Performance Evaluation Method and Optimum Selection of Overhead Line Insulators for Contaminated Environments

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Introduction

Pollution problems and related research work have probably been the reason for the largest number of publications in the field of insulators. The topic remains today of main interest given the complexity of the subject. The ever growing diversity of local conditions and operating conditions of overhead lines around the world brings daily challenges to line design engineers. While polymers have largely influenced the way people look at pollution mitigation problems, ceramics (glass and porcelain) are offering a full range of solutions for a large diversity of conditions. Testing and performance evaluation under contaminated conditions is therefore a central point of interest.

This document presents a few topics and ideas from various angles, products and materials, including testing techniques.

1. Rapid flashover method

1.1 Description of the testing protocol

Originally designed by experts to accelerate the processing of pollution testing, this method has been almost put aside when polymers came along with the complex question of preconditioning, mainly because of the dual condition of silicone housing which can be either hydrophobic or hydrophilic inducing two sets of performance levels.

This method remains nevertheless extremely interesting and should benefit of a greater interest from the technical community. It can have interesting aspects for both salt fog testing or clean fog testing of solid layer contamination.

Tests performed in CEB laboratory, BAZET, France and SEDIVER R&D laboratory, France, have involved toughened glass insulators typically fog type profiles, having a 550mm leakage distance but also other shapes and designs. This procedure was applied to both clean and salt fog procedures.

The procedure described in figure 1 varies from the traditional rapid method by the time lapses and initial applied voltage level and has been fine tuned and used in C.E.B. Bazet for many years now.

