Silicone Coating on Toughened Glass Insulators: Review of Laboratory & Field Performance

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Silicone coating on toughened glass insulator : Review of laboratory and field performance

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Silicone coatings have been largely used in substations for at least 30 years. Likewise it has been used by numerous utilities as a palliative approach to contamination problems for overhead line insulators [1], [2], [3]. Current trends demonstrate that silicone coated toughened glass insulators are now being selected from the design stage rather than as a fix of an existing pollution problem. While this market is expanding including in projects where polymers are no longer the preferred choice, there are still many questions related to material selection, performance, longevity…In this context, SEDIVER is devoting substantial resources in its Saint Yorre R&D facility in France concentrating simultaneously on laboratory research (including external partners), evaluating electrical performances and field monitoring. The following document provides some of the work done by SEDIVER on these topics.

Starting from a very basic question

At the beginning came the very simple but crucial question from several maintenance managers from different utilities around the world: how can we keep the unique benefits of toughened glass in cases where washing is necessary due to extreme contamination conditions? This refers to the ability of any maintenance team using glass to make an immediate inexpensive and fully reliable diagnostic of a string of insulators by naked eye compared to the possible hidden faults or difficult and not yet fully reliable inspection methods required for composite insulators. Additionally, when live line work comes in the equation you even get a stronger motivation for alternative solutions to polymers. With this question came the interest for coatings on overhead line toughened glass insulators.

Material selection

Silicone coating materials exist under a large spectrum of chemistries and like for composite insulators the need for evaluating the impact of environmental and electric stress conditions on the coating material is central in the selection of the silicone [4]. Under extreme pollution conditions silicone coatings generally speaking can make a decisive difference in withstand capabilities thanks to the hydrophobic nature of silicone. However, longevity, performance and ageing of the coating highly depends on the selection of an optimum chemistry, the application method and quality criteria. Supported by decades of research and testing of polymer insulators and rubber housing materials, SEDIVER has concentrated its initial screening of silicone coating on erosion, tracking and hydrophobic properties as they are likewise important. While tests such as the inclined plan are still controversial for silicone rubber and coating there are several other evaluation methods discriminating silicone coatings. Like for silicone rubber used in composite insulators, coatings can be made with silicone containing various fillers for increasing the resistance to erosion or none at all (quartz or ATH fillers are commonly used among manufacturers). As an example (among a large diversity of test protocols established for accelerated ageing tests) interesting results can be found from a 2000h multi-stress test (figure 1) combining UV, rain, salt fog, humidity, voltage on a weekly cycle performed according to a specification from TERNA (Italy). A clear discrimination appears between various coatings including coatings made with different types of ATH (figure 2).

Figure 1: 2000h multi-stress ageing test on coated insulators (SEDIVER laboratory)

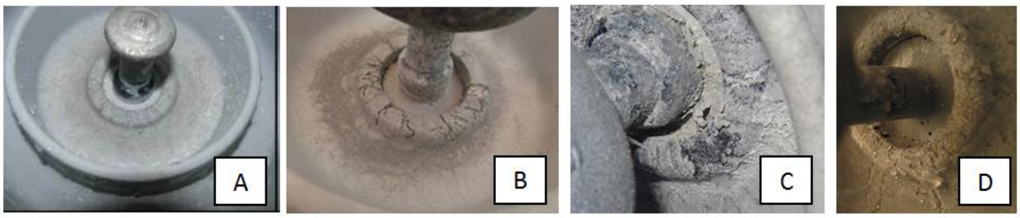

Figure 2 : Samples after 2000h ageing test. A: polymer 1 ATH type a – B: polymer 2 ATH type b – C: polymer 2 ATH type c – D: polymer 2 quartz filler

Ageing and longevity

When dealing with polymeric materials ageing becomes a central question. Composite insulators have now been around long enough to give an answer based on field experience. Today average expected service time of about 15 to 20 years is a commonly accepted number shared among experts and utility maintenance teams. Main weaknesses come from the erosion of the rubber housing and the seals which is key in the defense system of a composite insulator given the absolute necessity to prevent exposure of the core and moisture ingress.

Coating over toughened glass is different in a very fundamental way. While we are looking for the best possible material with respect to erosion resistance, the fact is that even when the coating is damaged the integrity of the glass insulator is never at risk. Whatever happens to the coating does not compromise the inherent properties of the glass material which still works like any normal non coated insulator.

The work done in our R&D center is therefore concentrating on three aspects:

- Erosion resistance
- Hydrophobicity evolution under various stress conditions
- Performance under pollution

The findings are to be considered with caution given the diversity of situations between a desertic environment like in the Peruvian desert [5] or along the coast of Sicily in Italy for example. Likewise behavior under AC or DC has to be analyzed with respect to the specific stresses implied.

