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DC Pollution Performance
Current Approximations & Future Needs

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INTRODUCTION

The performance of overhead line insulation in DC differs from AC mostly because of ionization of the airborne particles resulting from a unidirectional electric field. As a consequence contamination levels in DC is typically more severe than for AC in the same environment. CIGRE and IEC have published technical guides and mathematical models to handle this situation at the stage of designing the insulation of a DC line. This paper gives a comparison between the insulation levels defined by these new models, actual field observations and laboratory test results. The difference pointed out show the necessity to engage into a new evaluation of the models which otherwise could lead to string lengths largely over dimensioned given their pessimistic approach.

REVIEW OF THE KEY PARAMETERS

Pollution severity parameters

Pollution deposits on the surface of an insulator are classified between ESDD (Equivalent Salt Deposit Density) and NSDD (Non Soluble Deposit Density). Both are important and while the ESDD contributes to a higher conductivity of the water on the surface of the insulator and subsequently increase leakage currents, the NSDD works like a sponge sucking moisture at morning dew phases or during fog events providing water to the leakage current and dry band arcing mechanism. Additionally, contamination deposits in the field are usually non homogeneous with the bottom of an insulator being more polluted than the top surface. CUR is a parameter describing this property and defined as the ratio bottom to top ESDD levels. In laboratory testing, CUR is often set at 1 for practical reasons, thus it provides more severe conditions than with a higher CUR.
Other parameters such as shape and dimension of the insulator, altitude, dynamics of the deposit process of the contaminants, polarity,… matter as well and are clearly explained in the relevant documents [1] and [2]. We will focus our discussion on the determination of the leakage distance of a string of insulators based on CUR, ESDD and NSDD.
The severity of the contamination in any given environment is classified in [1] and [2] from very light to very heavy according to figure 1. The specific creepage distance is determined to avoid flashovers of the string of insulators under the given contamination conditions. One important element in this discussion is RUSC (Reference Unified Specific Creepage distance which is the minimum USCD calculated as per [1] and [2]). Once this is defined, the insulator unit design can be selected from a suppliers catalog as well as the number of insulators in the string.

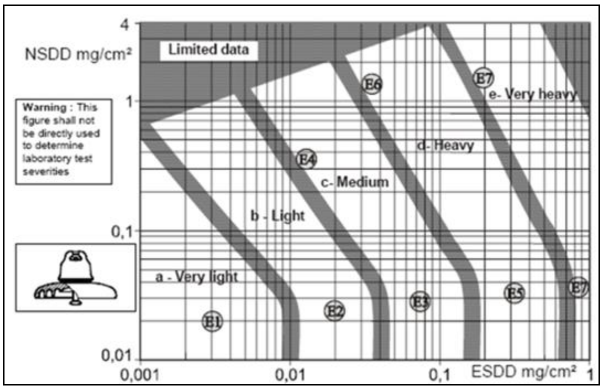

Figure 1 Pollution classification as in [1] and [2]

Example of string design based on the theoretical approach described in [1] and [2]

The following example shows the possible discrepency between the results from the theoretical method and laboratory test results. A typical 300kV dc string of 20 toughened glass DC units having an individual leakage distance of 550mm was tested with artificial pollution conditions established at an ESDD=0,047mg/cm² and NSDD=0,1mg/cm² (figure 2). This translates into a USCD=36.6mm/kV. According to [1] and [2], the theoretical RUSC for this environment would be 44,8 mm/kV. The performance of the string was excellent with leakage current peaks around 10mA (figure 3).

Figure 2 Pollution test on a string of 20 units with a USCD = 36.6 mm/kV

The difference of 20% is most likely very conservative given the low currents measured during this test. It is therefore permitted to believe that the model is not adequate for describing accurately the performance under pollution of a DC string. If such a line was designed with the results from the calculation method chances are that the string over design would generate unecessary over costs. Based on this first example it appears obviosuly that the model needs to be reviewed and challenged against additional testing and field evaluation.

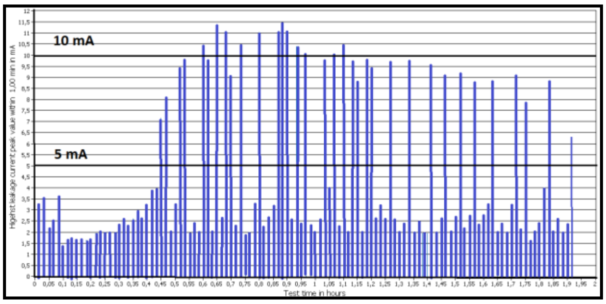

Figure 3 Leakage currents over a 100 mn withstand period measured on a string of 20 units for an ESDD=0,047mg/cm² and NSDD=0,1mg/cm². USCD = 36.6 mm/kV

FIELD PERFORMANCE AND LABORATORY TESTING

Going further in this comparison, several cases of actual DC lines have been evaluated measuring their real pollution levels by sampling their ESDD and NSDD levels on site. This information was used to determine through the theoretical model what the expected USCD should be while laboratory tests were performed on the actual string of insulators to determine their flashover values.