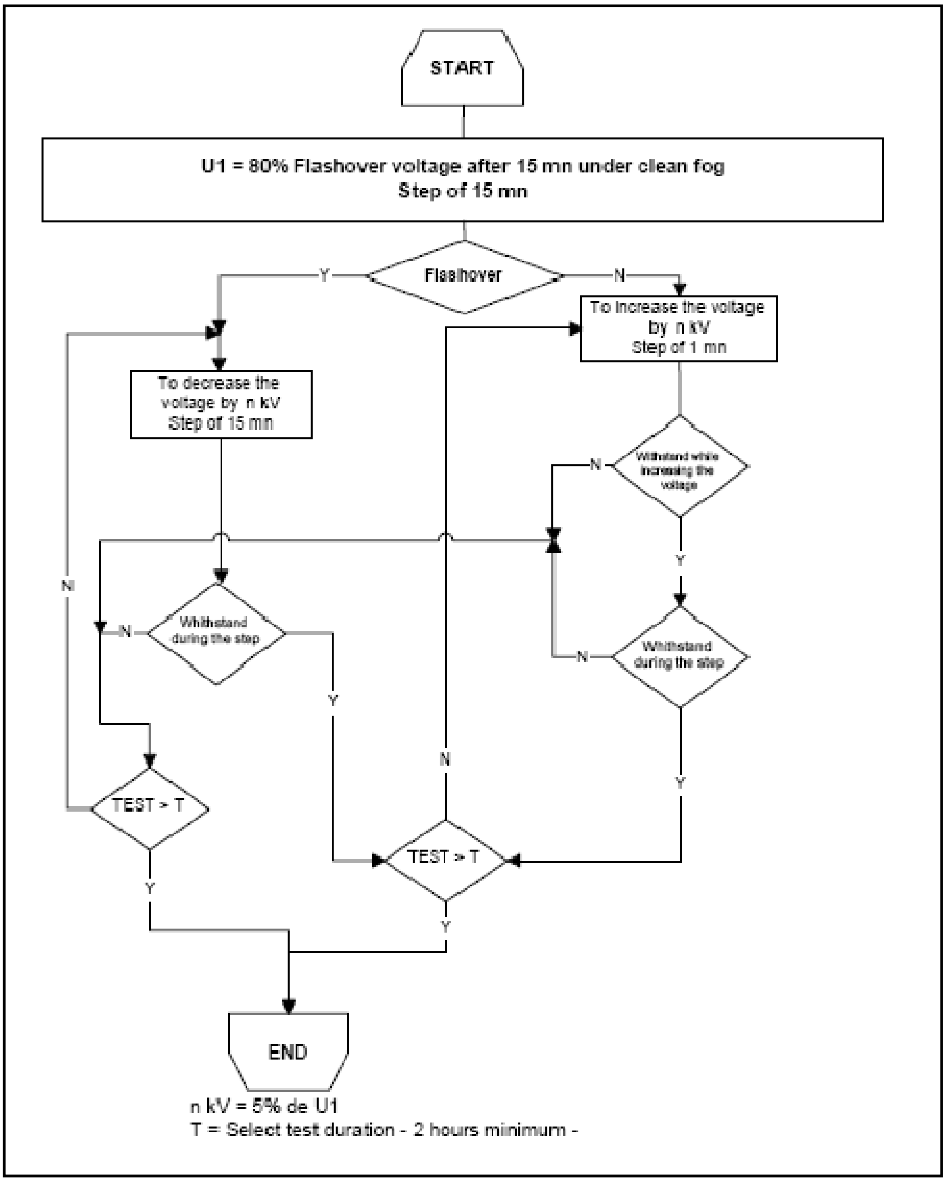


Figure 1: Rapid flashover test protocol adopted by CEB Bazet and SEDIVER R&D St Yorre

1. 2 Rapid flashover method for salt fog testing

The contamination conditions under salt fog are more stable than for clean fog conditions since the pollutant is produced by the fog itself, therefore less dependent from the condition of the solid deposit. Tests were performed at 80g/l in the pollution chamber of the SEDIVER R&D facility in Saint Yorre, France .

Insulator strings of 5 fog type units of 550mm leakage distance have been tested (figure 2). The results (Table 1) show a close consistency between the rapid method and the IEC 60507 method, confirming the interest for such testing technique, given the ability to obtain rapidly a good understanding of the performance of any given string.

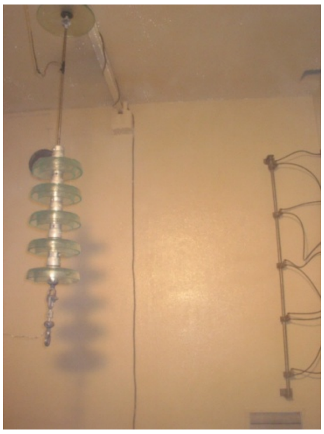


Figure 2: string of 5 units F160P in salt fog

	IEC 60507 METHOD	RAPID FLASHOVER METHOD
Leakage distance (mm)	2725	2725
MAX WITHSTAND (kV)	80,3	80,6
Max withstand kV/m leakage	29,3	29,6
Mean leakage current during max withstand steps (rms) mA	283	283

Table 1 : salt fog pollution test results from 2 test methods

1.3 Rapid flashover for clean fog testing

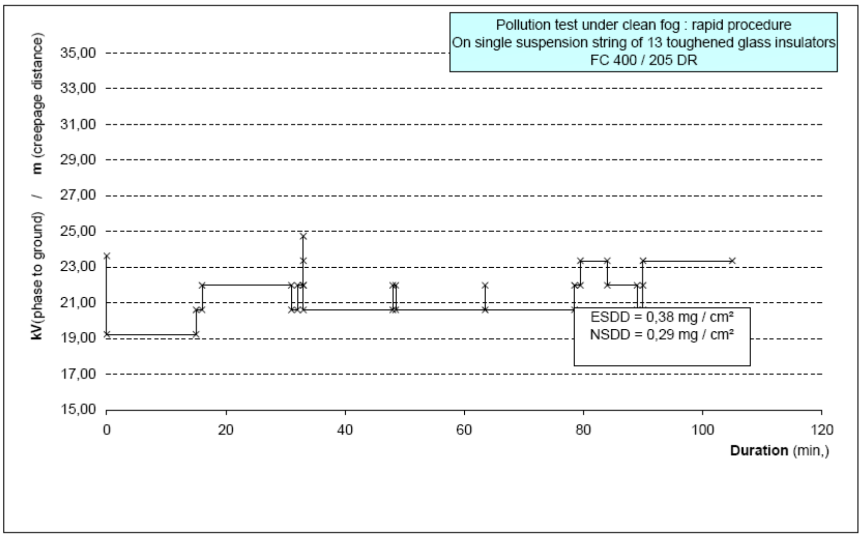
Under this testing protocol the pollutant is applied artificially and the main factor is in the solid layer characteristics and the possible variations resulting from it.

