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Review of 20 Years of Sediver Silicone Coated Insulators in the Field

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Abstract

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. Applications of the silicone coating can be performed in several ways: directly on insulator string in the tower, on site before assembly in tower or in insulator factory by the supplier before on site delivery.

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. This market is currently expanding including in projects where polymers are no longer the preferred choice. This paper presents projects where silicone coated toughened glass insulators have been successfully used for years in a variety of environments and describes the benefits of this technology through service experience and follow up analyses.

Introduction

Among the various options to fight contamination problems on overhead lines the choice today lies between using higher creepage distances on the insulators, and using silicone rubber housing materials or both. The latter solution can be achieved through a silicone housing as it is the case for a composite insulator or by the application of a silicone coating over a ceramic (glass or porcelain) insulator.

The failures encountered by quite a number of utilities with composite insulators have considerably impacted the confidence in the technology while actually often used to solve contamination problems.

The ageing mechanisms reported in the last decade are also an indication of the impact of harsh conditions on a component specifically installed there to sustain these very severe conditions.

More than 2 million of silicone coated toughened glass insulators (Sedicoat®) are in use today in more than 17 countries. They are systematically installed in harsh conditions where otherwise composite insulators would be installed. The limitation for the use of composite insulators is related to their short lifetime and difficulties of maintenance in service conditions where the severity of the environmental conditions is proven. The main driver for the decision of utilities to engage into a coating solution instead of a composite insulator is long term reliability, capability of live line work and easy inspection methods. All these features represent a major attribute of toughened glass insulators especially when compared to composite insulators or even porcelain discs.

Examples of service experience and performance of silicone coated toughened glass insulators are presented in this paper covering a variety of conditions.

1. Successful ongoing experiences in service

Many papers published by Sediver over the years [1-4] relates historical development performed with TERNA, the Italian TSO, who widely implemented the use of Coated toughened glass insulators in high voltage overhead transmission line. After 11 years of large scale use in heavy polluted environment, the silicone coating over toughened glass insulators technology keep offering reliable performance in service without any reported electrical fault or need for washing in areas which were previously regularly subjected to maintenance due to heavy pollution accumulation.

Another long lasting experience is in Qatar on a 132 kV overhead Line Al Shala- Umm Bad. Silicone coated toughened glass insulators with an open or aerodynamic profile were first installed in 1997 and are still in use with very good performances. Some samples units were evaluated in 2015 and the benefit of the silicone coating has easily been demonstrated after 18 years in service [1.] without any need for washing. The environment of the line is characterized by a mix of desert, marine and industrial pollution sources.

Sediver also already reported many examples of projects in coastal environment in the USA, in Canada, in Sri Lanka, North Africa, Latin America and many projects around the Mediterranean sea. All customers' feedbacks report good results and satisfactory performances to mitigate pollution born issue.

This papers will focus on some special cases of applications which can offer some deeper understanding of the benefits of the technology.

2. Experience in Peru, in highly polluted environment

Peru is an extremely biodiverse country with habitats ranging from the arid plains of the Pacific coastal region in the west to the peaks of the Andes mountains vertically extending from the north to the southeast of the country to the tropical Amazon Basin rainforest in the east with the Amazon river. The high voltage Peruvian network is mainly based on 220 and 500 kV overhead lines. The power network developed in the late 2010's is mainly located on the western region of the country along the Pacific coast with a 500 kV Overhead line running from north to south of the country. The environment of this line is characterized as desert, mountainous environment with locally severe exposure to sea born pollution. This combination of contaminants make the insulation of the line a critical point.

Following many line drops with composite insulators [5.] in a similar environment, the technology of toughened glass insulator and often silicone coated toughened glass insulators was selected for many projects and applications. Sedicoat® silicone coated insulators were used instead of regular toughened glass insulators when the distance to the sea coast was less than 10 km.

Insulation design was based on IEC 60815-1, using a specific creepage distance of 31 mm/ kV or recently renamed as USCD (Unified Specific Creepage Distance) of 53.7 mm/ kV phase to ground.
A typical design of the insulator string is based on 29 units of insulators with a 160 kN rating, fog profile with a creepage distance of about 620 mm per unit. The first case to be studied in this paper is the overhead line 500kV Chilca – Carabayllo was erected in 2010 and energized in 2011.
The line route is described in Figure 1.

