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Pollution of AC overhead transmission lines.
Definitions, mitigation methods and field experience

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Abstract

When overhead transmission lines cross regions where either natural or industrial contamination prevail, airborne dust or conductive contaminants can impact the electrical performance of insulator strings. The global term « pollution » describing this phenomenon is very often assimilated to anything that comes on the surface of an insulator, but such « pollution » should be defined precisely to allow for the most appropriate counter measure selection. Among the solutions adopted by utilities the increase of leakage distance is the most common method. Likewise, the use of a hydrophobic material such as silicone rubber has proven to be an effective tool.

We will explain the key concepts and definitions related to insulator pollution problems and solutions describing how they work and what their limitations can be.

When dealing with pollution problems, the first set of actions is to know what type of pollution the line is facing. Terms such as ESDD and NSDD are defined. Sampling techniques are described as well as ranking and classification charts established to determine the severity of the environment.

Once these concepts are clarified, it is possible to engage into the next phase by selecting the most appropriate insulator type and design. The mechanism of dry band arcing and dynamics of arcing will be examined showing that leakage distance is not the only parameter to take into consideration. Shape matters greatly and we will show how different shapes with the same leakage distance can generate different behaviors and withstand properties.

The use of silicone rubber on the surface of an insulator has proven to work well preventing flashovers from occurring in a variety of contaminated environments. To better understand how hydrophobicity can help mitigating pollution problems but also understand how such material can suffer and age prematurely in harsh environments we will describe the physico-chemical processes at work.

Finally, and while polymers have shown their own limits in terms of resilience (especially in very challenging environment) alternative solutions such as silicone coated toughened glass insulators will be discussed including field experience for more than 20 years in extreme conditions with outstanding performance.

1. Introduction and definitions

Pollution is a very generic term when it comes to outdoor insulation contamination. A general approach defines pollution like anything that comes and stays on the surface of an insulator which modifies the surface conductivity, therefore increase the risk of an electrical arc bridging the insulator itself. The deposits are usually airborne dust, sand, industrial airborne particles, soluble elements such a salt from the sea when a line is near a coast…

The challenge for line design engineers and maintenance crews is to know how such electric flashovers can be avoided by either using insulators catching less contaminants, more resistant to arcing or designed and made with materials which will reduce the ability of an external arc to take place.

When dealing with pollution problems experts use several definitions which are listed hereafter:

Creepage distance: (sometimes the word “leakage distance” is being used). It is the distance an arc needs to cover from one metal end fitting to the next following the surface of an insulator (figure 1).

Arcing distance: the shortest distance between ground and energized side of an insulator (figure 1)