Some key points to consider in the rapid flashover testing method include:

- Repeatability of the test results
- Accuracy of the test method compared to the traditional IEC 60507 protocol.

While salt fog test conditions remain stable since the pollutant is the result of the environmental conditions set up by the fog, the question of stability and washing of the pollutant under clean fog is more critical. The fact that the rapid flashover method gives an indication of the dynamics during the applied voltage time offers also a set of valuable information.

- A first parameter (washing effect) applicable to clean fog test is shown in figure 3, where a slight washing effect can be seen, with a magnitude having an impact of less than 10% to the result when considering the difference between beginning and end of the testing time. As time goes, slight washing takes place, which indicates also that passed a certain time, little risks of flashovers are left. The rapid method makes therefore a lot of sense since it captures as quickly as possible the real behavior of a string of insulators.



<u>Figure 3:</u> During the test time a slight washing effect of the solid layer pollutant after approximately 80 minutes under clean fog can be seen. The impact on the test value is less than 10%

Measurements of the pollutant before and after test have been evaluated during a pollution test. The fluctuations are indicated in table 2 below. This is not unique to the rapid flashover method, but occurs systematically during any clean fog tests.

mg/cm²	BEFORE TEST	AFTER TEST
ESDD	0.03	0.02
NSDD	0.8	0.7

<u>Table 2:</u> Variation of the pollutant measured before and after clean fog testing

- The second question is the accuracy of such a testing method. The same string of insulators has been tested 3 times with the same contamination conditions. A first point is to verify the consistency of the deposit between each test. In this case, the insulators were polluted with a target of ESDD=0.03mg/cm² and NSDD= 0.8mg/cm². The method of application, using warm disc surfaces dipped in a previously adequately prepared combination of salt and kaolin resulted in the following values:

- ESDD READINGS 0.03 +/- 0.0045 mg/cm² (15%)
- NSDD READINGS 0.79 +/- 0.03 mg/cm² (4%)

Later on, improvements in the deposit technique developed in C.E.B has further reduced the level of variation of deposit, allowing even better consistency and repeatability especially for the ESDD (including in the separate top/bottom ratios). The fluctuations in pollutant deposit are below 10%, which is to be considered as acceptable given the nature of the pollutants (figure 4). The pollution technique went from a dipping method to a smooth low pressure overflow on hot surfaces.

__Figure 4__ : Solid layer deposit on toughened glass insulators using CEB application method.

The flashover characteristics achieved during these three repetitions have indicated a value of 28kV/unit +/- 3kV under the above mentioned pollution levels. Such fluctuations, in the range of 10%, are reasonable given the inherent dispersion between deposit and wetting conditions. We can consider that the test method is sufficiently consistent to provide results that are considered as “significantly accurate”.

- The third aspect is the comparison with the traditional IEC 60507 testing method. In order to verify this point, a comparison was made using the same insulator, with the same pollution deposit and application method. Figure 5 shows quite good consistency between both methods.

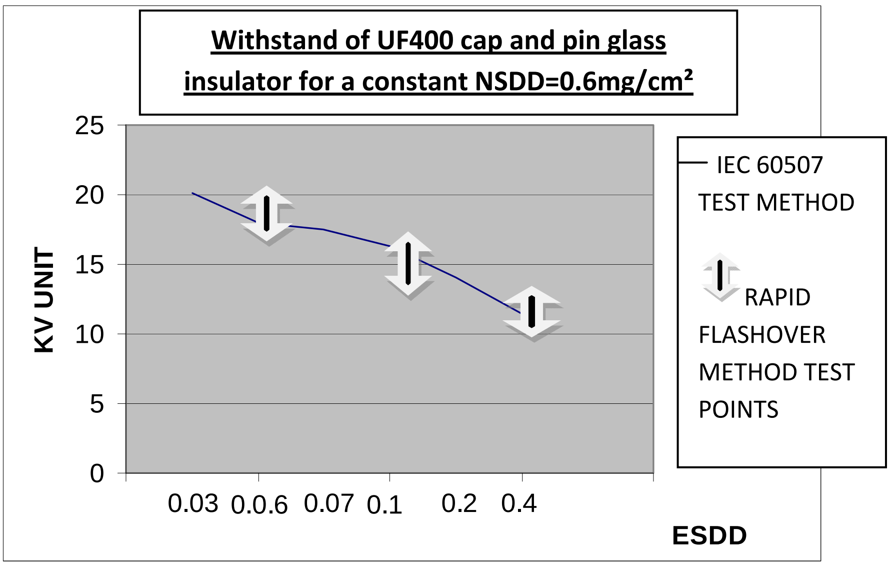


__Figure 5__: verification of the coherence between IEC 60507 method and rapid flashover method in the case of clean fog test protocol