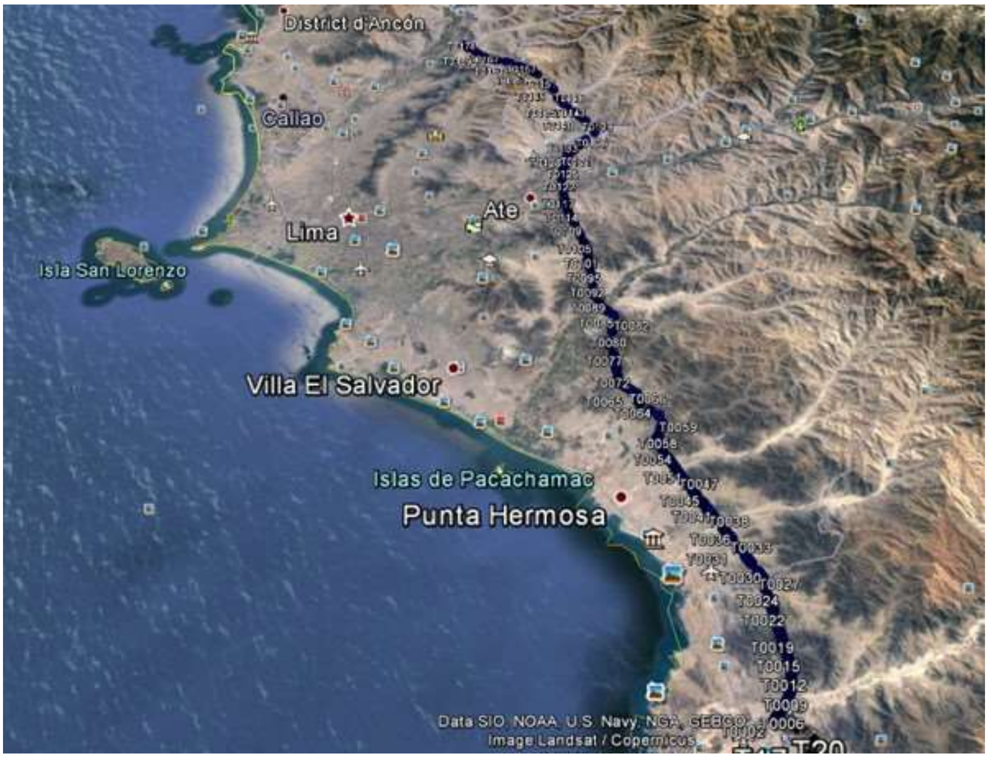


Figure 1 : Line route of the Chilca-Carabayllo 500 kV AC.

After about 5 years of service, a string of a suspension tower located in the south district of Lima was taken down and samples were submitted to evaluation. A series of tests was performed as follow :

- visual inspection
- the measure of the pollution level on the surface of these insulators according to IEC 60507 and IEC 60815 standards,
- and an electrical test in clean fog chamber according to IEC 60507 standard § 6.7.

2.1/ visual inspection

First observations: all insulators display a layer of pollution built up on their surface (especially on bottom surfaces) (Figure 2).

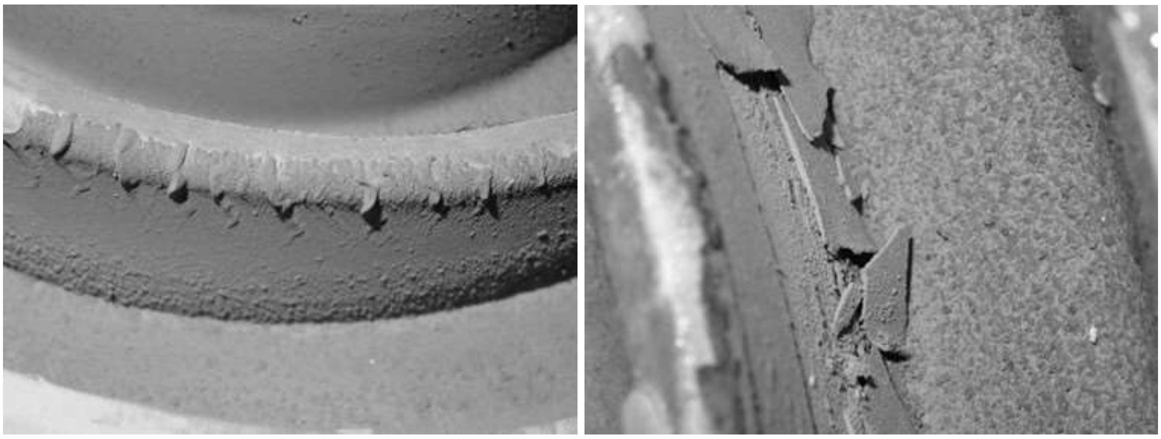


Figure 2: Example of pollution deposit on the bottom part of insulators.

Electrical damages due to the electrical activity linked to the accumulation of pollution have been observed around the pins of the units removed from the line.

First type of damage is an attack of the zinc sleeve (sacrificial anode) as shown in Figure 3. This type of degradation is the results of electrical activity around the insulator pin and is expected in such a polluted environment. This is also a proof that the sacrificial anode is perfectly doing its job as no degradation could be observed on the pin shanck. The pin sleeve protects the pin from corrosion and therefore ensures the long term mechanical reliability of the insulator.


Figure 3: Insulator number 1(left) and Insulator number 2 (right)

Second type of damage is the degradation of the silicone coating localized on the anti-corona rib and classified as light according to the SEDIVER Coating Erosion Class available in annex 1 (Figure 4).


