulator for DC.
  a) Results of erosion and ageing tests in AC are not representative of DC applications.
  b) DC insulators have specific shapes to cope with the dynamics of DC discharges. This shall be taken into consideration when testing coatings for DC applications. Testing slabs of coating as per IEC 60587 [8] is irrelevant and is not in the scope of the standard itself. Tests on real insulators is the only appropriate approach.
  c) The 2000h DC multi-stress test is a very good discriminator and the test performed in the Sediver laboratory has shown clear difference between coatings.

- Extreme pollution conditions beyond IEC classification such as areas in Peru with not enough leakage distance can damage insulators. Polymer insulators have shown erosion leading to line drops and separations. Coated glass insulators can shatter under such extreme conditions but will maintain a safe operation with stubs and no risk of line drop.

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