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Artificial Pollution Testing of HVDC Insulators

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Abstract

A review is presented on the performance of insulators under artificial pollution testing of HVDC insulators in the laboratory as per the test methods described in the standards which establishes the test facility required to meet technical specifications. Also, another test facility established as per the requirements of the standard for insulators used in the DC system is the puncture test. These two tests form an important characteristic for designing the insulators and reducing outages in transmission lines. Creepage length forms an important designing criterion for the insulators which influences the pollution performance wherein the puncture in an insulator reduces the creepage. The pollution test results had compared with the available literature and the results are found to be within the specified limits. In addition to the various tests specified in the relevant standard for DC insulators, establishing the test facility cater to one of the important test requirements for DC insulators i.e., artificial pollution test and puncture test which is the vision of Govt. of India in line with to make in India and atmanirbhar Bharat initiatives.

Keywords: Creepage Distance, DC Insulators, Pollution Test, Puncture Test, Solid Layer Method

1. Introduction

The industrial growth of a nation requires increased consumption of electrical energy. The generation of power at remote locations and its interconnections led to the search for efficient power transmissions at higher power/voltage levels. The problems of AC transmission for long distances have led to the development of DC transmission systems. The highest transmission voltage has reached to ±800kV. For a reliable HVDC transmission system, the flashover across the insulators must be as minimum as possible. One of the most important factors for the HVDC system is the pollution performance of insulators and the puncture of insulators. The failure rate of insulators in a DC system is higher compared to an AC system[1]. As compared to AC voltage, in DC voltages the electrostatic absorption due to continuous electrostatic force makes the insulator contaminate and deposit on the surface of the insulator. For the same design or profile of the insulator, the pollution contamination under DC electrostatic fields is 1.2 to 1.5 times that accumulating under other electric fields[2,3]. The absence of zero crossing in the dc systems intensifies the systems which will be difficult to get extinguish by themselves unless strong external forces such as wind, rain, etc quench the arc otherwise the insulator will definitely lead to flashover. Once the scintillating initiates across the profile of the insulator in dc along with continuous flashover or arcing across the profile of the insulator, the ion migration under dc causes a serious threat to the insulating materials too.

Porcelain insulators puncture and glass insulators shatter into small pieces. Breakage of porcelain insulators occurs due to corrosion near the pin or damage during flashovers or external damage by pelting stones etc which results in a reduction of leakage length, the weight of the electrode reduces, and a reduction in the total strength of the string in carrying transmission lines. This reduction in the porcelain portion of the insulator caused more threats during pollution flashovers. The pollution performance of the insulators and puncture tests are the two tests suggested in IEC TC 6124: 2015[4] and IEC 61325: 1995[5] respectively. Central Power Research Laboratory (CPRI), Hyderabad has established a test facility to conduct artificial pollution tests and punctures on glass and porcelain insulators meeting the requirement of National/International standards.

The IEC 61325 specifies various tests on DC insulators such as tests for mechanical strength and electrical

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strength. The electrical tests are the Lightning impulse voltage withstand test (dry), DC withstand voltage test (dry), lightning impulse voltage puncture test, and puncture test of a single disc insulator in SF6 gas environment. The IEC TS 61245 specifies test methods for artificial pollution tests using salt-fog and solid layer methods. For DC insulators, the preferred method is a solid layer.

2. Equipment used for Artificial Pollution Test Using Solid Layer Test Method

1. Test source: The HVDC source shall be strong enough to cater to the test requirements for pollution testing especially during scintillations across the insulator string and in order to get the unambiguous test results under dc test conditions[6]. UHVRL has an HDC source of ±1200 kV with a ripple factor of the test voltage ≤3%. The relative voltage drop occurring during individual tests resulting in withstand is not exceeding 10%. Another parameter is the relative voltage overshoot caused due to load-release caused by the extinction of electrical discharges or scintillations on the insulator surface, which is not exceeding 10%. As per the standard, if a flashover occurs during the time when a relative voltage overshoot is between 5% and 10%, the test is not valid.
   The voltage measurement is carried out by a voltage divider according to IEC 60060-2 suitable to measure continuous voltage and transients with required accuracy of ±1%. The photograph of the HVDC source used is shown in Figure 1. If the source has a feeble voltage supply, the drop will exceed the limits during partial arcing of the insulators. Having a strong AC source does not guarantee the voltage drop within limits. This source has a control circuit to maintain the voltage drop within the specified limits of the standard.
2. Test chamber: A stiff plastic test chamber is designed to accommodate the insulator and also the steam fog does not escape. The size of the test chamber is 6mX6mX15m. A photograph of the test chamber is shown in Figure 2.
3. Bushing: A bushing is designed to carry the HVDC voltage into the insulator under test. The bushing was made strong enough with fiberglass and required insulating material to cater to the needs of ±500 kV DC voltage. A photograph of the bushing is shown in Figure 3.