Such information has been accumulated by SEDIVER for almost 20 years now on silicone coated toughened glass insulators, with a monitoring program including yearly evaluations of samples removed from the lines. SEDIVER has already published several documents in relation with TERNA for most part, with AC and DC applications [6], [7], [8].

What can be learned from samples removed from service is the overall good preservation of the hydrophobic properties including for areas where previously washing cycles were performed almost quarterly. The stress level encountered in these applications translates into some reduction of hydrophobicity around the pin area, which is expected given the electric field distribution prevailing in that region. Figure 3 shows the hydrophobic status of such an insulator after 7 years in a coastal environment with a pollution level equivalent to the level E7 as described in the IEC60815-1. Figure 4 shows the electric field modelling around the pin explaining why this section of the insulator suffers more than the rest of the insulator.

Figure 3: Hydrophobic status (WC3) near the pin. Level of pollution E7 according to IEC60815-1

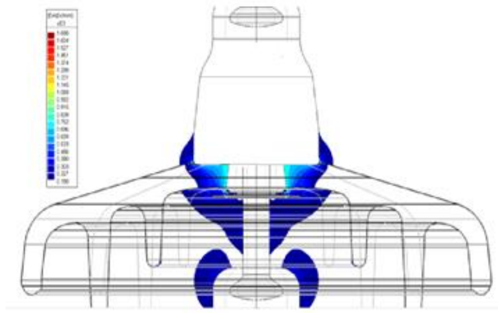

Figure 4: Electric field modelling

It also appears that the overall hydrophobicity of insulators even from the live end remains well preserved and is classified between WC1 and WC3. Additionally, what is clearly pointing out from our laboratory tests on short strings as well as field observations is the fact that a complete string never loses its global hydrophobic performance despite some hydrophilic areas on some localized parts of individual units along the string and mostly near the energized side.

Pollution Performance

Service performance has largely confirmed that coatings remove the needs for frequent washing, eliminating risks of flashover. The main function of the coating being the ability to prevent contamination flashover, SEDIVER has also put a special focus on artificial pollution tests.

1- Clean fog pollution tests with solid deposit layers

Clean fog pollution tests with solid deposit layers were performed in partnership with STRI in their laboratory in Sweden and the results were later on confirmed in the CEB high voltage laboratory in Bazet, France. One of the difficulties remains in the preparation and deposit of the contamination on a hydrophobic surface prior to testing with or without recovery to get a uniform pollution layer in a repetitive way.

The approach used by STRI Team is now internationally accepted and used as a basis for CIGRE Round Robin Test within CIGRE WG C4 303. The test procedure comprises the following steps:

- gentle cleaning
- Pre-conditioning
- Application of the pollution layer

The insulators are cleaned by washing with warm water and a sponge. Pre-conditioning is performed by applying a dry inert material in powder form (in our case Kaolin) to the clean and dry insulator surface by e.g. brush. This layer was applied as uniformly as possible, especially at places, which are difficult to reach. After the application, most of the powder is blown off by compressed air until only a very thin layer remains on the insulator surface. The adequacy of this layer was controlled both visually and by Wettability Class (WC) measurements performed according to IEC TS 62073 Method C, to ensure that the surface of the insulator was completely hydrophilic (WC=7) after pre-treatment

Then the insulators were dipped and twisted in a slurry comprising tap water, kaolin and salt in order to reach the targeted pollution level (figure 5). The insulators were then left to dry at room temperature before to be tested two days later (so a maximal time of 16 + 48 h as a rest time is allowed).

Figure 5 : pollution of silicone coated insulator by dipping process

Voltage tests were performed in accordance with the Rapid flashover Solid Layer Pollution test Method [9]. The polluted and dried insulators were put into the test hall as shown in figure 6. The insulators were wetted according to IEC 60507 into the hall. After 15 minutes of wetting the voltage was applied. Every five minutes the voltage was increased in steps of 4 kV (about 5% of the estimated flash over voltage). In case of a flashover the voltage was tripped and then immediately applied at a level decreased by one step (4 kV). The test is continued until the flashover level started to increase, indicating cleaning of the insulators. The total test duration was about 100 minutes.

Each test was repeated on two strings of 5 insulators (with a creepage distance of 445 mm per unit).

Figure 6 : view of the test set up in STRI

Test results of the pollution are typically summarized as in figure 7 where O stands for withstand and X means flashover.

Test voltage (kV)	Rapid flashover test results																																			
158															X				X																	
154														o		X		o		X																
150													o				o				X															
146												o										X														
142											o												X		X		X									
138										o														o		o		X		X		X		X		X
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Figure 7 : test results at SDD 0.1 mg/cm² on RTV coated insulators.