Among these cases, the pollution pattern of a 500kVdc line which did not show specific pollution problems over more than 40 years of service in a desertic environment show a non uniform distribution along the strings as described in figure 4. This line is designed with a USCD= 25mm/kV.

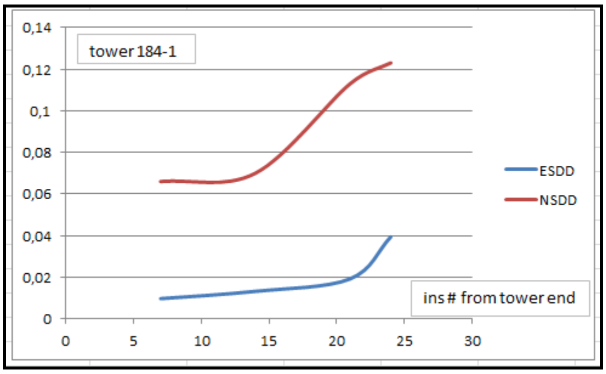

Figure 4 Distribution of the contamination along the 500 kVdc string

The theoretical model would recommend using at least 42mm/kV considering a uniform contamination along the string with an ESDD=0,04mg/cm² and a NSDD=0,1mg/cm², CUR=1.

A laboratory artificial pollution test was performed on toughened glass dc insulators selected for a voltage upgrade of this line. The string was set with a USCD= 23mm/kV ans tested with the same conditions as those used earlier for the theoretical estimation (ESDD=0,04mg/cm², NSDD=0,1mg/cm², CUR=1). The maximum current during this test sequence was 60mA. Going further in this investigation, another test was produced with an ESDD=0.07mg/cm² for a NSDD=0.1mg/cm². In this case the maximum leakage current was 100mA, but still without a flashover. Under the same conditions, the theoretical model would recommend using a string with a USCD= 51mm/kV which is twice what was tested. Even if we can agree on the effect of a possible non linearity between short strings and full length strings (the test was produced on short strings), the gap remains too high to accept the results of the model.

Another very interesting example comes from Brazil with the 600kVdc Itaipu bipoles. Several strings were removed from bipole 2 for evaluation. For this line the actual USCD value is 28.5mm/kV. The pollution levels are classified as “heavy” accounting for agricultural and industrial pollution near Sao Paolo. Figure 5 summarizes the pollution levels. It is interesting to see the very important CUR ratios in figure 6. While the maintenance department ensured that there was no line interruption related to pollution problems in this region the theoretical model predicts intense flashovers unless the strings are redesigned with at least a USCD=47mm/kV. Once could argue in this particular case that the CUR level is out of the classical range considered in the design of the model (the typical range of CUR in the model is CUR< 10), but once more we see the limits and innacuracies of the mathematical approach.

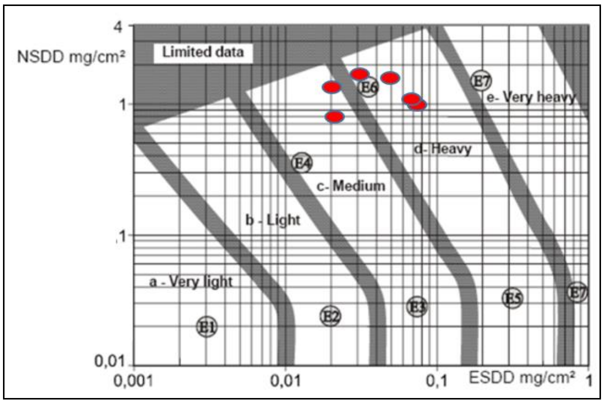

Figure 5 Pollution levels measured at Itaipu 600kVdc, Brazil

Location	Insulator nb. from tower	ESDD (mg/cm²)	NSDD (mg/cm²)	CUR
IBUNA	1	0,07	1,01	27,5
	14	0,02	0,89	9,67
	25	0,07	1,06	8,58
ITABERA	1	0,02	1,52	12
	14	0,03	1,77	22
	25	0,05	1,74	19,25

Figure 6 CUR levels measured at Itaipu 600kVdc

MITIGATION OF SEVERE POLLUTION

Most dc lines are built in relatively clean environments, except for a few cases located in urban/industrial areas (like China) or along a coast (Italy, New Zealand…). It is clear however that even in clean areas, the electrostatic effect of a dc line will attract airborne particles to form a higher pollution level than an AC line in the same location.
The problem for higher contaminated areas is therefore even more critical. Polymer insulators are sometimes considered in these conditions, mostly in China and very marginally in the rest of the world (mostly because of the lack of consensus and standard describing silicone housing and seal maximum stress levels for a dc application). Several cases of early degradation of the polymer housing or the seals have already been reported. [3], [4] and warnings for a more cuatious approach for polymers in DC start to be heard when comparing pollution performance to accelerated ageing [5].