Figure 1. **±1200 kV HVDC** source.

Figure 2. Test chamber for HVDC pollution test.

Figure 3. **±500kV HVDC** bushing.

4. Steam Generation: It is well known that the insulators under dry conditions may not lead to flashover under dry conditions. The test sample needs to be wetted for the formation of dry and wet bands. As per the standard, the wetting rate rather than the steam injection rate is prescribed. Hence, the measurement of layer conductance was checked for the wetting action of the fog. The wetting of the insulator string is done with a steam generator. A photograph of the steam generator is shown in Figure 4.

Figure 4. Steam generator.

5. Data Acquisition System (DAS): The multichannel DAS is a PC-based online monitoring and recording system continuously. It is designed to acquire voltages and leakage currents from the insulators using a DC voltage divider and shunt (resistive) respectively. A set of input signals and a PC-based plug-in multifunction card for digitizing the input signals were developed. The software program was developed in LABVIEW to control the digitizing hardware. The software analyses digitized data to a specified algorithm to acquire required (voltage and total leakage currents) parameters. The software can provide inputs such as the channels required, sampling rates, etc. The final output can be input into tabular and Excel sheets and graphical representation. A photograph of DAS is shown in Figure 5.

Figure 5. Data acquisition system.

3. Test Sample and Procedure

1. HVDC insulators: 46-disc insulators (V and single I configuration) are used in the string for ±500 kV whose photograph is shown in Figure 6. Each disc has a creepage length of 525 mm. Each disc is coated with SDD of 0.1 mg/cm^2 kaolin powder through the dipping method whose photograph is shown in Figure 7. After dipping and drying, the SDD has verified once again on a couple of insulators for uniformity coating.

Figure 6. HVDC disc insulators (‘V’ String).

Figure 7. Koalin powder coating on each disc insulator with SDD of 0.1 mg/cm^2.

2. Test procedure (As per IEC TS 61245): Procedure B i.e., wetting after energization is envisaged during testing where the test voltage is applied to a dry insulator before any wetting occurs. This situation simulates most of the frequent situations for sites with solid layer contamination which occurs in rural, industrial, and desert conditions. Steam fog is used for wetting the layer. The test object is wetted by means of fog genera-

tors which provide a uniform fog distribution around and covering the whole length of the test object. The temperature of the test object at the beginning of the wetting is maintained within 2 K of the ambient temperature in the test chamber. The fog generation in the test chamber is maintained constant until the end of the individual test at a constant steady rate of flow. The fog generation tubes are kept under the test object on the floor which is about 3 meters distance from as close as possible to the floor level. A plastic tent surrounding the test object limits the volume of the test chamber without influencing the pattern of fog development around the insulator.

The aim of this test is to confirm the specified withstand a degree of pollution at the specified test voltage of -500kV (Negative). The test voltage is maintained for 100 min (from the start of the test) where it is found that the risk of flashover has come down as per the leakage current measurement. The peak of the leakage current was between 30 min to 60 min. The specified characteristics of the insulators are confirmed where there was no flashover occurred during three consecutive individual tests performed. If a flashover occurred, a fourth test would have been performed and the insulator then passes the test if no further flashover occurred. The measurement of voltages and currents are shown in Figures 8, 9, and 10 for Single 'V' Suspension String and Figures 11, 12, and 13 for Single 'I' Suspension String.

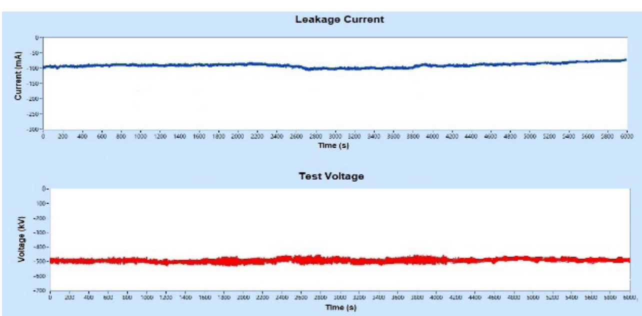


Figure 8. Voltage and current characteristics for 1st hour ('V' String).