	Test 1	Test 2	Average
RTV-coated, SDD 0.3 mg/cm²	88 kV	80 kV	84 kV
RTV-coated, SDD 0.1 mg/cm²	128 kV	136 kV	132 kV
Non coated glass, SDD 0.1 mg/cm²	76 kV	76 kV	76 kV

Figure 8: Clean fog pollution test with solid layer ESDD: 0,1mg/cm², NSDD: 0.19 mg/cm²
CUR: 0.7 on short string of 5 insulators

These results (figure 8) show a substantial increase in the withstand voltage compared to a non-coated string with a performance similar or superior to an equivalent composite insulator.

2- Clean fog pollution test on samples removed after about 20 years in service.

Sediver performed in CEB high voltage laboratory a clean fog pollution test to evaluate the performance level of silicone coated insulators removed from the field after about 20 years in service (figure 9) in an environment characterized by a mixt of desertic, marine and industrial pollution sources. On one sample insulator, ESDD and NSSD was measured in order to apply a similar level of pollution on new glass insulators (ESDD of 0.1 mg/cm² and NSDD of 0.1 mg/cm²) for the sake of comparison of performance.

Figure 9 : samples on RTV coated insulators removed after about 20 years in service)

A test was performed in clean fog condition according to Rapid flashover solid layer pollution test method for a duration of 100 minutes on a string of 4 units as displayed in figure 10.

Figure 10 : *Right*: view of the tested string and *Left*: view of the test arrangement

The string of 4 units of artificially polluted insulators shows a U_{50} values of about 72 kV in the test conditions. The 4 units returned from the field after about 20 years of service flashed over at 240 kV and were characterized by a high level of hydrophobicity (figure 11). This result highlights the benefit of the RTV silicone coating and the performance level achieved after 20 years of exposure in a heavily polluted environment.

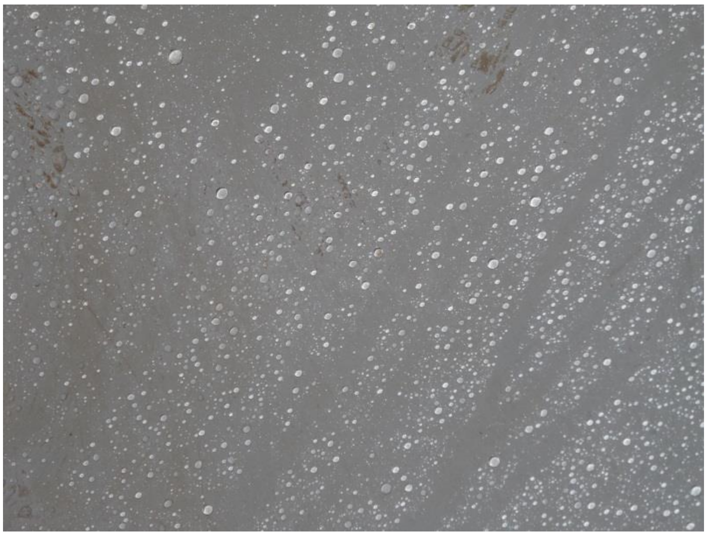
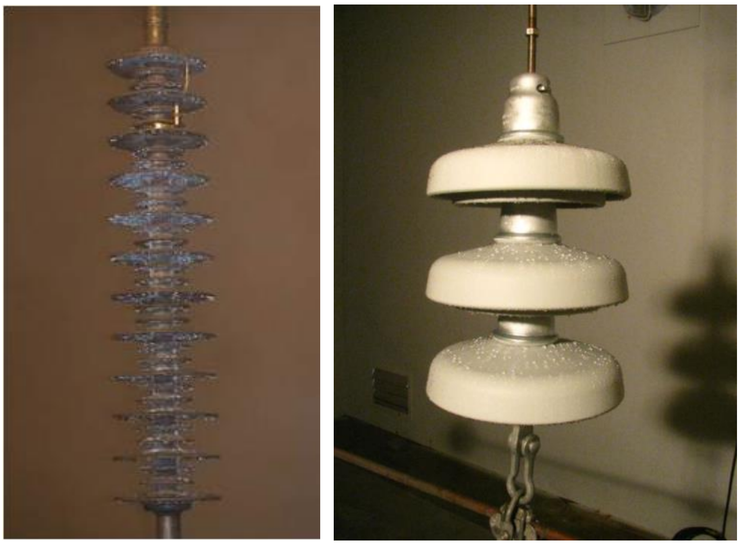


Figure 11 : hydrophobicity of RTV coated insulators after 20 years in service

3- DC Salt fog pollution test

Salt fog pollution tests (80g/l) were performed in DC (negative polarity) on silicone coated glass insulators in the SEDIVER St Yorre facility (figure 12). To complete the tests series in salt fog conditions, composite insulators with a typical DC silicone housing profile with similar creepage distance and arcing distance as the glass string were also tested.

Substantial improvements have been pointed out during this program with an advantage for the silicone coated toughened glass insulators compared to composite insulators. This result is in line with field monitoring on an actual DC line equipped with SEDIVER silicone coated toughened glass insulators.