Figure 4 : n°1 (high voltage end) classified as CE 1 / CE 2(left) and n°2 classified as CE 1 / CE 2 (right)

All others insulators in the string show an erosion level of the coating that is classified as CE1.
The section around the pin of the insulator will be the most severely challenged during the life of the insulator, and hydrophobicity will decrease primarily there as shown in Figure 5.

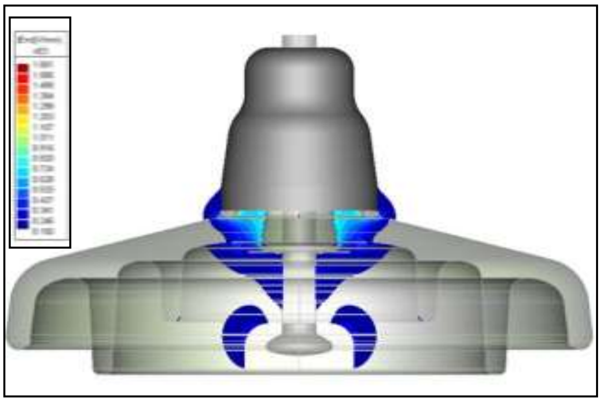


Figure 5: Electric field around the pin of a suspension cap and pin insulator.

2.2/ Evaluation of the site pollution severity

The measures have been performed according to IEC 60507 appendix D6 and the pollution level is given according to IEC 60815.

Insulator	Time in service	ESDD (mg/cm²)	NSDD (mg/cm²)	Pollution level
Insulator n°1 (Top surface)	About 5 years	0.17	3.10	Very Heavy
Insulator n°1 (Bottom surface)		0.41	12.5	Very Heavy
Insulator n°1 total		0.33	9.24	Very Heavy
Insulator n°14 (Top surface)		0.02	5.54	Heavy
Insulator n°14 (Bottom surface)		0.21	17.18	Very Heavy
Insulator n°14 total		0.14	13.15	Very Heavy
Insulator n°19 (Top surface)		0.03	6.71	Heavy
Insulator n°19 (Bottom surface)		0.25	17.19	Very Heavy
Insulator n°19 total		0.17	13.56	Very Heavy
Insulator n°29 (Top surface)		0.02	1.39	Medium
Insulator n°29 (Bottom surface)		0.23	14.25	Very Heavy
Insulator n°29 total		0.16	9.80	Very Heavy
Average value for the string		0.20	11.43	Very Heavy

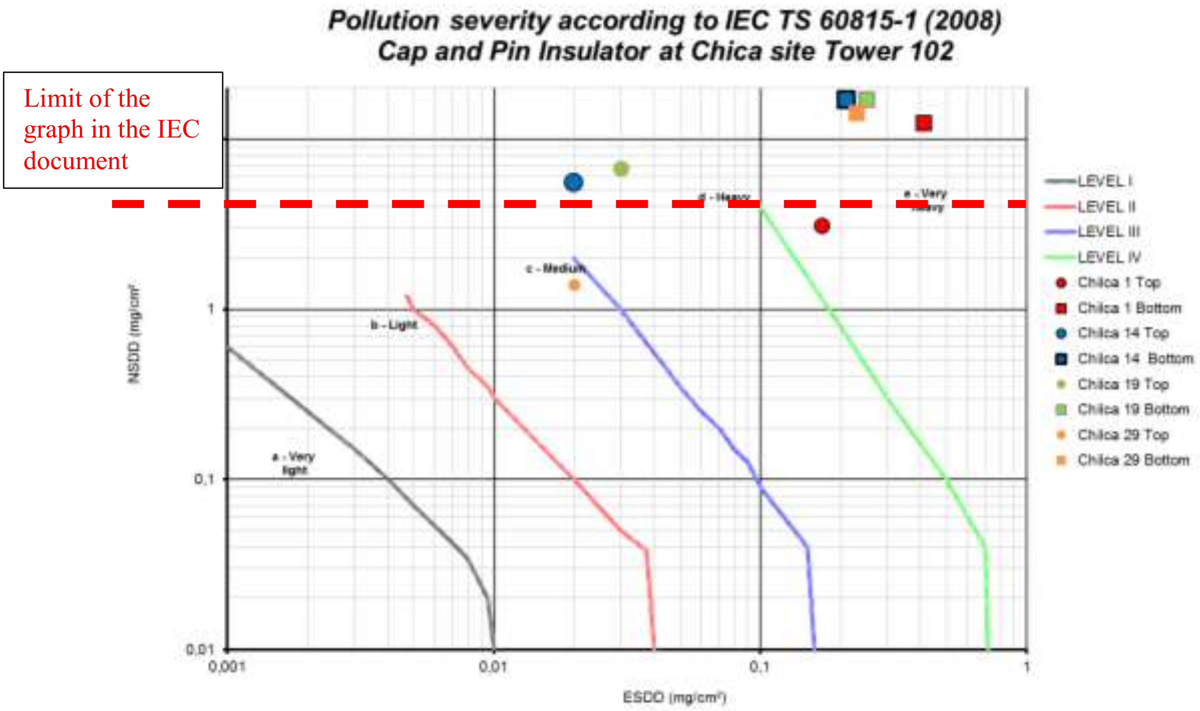


Figure 6 : graph of the pollution site severity

First it should be highlighted that from the 8 measurements, 6 results fall out of the limit of the graph given in IEC TS 60815-1 (2008) and that in order to plot those values in the graph the limits for the highest NSDD values have been increased from 4 to 20 g/cm². This clearly shows the unusually high values of the NSDD components measured on those insulators.