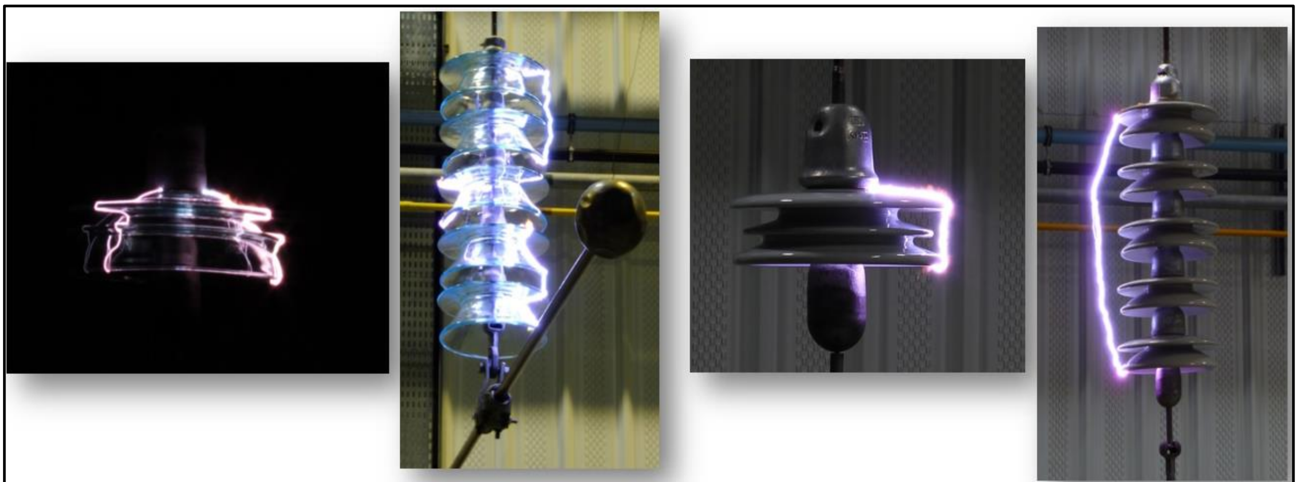


Figure 1: arcing distance (left) versus creepage distance (right)

ESDD is the acronym for Equivalent Salt Deposit Density. It represents the quantified value of the contaminants which dissolve in water like salt. When salts dissolve in water the conductivity of the humid/wet film on the surface of the insulator increases, and subsequently the risk of having a flashover increases as well. The unit of measure is mg/cm²

NSDD is the acronym for Non-Soluble Deposit Density. It corresponds to the amount of deposit on the surface of the insulator which does not dissolve in water and remains inert on the surface. Sand for example is a typical component of NSDD. The non-soluble component of the pollution layer will work like a sponge catching more humidity which in turn will facilitate the conductivity on the surface of the insulator

Leakage current: is the electric current flowing along the surface of an insulator along the leakage distance. Each insulator type has a limit above which the leakage current will lead to arcing and possibly a complete bypass of the insulator (this final stage of arcing is then called flashover).

Specific leakage distance: the ratio between the leakage distance of an insulator (or string of insulators) and the phase to ground voltage. The unit is inch/ KV and referred to as USCD (Unified Specific Creepage Distance)

Dry band arcing: is a dynamic process by which an arc once initiated will dry the area where it takes place. By drying a segment of the insulator, the arc will progressively have more and more difficulties to be sustained, will self-extinguish until the surface is wet again, leading to currents which will generate new arcs, new dry spots….

The evaluation of the pollution level in any given area on an insulator can be made by measuring both ESDD and NSDD. The procedure consists in washing the surface of the insulator with deionized water which conductivity is measured prior to washing. After washing, the conductivity is measured again, and tabulated for conversion in equivalent salt weight. This number is then divided by the surface which was washed. Once this is done, the washing water is filtered on a paper filter which needs to be dried in an over. The weight of solid deposit is divided by the surface of the insulator to give the final NSDD in mg/cm². (figure 2)