	Composite insulator	RTV coated insulator
Arcing distance	775 mm	715 mm
Creepage distance	2774 mm	2090 mm
Withstand voltage (3 hours)	- 54 kV	- 70 kV
Flashover voltage	- 70 kV during 2nd hour	> -80 kV

Figure 12: DC salt fog tests results. (SEDIVER R&D laboratory)

Field monitoring

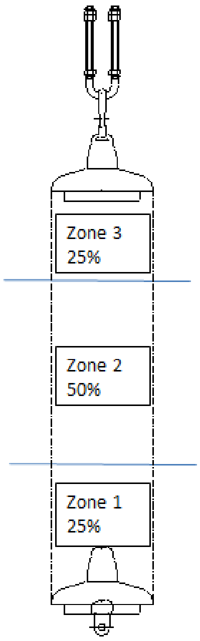


Figure 13 : String sectioning for coating evaluation

As discussed earlier, SEDIVER R&D is simultaneously working on laboratory tests and field monitoring. Various aspects are closely monitored including the overall condition of the insulators, adherence, thickness, comparing hydrophobicity, recovery, pollution levels, and contaminant conductivity measurements…. Besides the benefit of calibrating our laboratory testing procedures to the findings in the field we have also measured what we call the gradient in stress on the coating along the string. Some units can be partially WC5 as explained earlier, but overall the string itself remains fully hydrophobic. This has been observed so far in all the environments investigated. To help monitoring the evolution along a string we have established a geometric approach dividing a string in 3 sections: bottom 25% top 25% and middle of the string for 50% of the length (figure 13). So far we have only seen some light erosion (type CE2 in the bottom portion of the string as per SEDIVER Coating Erosion Class guide see figure 14). Likewise for hydrophobicity, only some areas of the same portion have been affected. This demonstrates the very strong buffer and the very high resilience of silicone coating as applied to our glass insulators. No flashover has been encountered on the coated insulators so far with no need for washing.

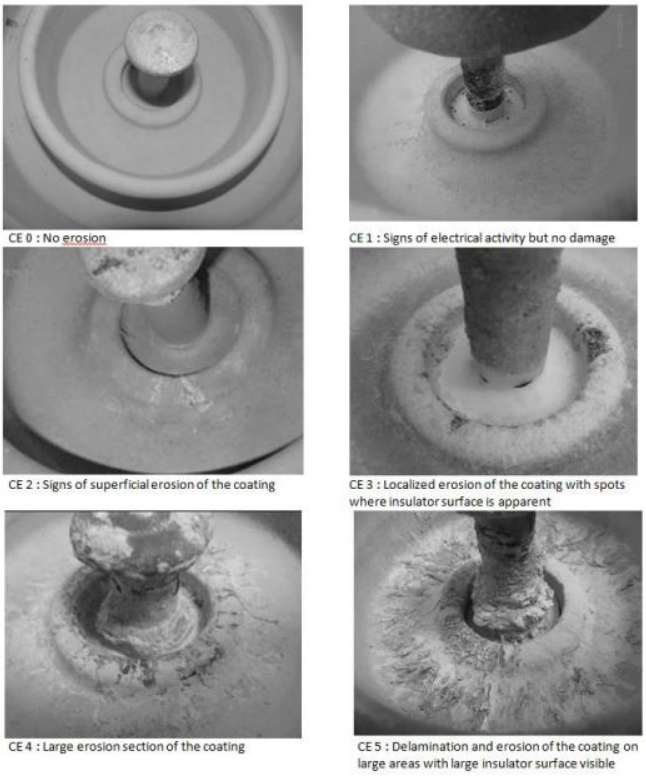


Figure 14: Sediver Coating erosion Class guide

Conclusion

Silicone for overhead transmission lines is being used mostly in the two conditions described in this paper. Either it is used as rubber housing for a composite insulator or as a coating over a traditional glass or porcelain insulator.

For polymer insulators any damage, erosion or reduction of hydrophobicity along the core can lead to an acceleration of the ageing resulting at some point in time in a failure. For a silicone coated toughened glass insulator there is no such critical condition since underneath the coating there is a toughened glass dielectric body which is immune to the environmental conditions.

Pollution performance in AC and DC of silicone coated toughened glass insulators have been demonstrated by Rapid Flashover Solid Layer Pollution test either on artificially polluted units or from naturally polluted samples returned from the field.

SEDIVER has initiated a monitoring of the performance of coated insulators in the field. As of today what appears clearly from strings removed after more than a decade of observation is a partial reduction of hydrophobicity on some units (units removed after 20 years of service have shown excellent hydrophobic properties). Overall, the insulator string itself always remains fully hydrophobic which is the key factor impacting the performance in service with an elimination of the need for washing.

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