A higher level of pollution can be observed on the bottom surfaces of the insulators compared to the top surfaces. The lower level of pollution measured on top surfaces compared to the bottom surfaces might be the result of the natural washing effect due to wind, rain or fog condensation.

A second comment is that the level of pollution along the string length is homogeneous, specially for the bottom surfaces of the insulators. Regarding top surfaces, a difference can be noticed between insulator 1 (at the bottom of the string on the high voltage end) and insulator 29 (at the top of the string near the tower structure) and can be explained probably by the efficiency of the natural washing effect (no protection from any upper unit).

Pollution level on top surfaces is measured as “Heavy” according to IEC 60815-1 (2008) whereas the bottom surfaces exhibit a pollution level that is classified as “Very Heavy” especially for the Non Soluble Deposit Density component which is almost outside of the IEC 60815 chart limits (Figure 6). Those high NSDD values can be explained by the dry and desertic direct environment of the tower.

Another commonly used factor to describe the site pollution level is the CUR factor which stands for Contamination Uniformity Ratio. This factor is defined as the ratio of the ESDD component of the bottom surface divided by the ESDD of the top surface.

- Insulator 1: CUR = 2.4
- Insulators 14, 19 and 29: CUR is about 10

Those CUR values clearly indicate that the pollution deposit is concentrated on the bottom surface of the insulators.

Based on those measurements, it clearly appears that each tested insulator display a pollution level (top and bottom surfaces included) that is ranked as “Very Heavy”.

2.3/ Clean fog voltage withstand test

Short strings of 5 units (naturally polluted in service) have been tested in a clean fog environment according to IEC 60507 § 6.7 in order to assess the electrical performance of the naturally polluted string of insulator and the efficiency of the coated glass insulators (Figure 7).

- The steam input rate is defined by IEC 60507 § 6.7 as 0.05 kg/h ± 0.01 kg/h/m^3 of the test chamber volume.
- The test consists in applying a voltage for 100 min according to test procedure B (§ 6.7.3 in IEC 60507).
- The test is passed if no flashover occurs during the 100 minutes.

Test	Short string description	Applied Voltage	Stress (phase to ground)	Stress (phase to phase)	Test Results
1	5 units	75 kV	41.3 mm/kV	23.9 mm/kV	Withstand 100 min
2	5 units	95 kV	32.6 mm/kV	18.8 mm/kV	Withstand 100 min
3	5 units	115 kV	27 mm/kV	15.5 mm/kV	Withstand 100 min
4	5 units	135 kV	23 mm/kV	13.2 mm/kV	Flashover 97 min
line	29 units	550 / √3 kV	56.3 mm/kV	32.5 mm/kV	

Figure 7: test set up for the clean fog test

A short string of 5 units naturally polluted in service can withstand a voltage of 115 kV.

This voltage would correspond to a design of 27 mm/kV phase to ground (equivalent to 15.5 mm/kV phase to phase) whereas the actual service design is about 32.5 mm/kV phase to ground if we consider a maximum voltage of 550 kV.

In addition, during the test, leakage currents were recorded and the test at 115 kV only displays leakage current with a peak intensity of about 20 mA during the 100 minutes of test. Those low values of leakage current are a proof of the effectiveness of the silicone coated string design for the actual level of pollution after 5 years in service.

3. Performance of degraded silicone coated insulators units

A second case of applications of Sedicoat® silicone coated toughened glass insulators in another 500 kV overhead transmission line in Peru delivered interesting data regarding the performance of the units under a degraded status linked to very challenging operating conditions as detailed here after.

The section of the 500 kV transmission line is in the south district of Lima, named Chilca District, where a power plant is built on the pacific coast. Maintenance team of the local utility reported evidence of electrical activity (dry band arcing activity but no flashover) on the first towers exiting the power plant, few meters away from the ocean. (Figure 8)