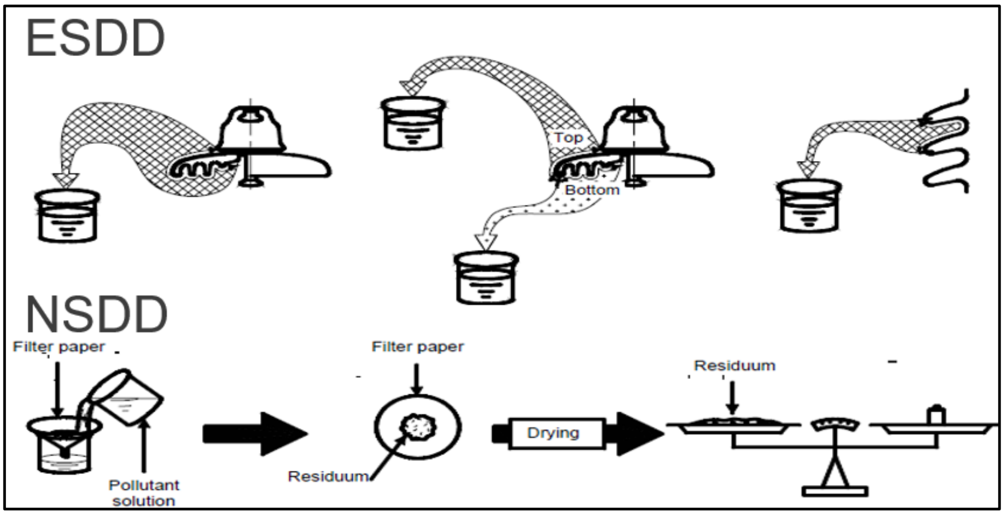


Figure 2: ESDD/NSDD evaluation method

Once ESDD and NSDD are defined, it is possible to establish the pollution class as per IEC 60815 (figure 3).

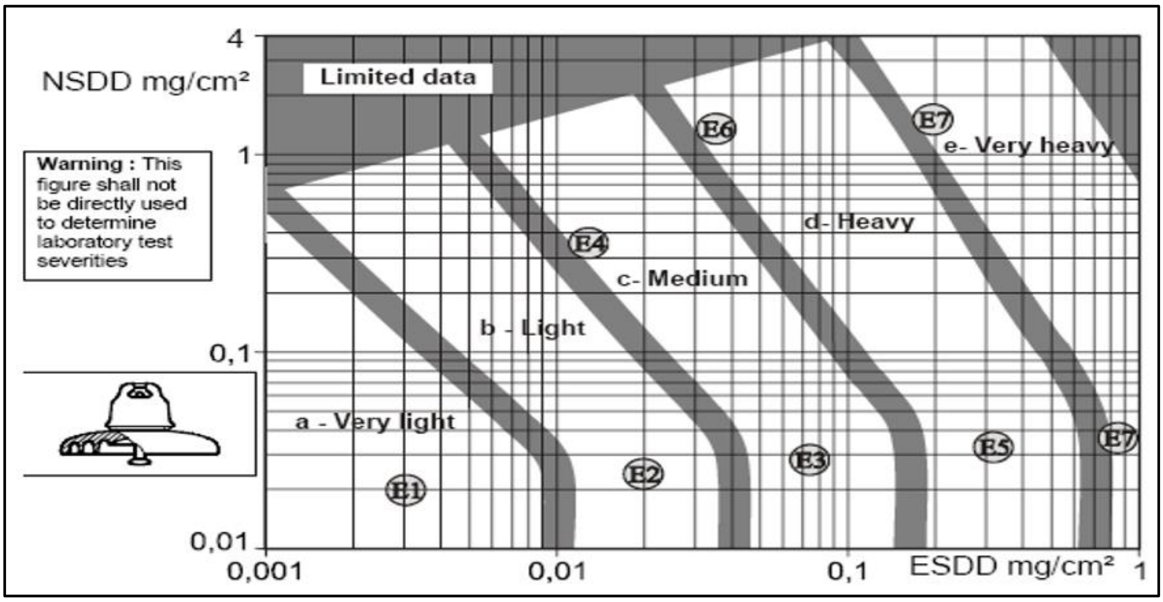


Figure 3: IEC 60815 pollution classification

For each class of pollution IEC gives an average USCD as a reference base value for selecting a leakage distance in the environment under consideration (figure 4).