2. Insulator selection for various contamination conditions

2.1 Shapes adapted to coastal conditions

It is not uncommon to see engineers making calculations and string definitions for polluted areas using results from pollution tests obtained with so called “standard bells” and extrapolated to strings using units with other specific shapes. The concept is based on the fact that leakage distance should be considered as the key factor, disregarding shapes specificities. This does not provide sufficient accuracy to help insulator selection.

Obviously, leakage current and leakage distance are important parameters, but the effectiveness of leakage distance can take a superior role in the global efficiency of a given insulator. The results shown in table 3 demonstrate the importance of profile versus pure leakage distance reasoning.

Under the same testing conditions (rapid method) at 80g/l, three strings of insulators with very different profiles have been tested in a salt fog chamber. Insulators are described in figure 6.

With the same leakage distance, two out of the three different profiles tested offer very different results. This demonstrates, if still needed, that extrapolation from “standard bell results” can be seriously misleading if considering only leakage distance as a driver. In a more global approach, flashover prediction cannot be correctly extrapolated to a given type of insulators from results obtained with a different shape and design.

Shape 1: Fog type (550mm)   Shape 2: Outerib 550mm   Shape 3:Open profile (370mm)

Figure 6: Shapes and leakage distance of the tested insulators

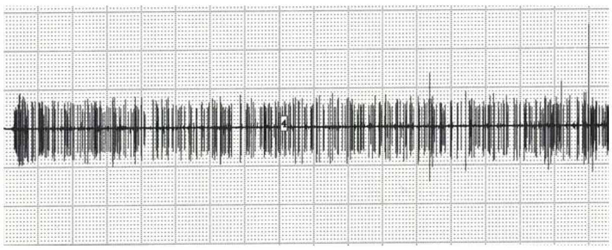
	5 x F160P/170	5 x F160PH/170	6 x F160D/146
Leakage distance (mm)	2725	2750	2220
MAX WITHSTAND (kV)	80,6	53.2	49
Max withstand kV/m leakage	29,6	19.3	21.7
Mean leakage current during withstand steps (rms) mA	283	127	212

Table 3: Results of salt fog tests using the rapid flashover method on insulator strings with similar leakage distance or not and different profiles

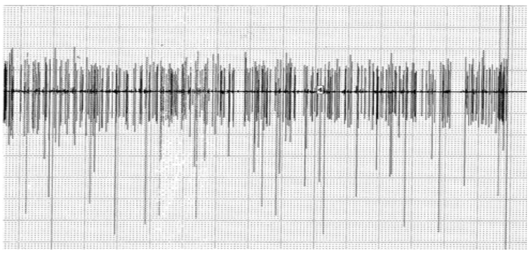
Another common mistake is to correlate the flashover forecast with the leakage current. While this approach can make sense when comparing similar profiles, once again it appears that each and every family of bell shape requires a separate approach. Leakage currents measured on standard bells for example, cannot be extrapolated to define how another shape might react under similar pollution conditions.

Figure 7 shows the leakage currents measured during a maximum withstand test under salt fog, comparing all three profiles described in figure 6. The test was performed at 80g/l, the flashover values show a clear advantage for the fog type, while actually it had the highest currents before flashover occurs. The outerib which has the same leakage distance shows a maximum leakage current prior to flashover much lower than the fog type. On the other hand, the open profile, which has much less leakage distance has a leakage current prior to flashover close, if not similar to the outerib, with a slightly higher pulsing activity. Simulations and flashover predictions based on leakage currents should therefore be carefully considered before deciding current related criteria.

(a)



(b)



(c)

Figure 7: (a) leakage current measured on a fog type at 80g/l during max withstand period.

(b) Same measure for an "outerib" profile in the same conditions.