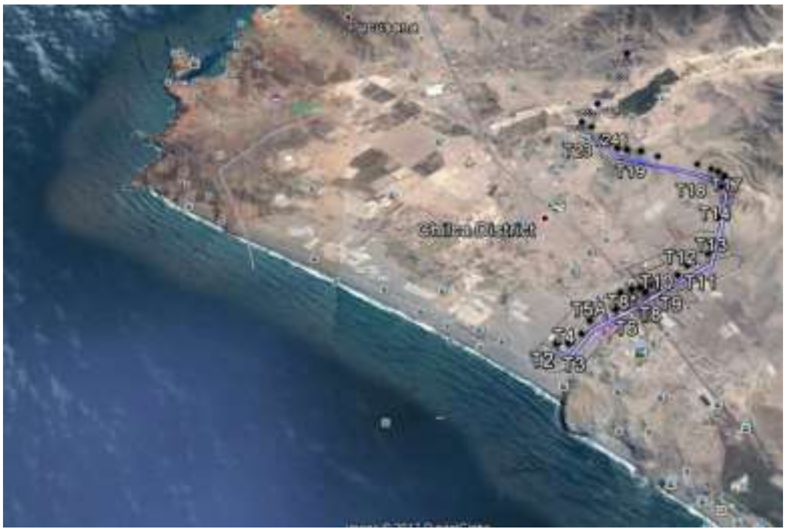


Figure 8: site description for the Chilca Fenix overhead line

In this line section, the insulators strings were designed with a specific creepage distance of 31 mm / kV (phase to phase) equivalent to a USCD of 53.7 mm /kV (phase to ground), using 28 units of an antifog insulator, with a 160 kN rating.The line was first energised in 2013. A jumper string of tower 2 and a suspension string of tower 3 were taken down for evaluation.

3.1/ <u>visual inspection</u>

Electrical activities leading to coating degradations can be observed all around the pin on the bottom side of the insulator. Those degradations can be classified according to the Sediver coating erosion chart (see Annex 1). Figure 9 shows the coating degradation all along the string of tower 2 and Figure 10 shows units from tower 3.

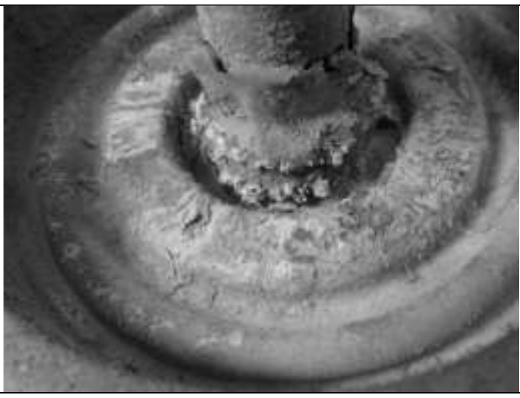
	
n°1 classified as CE 4	n°6 classified as CE 5
	
n°16 classified as CE 5	n°17 classified as CE 5
	
n°21 classified as CE 5	n°25 classified as CE 2

Figure 9: Close views on the insulators pins for Tower 2

	
n°1 classified as CE 5	n°5 classified as CE 2

Figure 10: Close views on the insulators pins for Tower 3

Evaluation of the hydrophobicity along the string of Tower 3 the day after string removal :

Insulator	Hydrophobicity Class on top surface	Hydrophobicity Class on bottom surface
T.3- 1 (high voltage side)	HC 3 and 6 cap edge	HC 3/4
T.3- 5	HC 6	HC 5
T.3- 9	HC 6	HC 1/ 2
T.3- 13	HC 4	HC 5
T.3- 17	HC 5/6	HC 3/4
T.3- 21	HC 4/5	HC 2/3
T.3- 25 (towards ground side)	HC 5/6	HC 2/ 3

It should be noted that in the very close vicinity of the insulator pin (few cm), in the area where some surface degradations could be observed, the coating offers hydrophilic surface properties. Moving away from the pin, the silicone coating gradually exhibits better hydrophobic properties, showing the influence that the electrical field density may have on the hydrophobicity property of the silicone material. In the table above, the hydrophobicity class given for the insulator is to be considered as the average hydrophobicity of the section, even if a difference of performances can be observed from one location to another. The overall conclusion is that despite a high level of pollution, evidence of electrical activity leading to a reduction of the hydrophobicity properties, the string of Sedicoat® insulators can still maintain its insulation fonction. In addition it can be mentioned that such surface degradations are not compromising the insulator integrity as the underneath toughened glass is immune and mechanically safe. A similar situation on a composite insulator would require a deep inspection of the units and units with eroded housing should be changed immediately to prevent catastrophic failures of the line.

3.2/ Evaluation of the site pollution severity

The pollution level has been determined with the ESDD and NSDD method.

The measures have been performed according to IEC 60507 appendix D6 and the pollution level is given according to IEC 60815.

Insulator	Time in service	ESDD (mg/cm²)	NSDD (mg/cm²)	Pollution level
Fenix T.3 n°1 (Top surface)	About 4 years (no washing)	0.4669	1.969	Very Heavy
Fenix T.3 n°1 (Bottom surface)		0.9897	3.004	Very Heavy
Fenix T.3 n°1 total		0.7283	2.486	Very Heavy
Fenix T.3 n°13 (Top surface)		0.0989	0.720	Heavy
Fenix T.3 n°13 (Bottom surface)		0.2259	1.974	Very Heavy
Fenix T.3 n°13 total		0.1624	1.347	Heavy
Fenix T.3 n°25 (Top surface)		0.0870	0.961	Heavy
Fenix T.3 n°25 (Bottom surface)		0.1639	1.368	Very Heavy
Fenix T.3 n°25 total		0.1254	1.164	Heavy
Average value for the string		0.339	1.666	Very Heavy

The pollution measured along the string is heterogeneous with a pollution profile along the string. The insulators on the live end (bottom of the string) have collected more pollution than insulators on the ground end side of the string (at the top). In this case, the bottom surfaces collect more pollution than top surfaces.