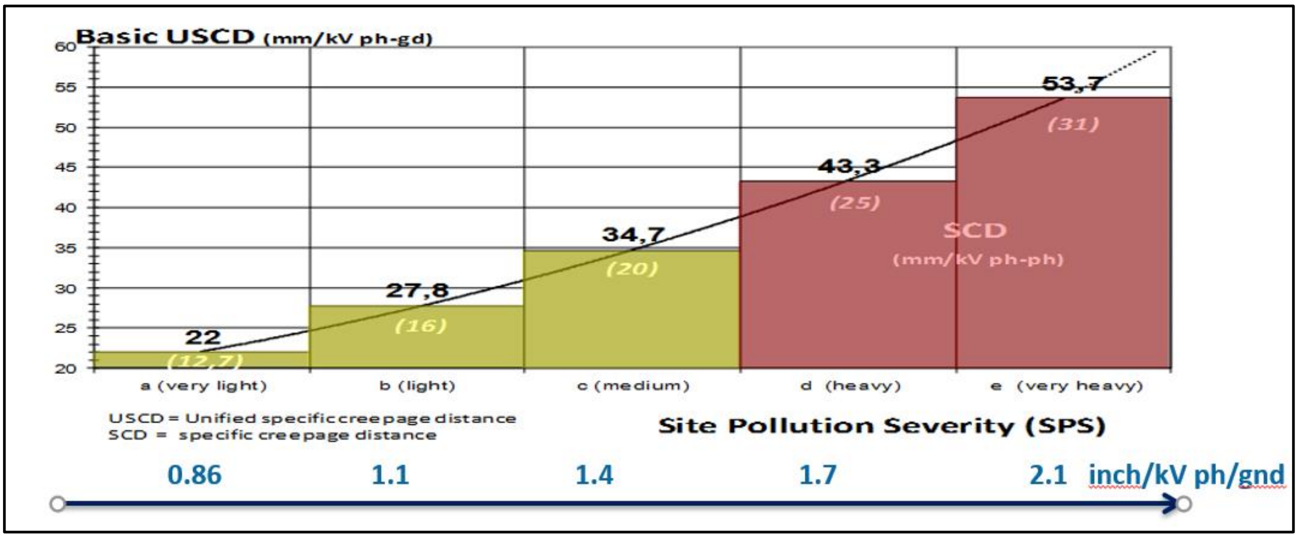


Figure 4: Typical USCD values per pollution class as per IEC 60815

2. Insulator shapes and pollution

Insulators exist with different shapes and different leakage distances. Depending upon the local environment one shape might be a best fit than another one. Some shapes will catch and retain more dust while others are more adapted to fight arcing activity in moist, humid or foggy conditions. Figure 5 shows a selection method based on shapes.

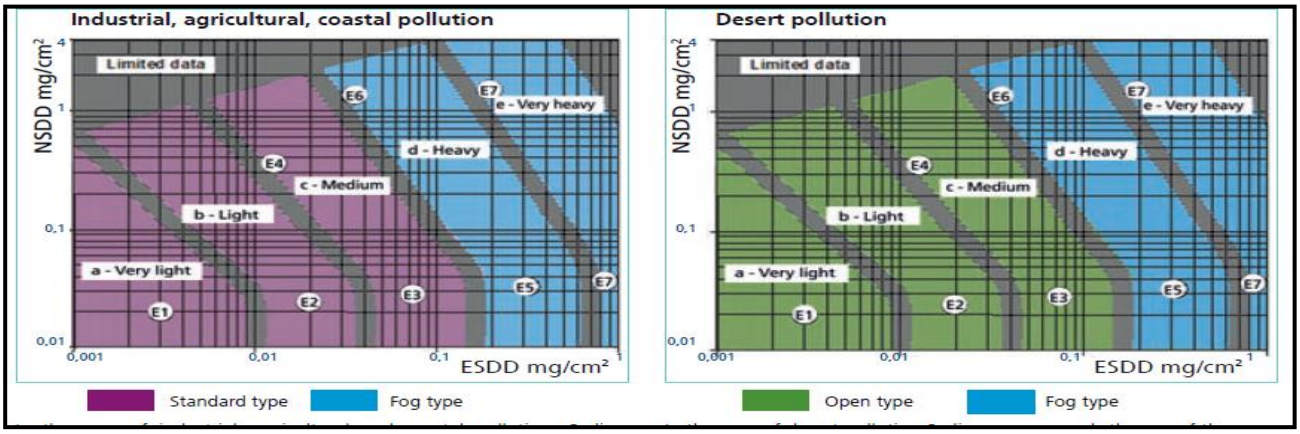


Figure 5: recommended shapes for various pollution environments (shapes as per SEDIVER catalog)

Another important aspect in pollution mitigation is the fact that shape will dictate the dynamics by which the leakage current and the dry band arcing will behave. Figure 6 shows an example where insulators with the same leakage distance have very different flashover values and very different ultimate leakage currents threshold values. It is easy to understand that it is not possible to set a maximum reference leakage current value without defining the type and shape of insulator under consideration.