(c) Same measure for the open profile.(identical scale)

Beyond the interest for the study of leakage current patterns, the previous case also illustrates the influence of the shape itself. The fact that the “outerib” shows such a low performance under salt fog conditions can be explained by the fact that dry bands along the inner surface are not interrupted by any ribs and will easily stretch out, with a permanent rebuilding of the wet surface. Equipotentials are also following the shape of the bell. The fog type, on the other hand will benefit from the protection of inner rib space. This can be seen from the dry salt pattern left after the test in the inner rib section of the fog type insulators (figure 8)

Figure 8 : bottom view of the fog type after the salt fog test

To the same extend, open profiles (see results in table 3 for a string of 6 units), tested in the same sequence, will work more like the “outeribs” given the absence of ribs. This does not mean that such insulators are not fit for polluted conditions, but simply that they are not the best performers for coastal conditions for which the traditional “fog type” is the best choice.

2.2 Shapes adapted to solid pollution conditions

It is very important at this stage to make a clear difference between the reason for selecting high creepage distance and the effectiveness of this parameter. Beyond the “pure” electrical behavior, it is of upmost importance to understand that different shapes will collect different amounts of pollutants especially under dusty environment such as a desert, mixed pollution or industrial pollution. Because NSDD is becoming a major factor, the focus will be placed on solid particle accumulation.

a) Dust accumulation

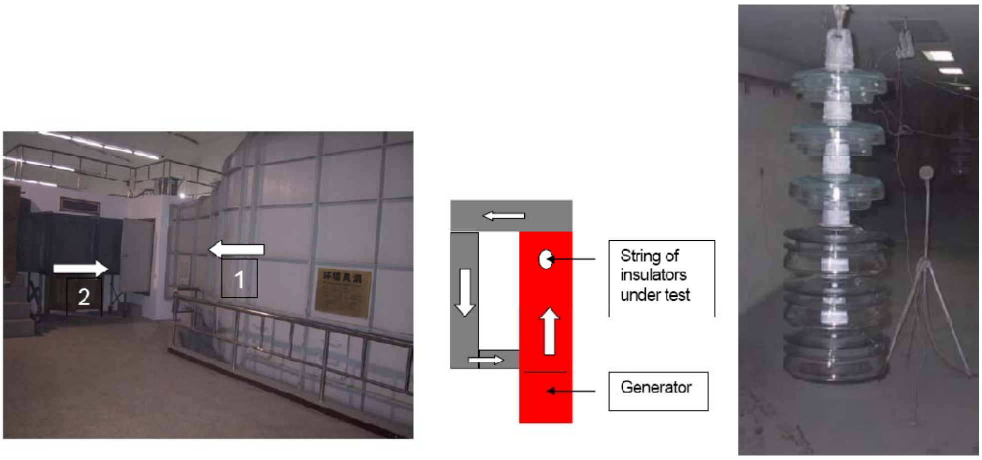
Open profiles are clearly not recommended for coastal conditions as explained in the above section. Field experience and testing, including test stations have shown the superior performance of this profile under dusty conditions where high NSDD are expected from “standard bell” or “fog type” bells. Open profiles (flat discs) are today largely used in the Middle East region, and most desert type environments. The ability of open profiles to be “self cleaning” with the wind has been demonstrated in Dubai, for example, in the 1980's on a 132kV test line. Under desert type pollution the open profile top and bottom surfaces had approximately the same very low ESDD levels, resulting from a bottom self cleaning identical, almost, to a normal top surface. Airborne particles did almost not accumulate on these surfaces. This is to compare with "standard shape", with ribs, which collected pollution up to more than 10 times higher at the bottom, while the top was actually similar to the other insulators. Similar advantage of this shape was demonstrated under mixed pollution, and in many other countries and locations. In the last twenty years this type of product has been generalized in similar conditions worldwide.

The same approach had driven the concept of "outeribs" for which the ribs are no longer under the skirt but outside to provide a better self cleaning of the bottom section of the shell. This shape, which SEDIVER had started to design in the early 1970's, did not get a large attention by the utilities which at that time more in favor of fog type insulators.

More recently, and mostly under the dynamics of Chinese extreme polluted areas and needs for solutions, the decision was made to go back to the earlier studies and fine tune such a profile (Figure 9), using the knowledge acquired during all these years.