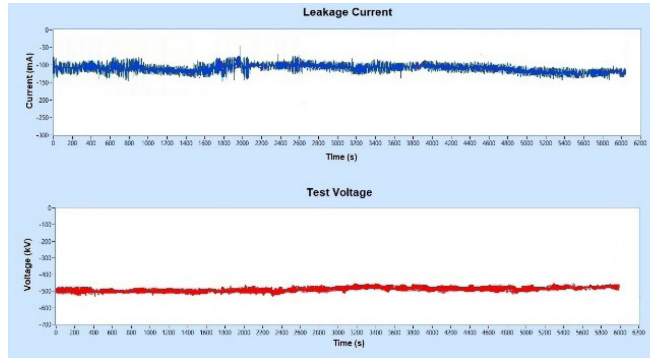


Figure 9. Voltage and current characteristics for 2nd hour ('V' String).

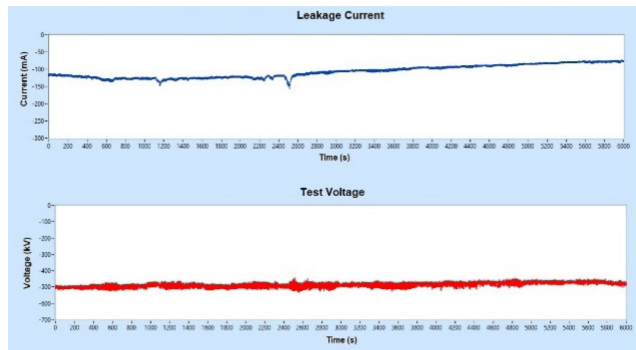


Figure 10. Voltage and current characteristics for 3rd hour ('V' String).

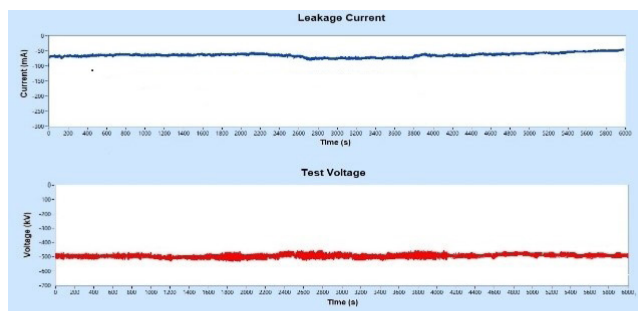


Figure 11. Voltage and current characteristics for 1st hour ('I' String).

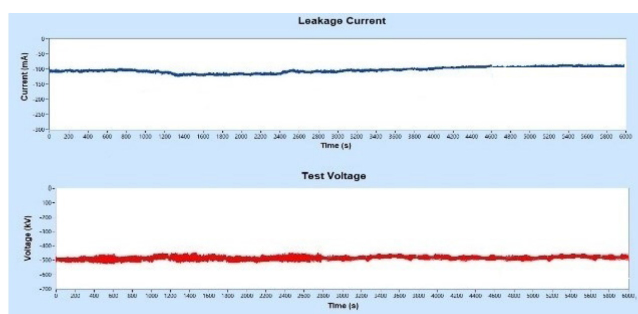


Figure 12. Voltage and current characteristics for 2nd hour ('I' String).

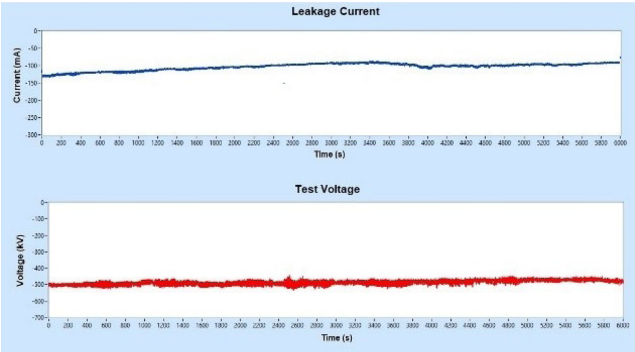


Figure 13. Voltage and current characteristics for 3rd hour ('I' String).