	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 6: salt fog test with equal leakage distance values on different shapes of insulators

3. Silicone and pollution

Silicone is often described as an ideal material to reduce risks of flashover. This is the consequence of the ability of this material to be water repellant. Hydrophobicity is the generic term used to describe this property. A material is considered as hydrophobic if the contact angle on the surface of the material exceeds 90° (figure 7). A material with this property will remain dry, shed water droplets and therefore will keep the leakage current at low values, preventing flashovers from happening. Silicone compounds have also the ability to transfer this property to any contamination on its surface. This mechanism called “hydrophobicity transfer” is the result of low weight molecules (LMW) inherently part of the silicone compound migrating to the surface and embedding the pollutants on the surface. The surface can remain water repellant even with surface contamination.

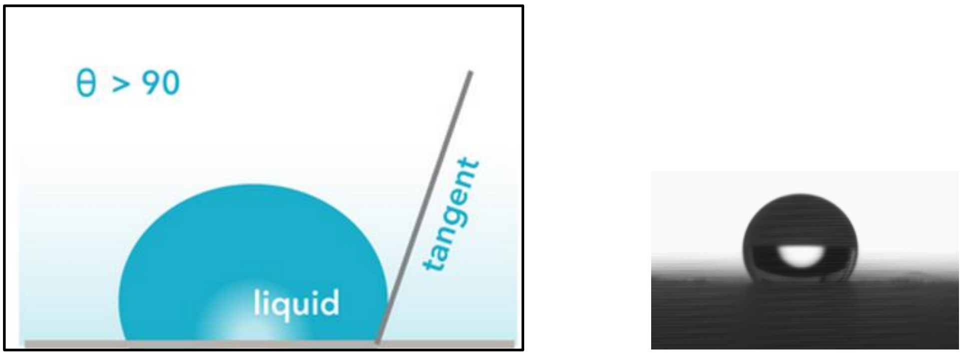


Figure 7: Hydrophobicity

While these properties seem extremely attractive, silicone shows also some weaknesses. Among those is the fact that silicone is relatively sensitive to dry band arcing, leading to erosion and possible cracking of the material (figure 8). Electric arcing under the form of dry band arcing or corona (result of the breakdown of air under intense electric field) generates ozone which in turn reacts with nitrogen in air to form nitric acid. To reduce such effects silicone can be designed with additives such as fillers (like Alumina Tri Hydrate, ATH) slowing down the degradation process.

However, failures of silicone polymer insulators are occurring mostly once the rubber housing is deteriorated leaving moisture to penetrate inside the core. These degradation mechanisms are not easy to spot during line inspection and failure modes such as brittle fractures, cannot be anticipated. This poses problems for maintenance but more so for live line work.

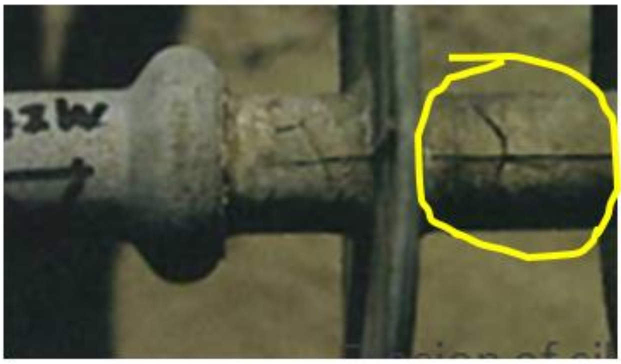


Figure 8: Erosion of silicone rubber under the effect of electric activity

While in the past silicone polymer insulators were expected to last as long as porcelain or toughened glass, reality from the field has proven otherwise with life expectancy down to 15 to 20 years, sometimes more, sometimes less. Additionally, counter measures such as grading rings to reduce the electric field on the silicone compound have been implemented at voltage levels much lower than initially thought (as low as 115 KV or even 69KV in some cases) reducing arcing distance and clearances.