Figure 9: Typical "Outerib" glass insulator profile designed by SEDIVER

Some initial studies were performed under dust wind tunnel conditions (figure 10) in Nanjing, China. The accuracy of such tests is always questionable and consistency difficult to achieve. Nevertheless, such tests can help to see trends. One of the finding was that the "outerib" was holding less dust than a traditional fog type. Similar comparisons were made with existing porcelain "outeribs" which were accumulating relatively more dust. (More complex shape, as a result of manufacturing limitations and difficulties inherent to the material, easily demonstrated when performing steep front test where high rates of punctures are found).



<u>Figure 10</u>: Dust wind tunnel test of “outerib” profiles

2.3.<u>Rapid flashover method under clean fog</u>

Artificial solid pollution with a mix of kaolin and salt was applied on insulators and tested in clean fog in CEB Bazet laboratory, France (Figure 11). Tested strings were made of fog type and outeribs in equivalent conditions with the same leakage distance.

<u>Figure 11:</u> Clean fog pollution set up in CEB Bazet, France

The test was performed with a top to bottom ratio of 1/10. The graph (figure 12) is showing stable up and down conditions, which can be explained on one hand by the effectiveness of the test method, and also by the fact that the fog is taking the pollutant from a bottom to the following top surface of the next unit. Results have to be considered carefully, and single unit testing would be meaningless. A general statement about performance under pollution requires always a clear understanding of the testing conditions and/or the exact conditions where the line is being located. In fact, these results are reversing completely the ranking made earlier under salt fog conditions.

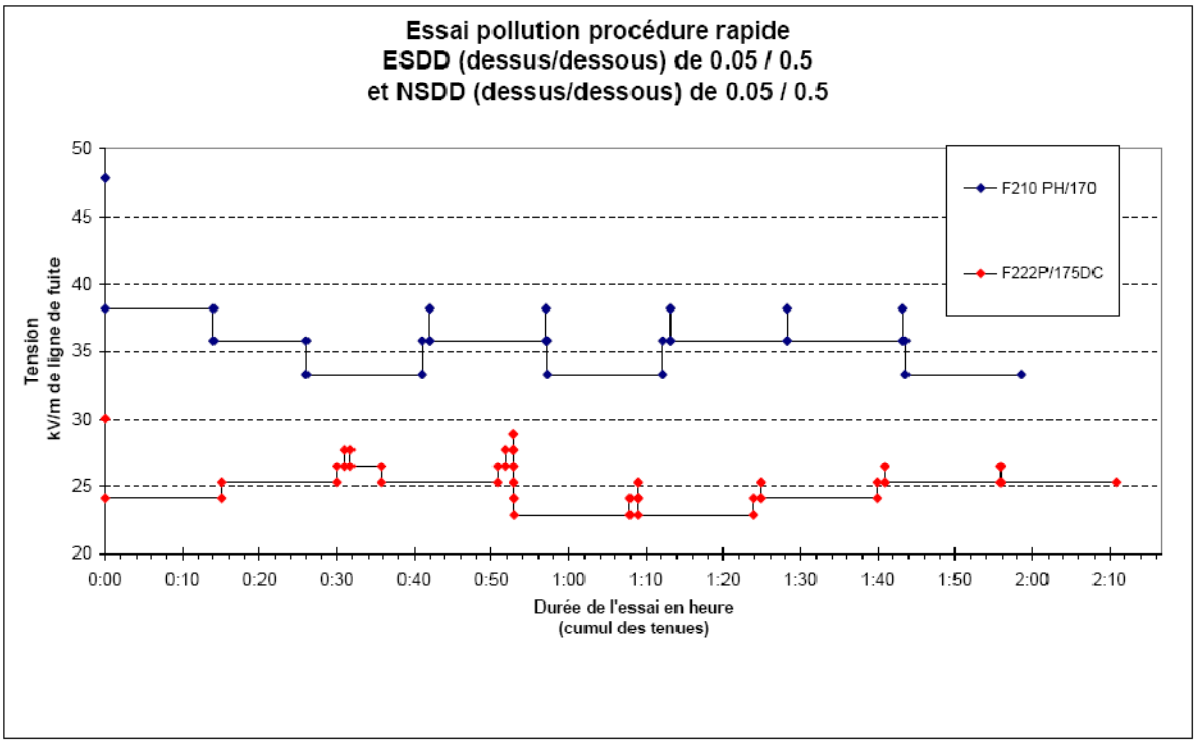


Figure 12: Test results from the clean fog type with two different types of insulators.