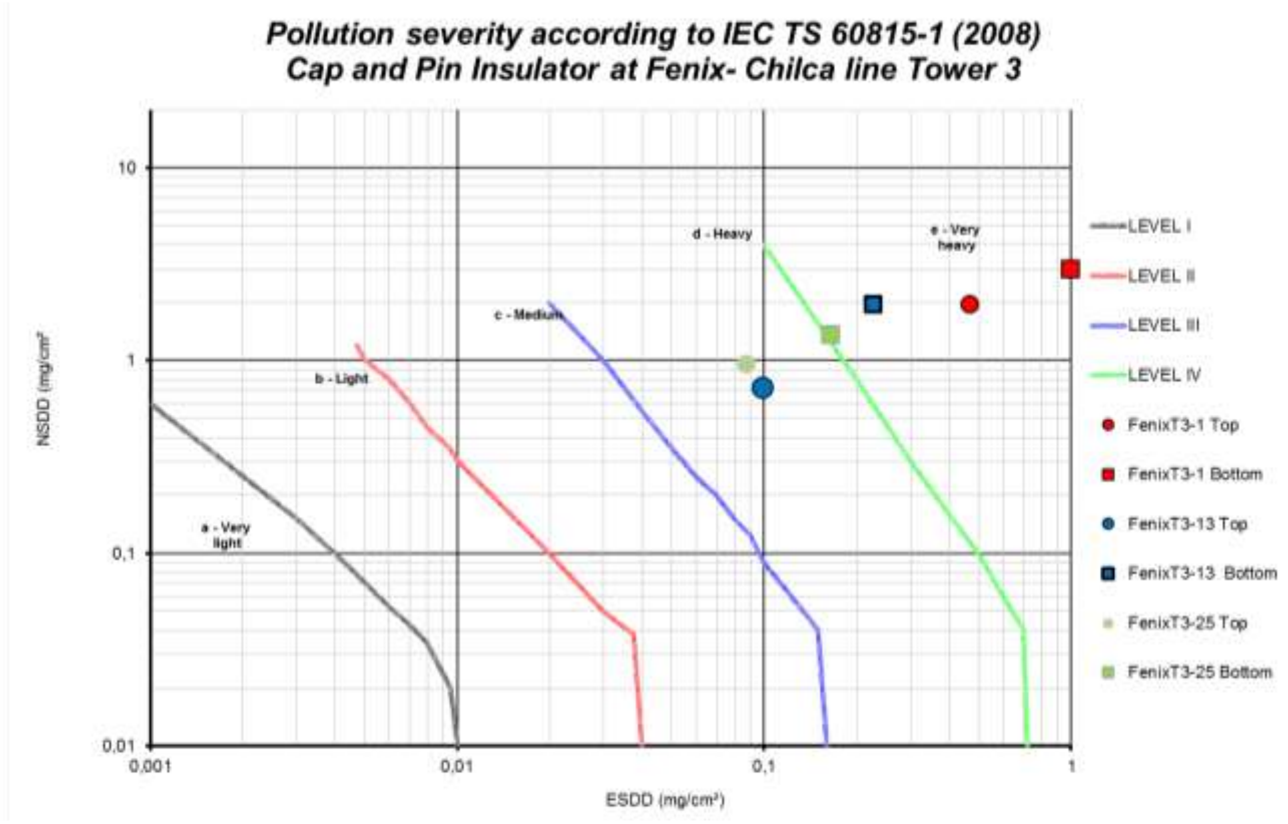


Figure 11 : graph of the pollution site severity

It clearly appears on this chart (Figure 11) that the pollution is characterized by strong ESDD components (obviously related to the vicinity of the Pacific coast).

3.3/ Clean fog voltage withstand test

Short strings of 4 units (naturally polluted in service) have been tested in a clean fog environment according to IEC 60507 § 6.7 in order to assess the electrical performance of the naturally polluted string of insulator and the efficiency of the coated glass insulator.

The steam input rate is defined by IEC 60507 § 6.7 as 0.05 kg/h ± 0.01 kg/h/m3 of the test chamber volume.

The test consists in applying a voltage for 100 min according to test procedure B (§ 6.7.3 in IEC 60507). The test is passed if no flashover occurs during the 100 minutes.