4. Silicone coating over toughened glass insulators

Field experience has shown that extreme pollution can be handled with silicone, but at the same time it has been established that more the contamination is severe the faster the degradation and risk of failure of polymers. On the other hand, the resilience of toughened glass is known to be a major asset for overhead lines stability. Combining both has been a concept introduced more than 20 years ago, with great success. Silicone coatings work best when applied in an industrial controlled environment. In some cases, the application is made in the field but thickness of the coating as well as adherence remain out of control. In a factory environment both parameters are carefully controlled. Thicknesses in the range of 10 to 15 mils. Adherence can be checked with EN ISO 2409 or through a water boiling test as described in IEEE 1523.
The performance under pollution has been established in laboratory tests either with salt fog conditions or with solid deposits having an ESDD/NSDD under clean fog conditions (figure 9). It was shown during these tests that toughened glass insulators work extremely well even when the coating is applied only on one side, underneath the glass bell (figure 10). This is something some utilities might consider for handling purpose (less damage to the coating when mishandled). Note however that the performance of the coated insulator is not degraded even when small tears or damage occur to the coated insulators.

Field performance confirms these results with more than a million units used only in Italy along the coasts removing the need for washing for more than 12 years. Likewise, in the Middle East, silicone coated glass insulators have been successfully in service for about 20 years. Samples have been removed from the line for a performance check and the results show that these units outperform after 20 years new non-coated insulators tested with artificial pollution deposits equivalent to those measured on the line (figure 11). In the USA the same trend exist, and large utilities are now using either fully coated or half coated units in replacement of polymer insulators.

1. Salt fog test

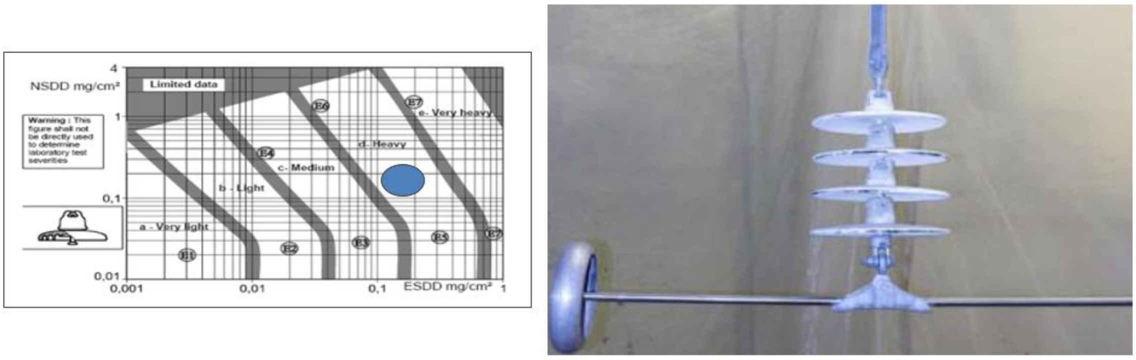
40g/l salt fog	Non coated	Under coated	Fully coated
Average max withstand (kV)	15	18.6	17.6
Gain	100%	122%	117%
USCD (mm/kV p/g)	29	24	25

2. Solid pollution under clean fog test

Type of insulator	U50 (kV)	GAIN
Non coated glass	76	100%
Fully coated glass	126	166%
Under coated glass	112,5	148%

Figure 9: Pollution performance of silicone coated toughened glass insulators

Figure 10: silicone coated toughened glass insulator and half coated version



Non coated string : U50 = 73 kV
19 year old coated string: U50 = 240 kV (*)

Figure 11: Pollution performance of coated glass insulators after 20 years in service