3. Considerations for pollution testing of polymer insulators

The definition of the contamination performance of polymers remains a topic of strong debates. While there is a consensus on the benefits under some extreme pollution conditions of polymers, the performance evaluation under artificial pollution conditions is still under discussion. One of the most interesting questions is to know if silicone insulators should be tested when the housing is hydrophobic or hydrophilic. Round robin testing programs are under evaluation. Engineering wisdom would recommend designing a transmission line with a “worst case scenario” concept. In this regard, pollution performance should be defined when the housing is hydrophilic. Figure 13 shows the comparative test results of the same insulator type under various ESDD conditions either when the rubber is hydrophobic or when it is hydrophilic. These tests have been performed in the SEDIVER laboratory in Saint Yorre, France.

Tests were made according to IEC 60507. It appears that an engineer in charge of the selection of insulator strings could make a mistake in performance of about 20% if he uses the “hydrophobic condition”.

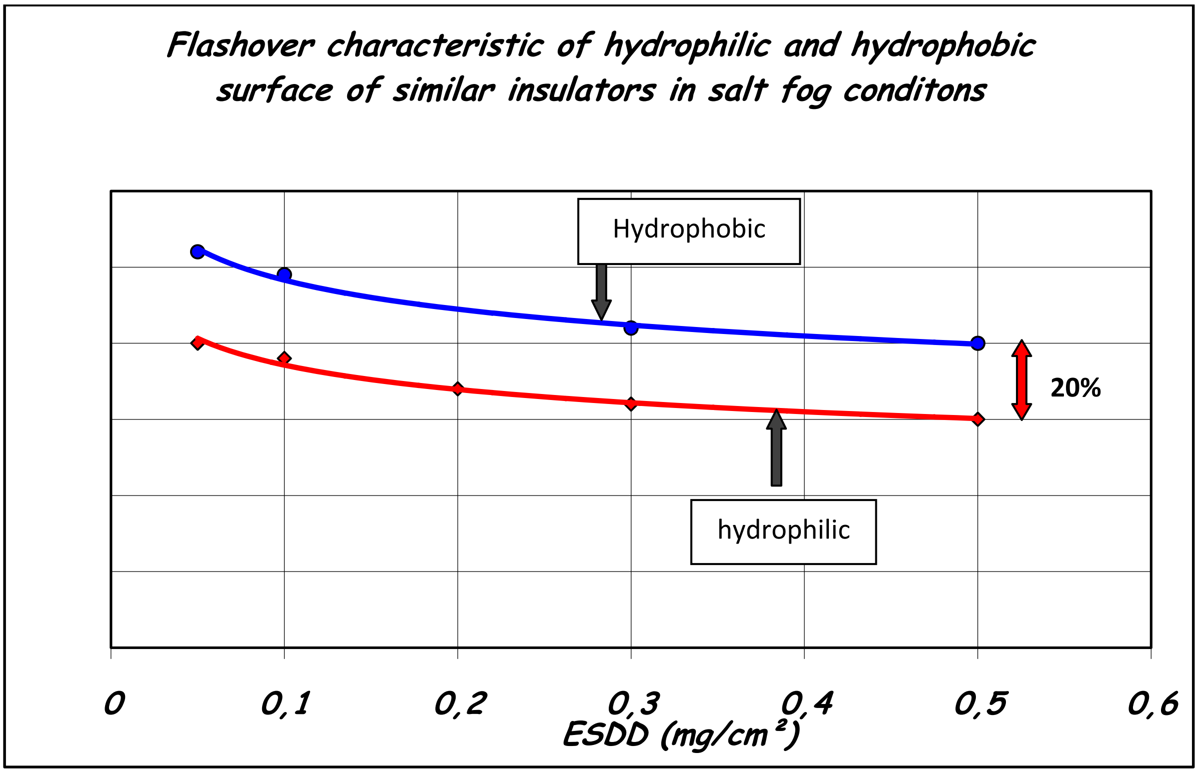


Figure 13: Salt fog test results on hydrophobic and hydrophilic surfaces

A similar study on polymers in solid pollution flashover was performed as a function of ESDD for a constant NSDD level. Figure 14 shows that EPDM or hydrophilic silicones have equal performances, and here also, under solid layer pollution conditions, the gap between hydrophobic and hydrophilic performance of silicone is in the range of 20 % to 30%