One way around this difficulty is the use of silicone coating applied on the surface of traditional glass or porcelain insulators. While China is extensively going today in this direction (Ximeng – Taizhou – Shanghaimiao – Shandong 800kVdc line currently under construction is using several hundred thousands of factory pre-coated toughened glass insulators), other examples show the benefits of using a risk free solution such as toughened glass coated insulators.

Terna in Italy for example is now using such products on their 200kVdc line [6] in Tuscany (figure 7 and 8) and Sardinia eliminating washing for now at least 5 years (so far no washing was needed compared to previous years practice). Some areas are classified as "very heavy" as shown in figure 7.

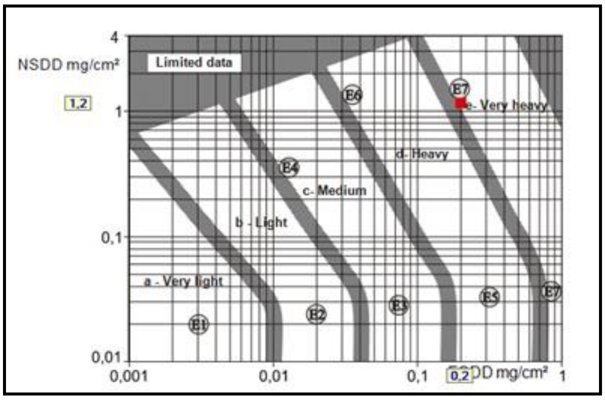

Figure 7 Level of contamination measured on the 200kVdc line from Terna.

Figure 8 silicone coated toughened glass insulators installed in Italy on the Terna 200kV dc line.

A comparative pollution test between toughened glass precoated insulators and polymer insulators was performed in salt fog conditions for a coastal application. The results are summarized in figure 9 showing the benefits of a classical glass string coated with silicone compared to a composite silicone housing insulator.

80g/l IEC 61245	polymer	Silicone coated glass
Min withstand USCD	Min -39 mm/kV	Min -30mm/kV

Figure 9 Salt fog test comparison

These results show the difficulty to come up with a general performance statement without doing actual testing. In this particular case both test objects are considered as hydrophobic materials. In both cases their respective leakage distances were equivalent during the tests but material and shape matters.

It is also interesting to note that while silicone coated insulators were used so far either with the application of silicone made on site or made in an industrial apporach so called “factory precoated”, a new 800kV dc line (figure 10) in China (Ximeng-JiangSu TaiZhou) has been built this year using the latter option with nearly 400 000 glass insulators (as well as porcelain insulators) for tension applications. The demonstration explained in figure 9 should be an indication that the theoretical model will need more work and modifications for hydrophobic materials (HTM) especially if more coated insulators are being used instead of polymers in the future. Like for AC, shape matters [7] and the assumptions made for HTM in the theoretical model were mostly made for polymer shapes and not cap and pin insulators..

Figure 10 Inner Mongolia XiMeng – JiangSu TaiZhou +/- 800kV ultra high voltage DC transmission line with coated glass insulators.

CONCLUSION AND FUTURE DIRECTION

The large spread of results and inconsistencies between laboratory test, field performance and theory demonstrate the absolute necessity to produce an actual design test for any given project and not rely on the theoretical set of equations which can be found in various documents today.

Figure 10 gives an idea of the magnitude of the margin of error in the theoretical evaluation of the RUSCD versus laboratory or field performance. This graph needs to be further adjusted by more test results to fine tune the reference to a RUSC.

The type of errors possible with a mathematical model can lead to a possible overdesign of 20% to 30% or more. The consequence in cost is huge and can make a line design become unacceptable to the utility. Large campaigns of pollution tests in dc are required to better document the actual performances.

Likewise, most if not all laboratories produce tests only with a CUR=1 while in reality CUR varies often between 3 and 5 or 7. There is a necessity to define new contamination deposit methods to be able to duplicate with consistency such variable CUR levels in the tests. This will help to better simulate actual field conditions without relying on theoretical correction factors.

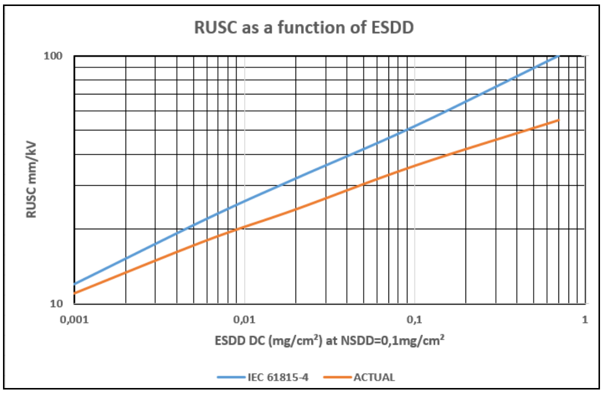

Figure 10 specific creepage distance as per [1] and [2] versus test data and field experience gathered over the last years (in blue the current curve versus red the estimated true performance)

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