The tests results are :

Test	Short string description	Applied Voltage	Stress (phase to ground)	Stress (phase to phase)	Test Results
Tower 2-1	2-3-4-5	50 kV	49.6 mm/kV	28.6 mm/kV	Withstand 100 min
Tower 2-2	17-19-21-28	70 kV	35.4 mm/kV	20.5 mm/kV	Withstand 100 min
Tower 3-1	2-3-4-5	50 kV	49.6 mm/kV	28.6 mm/kV	Withstand 100 min
Tower 3 -2	6-7-9-17	70 kV	35.4 mm/kV	20.5 mm/kV	Withstand 100 min
line	28 units	550 kV	54.7mm/kV	31.6 mm/kV	

A short string of 4 units naturally polluted in service can withstand a voltage of 70 kV.

This voltage would correspond to a design of 35.4 mm/kV phase to ground (equivalent to 20.5 mm/kV phase to phase) whereas the actual service design is about 54.7 mm/kV phase to ground if we consider a maximum voltage of 550 kV.

The degradations of the silicone coating and the reduction of the hydrophobicity around the pins of several units are not compromising the performances of the string.

4. DC case in China

As a proof of the development of the silicone coating technology and of the fact that this technology is now fully introduced in the market, the case of the HVDC line design by SGCC (China northern utility) should be mentioned. For the last HVDC 800 kV projects, coated cap and pin insulators were specified for the tension strings.
The Inner Mongolia XiMeng – JiangSu TaiZhou +/- 800kV ultra high voltage DC transmission line was built with a 550 kN rating insulators for tension strings. Unlike previous cases in China, the specification required that the insulators were factory precoated and no longer coated after installation in order to benefit from all the advantages of an industrially controlled process rather than field hand made coatings. It is established today that the longevity and perfomance is much better when the insulators are factory coated versus “on site” treatment [7] The line erection work was completed early 2017 and required the supply of about 800.000 cap and pin insulators.
For this project the customer requested to have 2 colours of coating (Red and White). As shown in the Figure 12, every 10 pieces a red coloured unit is placed in the string of white coated units in order to ease the inspection of localization of any defects for the maintenance crew.

Figure 12: Tension strings of the Inner Mongolia 800kV HVDC line with red and white coloured coatings over toughened glass insulators

5. Improved silicone coating properties

Over the last 10 years of regular supply of silicone coated insulators around the globe to help mitigating pollution born insulation issues, Sediver collected regularly the voice of the market through continuous communication with end users. One of the major feedback received from the maintenance crew in the field is that silicone coated insulator can easily be damaged during handling, storing, assembling. (Figure 13)
Such comments would obviously come primarily from utilities used to normal toughened glass. Basically a very thin layer of rubber at the surface of a rigid material is more prone to degradation during on site transportation, in case of impact, rough handling, etc... In addition it should be mentioned that silicone rubber despite its numerous benefits for outdoor application is a relatively weak material in terms of mechanical property.
Even if many test data can prove the fact that small defects (limited area to few cm²) will not adversily impact the performance of the coating, the need was clearly expressed to work on this feature looking forward to be able to offer a solution to the market which would overcome this weakness in terms of handling.

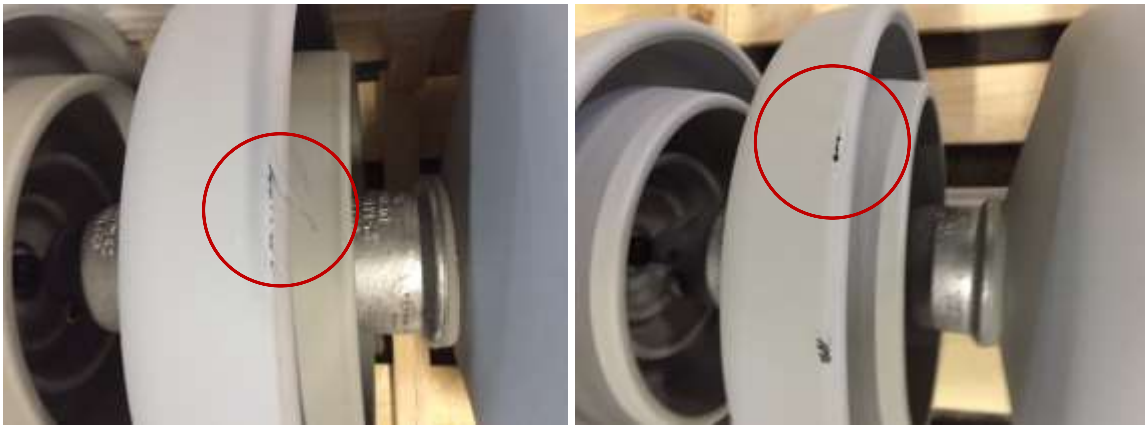


Figure 13: Example of aesthetical defect met on coated insulators

Sediver devoted resources in its R&D department to come up with a new silicone coating that would match the following requirements when applied in factory:

- Basic criteria of the Sediver homologation such as a high hydrophobicity level to improve performance under pollution (key aspect of the product) but also including :
    - 2000h multiple stresses ageing test (Figure 14)
    - Adherence to the glass surface
- Mechanical properties that would allow the shattering of the glass shell to not hide one of the key benefit of the toughened glass technology (fail-safe inspection through at a glance visual inspection)
- But mechanical properties that will allow an easy handling of the product with limited risk of degradation.