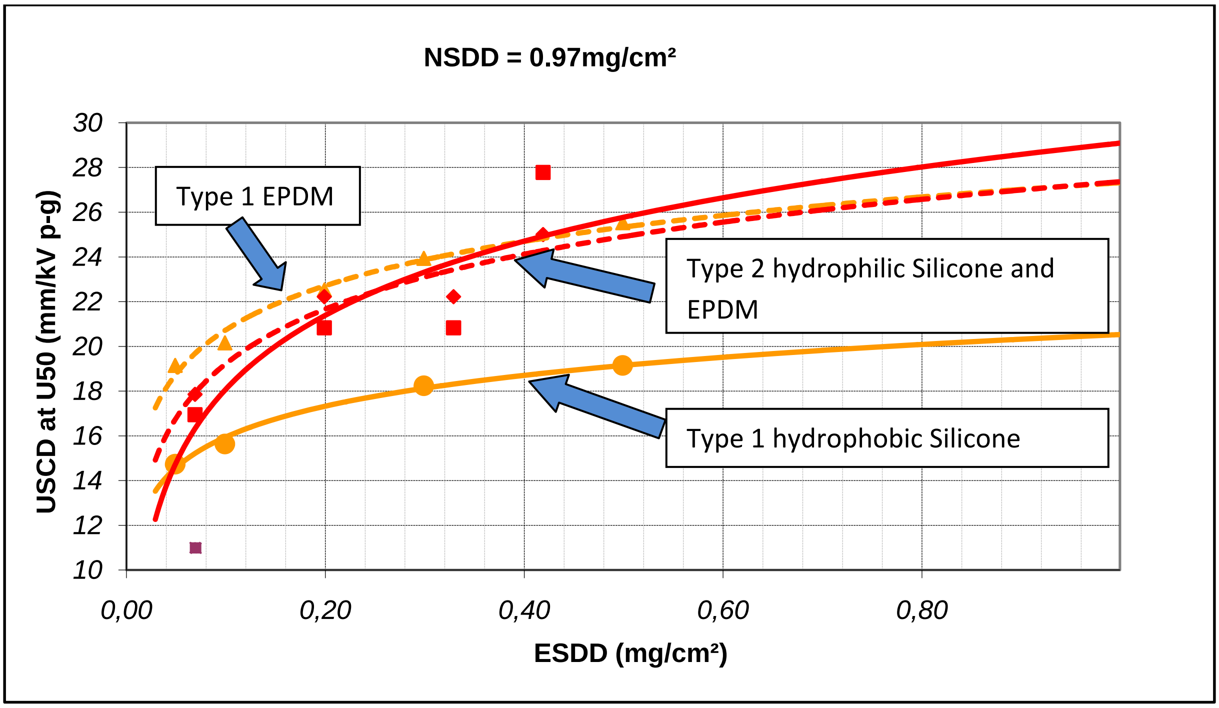


Figure 14: Solid layer contamination characteristic of various materials (USCD)

Conclusion

- The rapid flashover method described in this paper is an interesting method offering consistent results, in line with data gathered from pollution tests performed under the traditional IEC 60507 methods. It can be used for either salt fog or clean fog conditions and generates not only good results but also information on the dynamics and evolutions of the performance of the string of insulators during the tests.

- The selection of specific insulating strings for polluted environments requires the knowledge of the performance of the particular shapes of discs under consideration. Leakage distance or leakage current generic criteria disregarding the shape can be highly misleading. While some shapes are ideal for coastal conditions, they can perform very poorly in dusty or industrial environment and vice versa. Extrapolation from one shape to another can lead to severe mistakes.

- Silicone rubber insulators have a pollution performance which can vary in a bracket of 20% to 30% depending upon the hydrophobic or hydrophilic status of the rubber housing. The existence of hydrophilic insulators in service can induce a major risk if a transmission line is designed on criteria based on hydrophobic conditions. Wisdom would recommend not to design a line with a fully hydrophobic surface pollution data. The fact that EPDM is not hydrophobic removes the uncertainty of such dynamic situations.