Newly developed Sedco® silicone coating can now match the above mentionned criteria and allow a more user friendly handling, similar to what is more common for regular cap and pin unit handling (Figure 15).

Figure 14: Insulator coated with newly developed SEDCO® coating at the end of the 2000 h multiple stresses ageing test according to TERNA specification LIN-00J116 Rev. 1 dated 08/05/2013.

Figure 15: Scratch resistance of the new coating

In addition, this Sedco® coating offers outstanding adhesion to the glass surface as shown through by the boiling water test described in IEEE 1523 [5]. In this test silicone coated insulators are immersed in boiling water for 100h and then the adhesion of the coating should be controlled. (Figure 16) This boiling water immersion test can be used to check the adhesion of the coating to the glass shell.

Figure 16: Results of 100 h boiling water test for a commercially available and for the newly developed Sedco® coating

Conclusion

Sediver has acquired substantial R&D and field knowledge to offer a unique expertise on silicone coated toughened glass solutions in substitution to traditional composite insulators for harsh environments.

The performance under severe or extreme pollution of silicone coated toughened glass insulators is proven by numerous field results and the case of applications in 500 kV OHL in Peru is a typical example. The unique combination of pollution performance (through the silicone coating), of the long term reliability of this product (through the toughened glass insulator and factory applied coating process) and the at-a-glance inspection capability make this product a perfect fit for highly demanding insulation strings.

This solution is more and more the preferred choice of utilities sensitive to full cost of ownership, reliability, inspection and live line work.

Publications

1. George JM, Prat S, Virlogeux F. “Silicone coating on toughened glass insulator : Review of laboratory and field performance”, INMR World Congress, Munich, Germany, 18-21 October 2015.

2. George JM, Prat S, Virlogeux F. “Coating glass insulators for service in severe environments”, INMR, 2014, Vol. 22, No. 4, pp. 60-64.

3. Cherney EA, El-Hag A, Li S, Gorur RS, Meyer L, Marzinotto M, George JM, Ramirez I. “RTV Silicone Rubber Pre-coated Ceramic Insulators for Transmission Lines”, IEEE Transactions on Dielectrics and Electrical Insulation, 2013, Vol. 20, No. 1, pp 237-244.

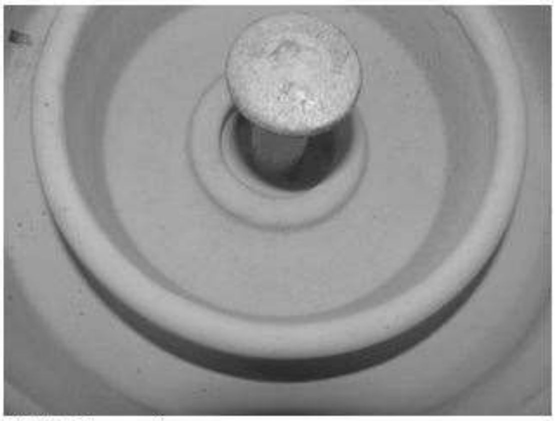
4. Rendina R, Guarniere MR, Posati A, George JM, Prat S, De Simone G. “First experience with factory-coated glass insulators on the Italian transmission network”, INMR World Congress, Rio de Janeiro, 2007.

5. “South American utilities plan live line replacement program to solve problems with composite insulators”, INMR, 2011, Vol. 19, No. 1, pp. 82-89.

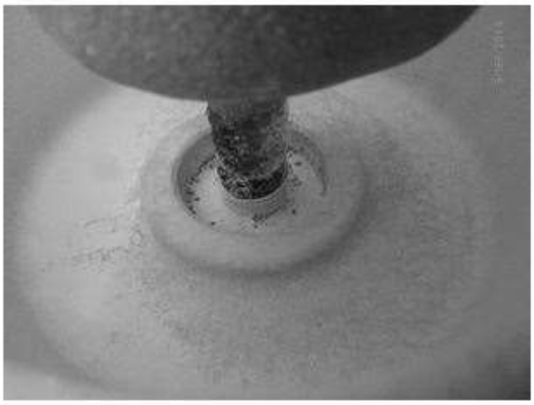
6. “IEEE Guide for the Application, Maintenance, and Evaluation of Room Temperature Vulcanizing (RTV) Silicone Rubber Coatings for Outdoor Ceramic Insulators” IEEE Standard 1523, 2002.

7. Znaidi R. “Maintenance Strategy Designed to Support Gulf Regional Energy Security”, INMR Weekly Technical review, 2017, No. 37, September 11.

Annex 1 : SEDIVER Coating Erosion Chart



CE 0 : No erosion



CE 1 : Signs of electrical activity but no damage

CE 2 : Signs of superficial erosion of the coating

CE 3 : Localized erosion of the coating with spots where insulator surface is apparent

CE 4 : Large erosion section of the coating

CE 5 : Delamination and erosion of the coating on large areas with large insulator surface visible