4. Puncture Test on DC Disc Insulators

This test is performed as per IEC 61325. The test chamber is made of Metallic (MS) material with sufficient dimensions inside to hold a single insulator at a time. To apply the DC test voltage, a GIS bushing rated 245 kV was mounted on the metallic chamber. A pressure gauge is fixed to the chamber to monitor and maintain the SF_6 gas pressure to the required level. The total setup was fixed to a movable metallic stand. The photograph of the chamber is shown in Figure 14.

Figure 14. Test chamber for puncture test on DC disc insulators.

A DC disc insulator is mounted inside the chamber in reverse for the convenience of applying a voltage to the insulator pin. A cap is fixed to the insulator pin to avoid unnecessary voltage gradients. An insulating medium i.e., SF_6 gas is maintained at a pressure of 0.2 to 0.4 MPa to avoid the flashover to the metallic chamber.

The positive DC voltage is applied to the pin and raised as quickly as possible to the desired voltage. A voltage equal to 1.5 times the dc withstand voltage is applied for 20 minutes. This procedure is repeated on 10-disc insulators of the same profile and ratings.

5. Results and Discussion

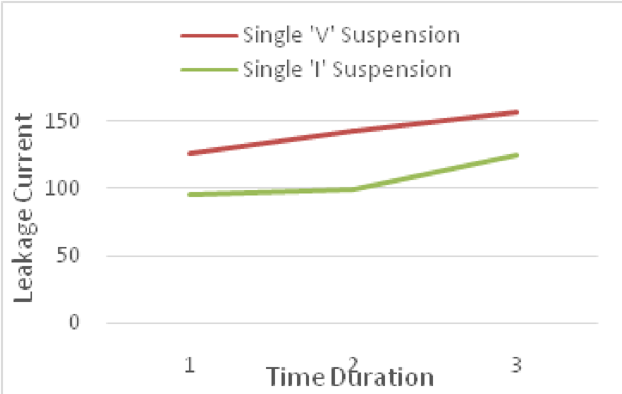
1. The leakage currents and respective voltage variations are shown in the figures. The values during peak conditions of leakage currents are tabulated herewith in Table 1 for Single 'V' Suspension String and Table 2 for Single 'I' Suspension String. The average and peak voltage drops are shown. These values appear to be within the specified values as per the standard. Tabulated values are also shown in Graph 1. The peak value of the leakage current is found to be within the time range of 30 min to 60 min duration which means the wetting rate of the contaminated insulators meets the requirement. Also, the leakage current values are as per the literature[7] (as shown in Figure 15) for all three consecutive one-hour duration.

Table 1. Single 'V' suspension string

Duration (In hrs)	DC test voltage -500 kV		
	Voltage drops (%age)	Peak Value of Leakage Current (mA)	Remarks
1	7.51	-126	Withstood
2	7.74	-143	Withstood
3	8.25	-157	Withstood

Table 2. Single 'I' suspension string

Duration (In hrs)	DC test voltage -500 kV		
	Voltage drops (%age)	Peak Value of Leakage Current (mA)	Remarks
1	6.51	-95	Withstood
2	6.74	-100	Withstood
3	7.25	-125	Withstood



Graph 1. Leakage current vs time duration.

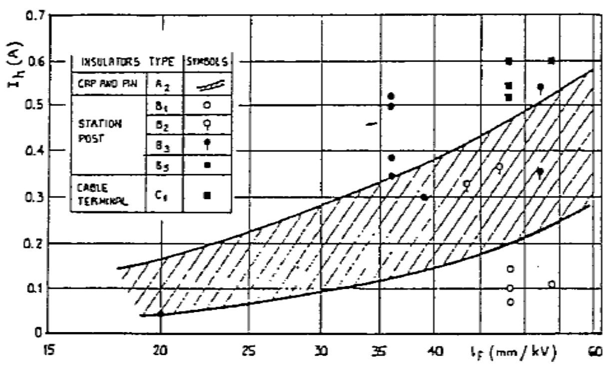


Figure 15. Leakage current vs creepage distance per unit withstands voltage.

2. The 10-disc insulators have undergone a puncture test in SF6 gas medium which withstood a voltage of 225 kV (which is equal to a dc withstand voltage of 150 kV * 1.5 times). After the test is completed, the voltage for one insulator is increased up to the puncture (after 20 min withstands) voltage. The source got immediately tripped after the puncture. The resistance of the punctured insulator to withstood insulator is verified for confirmation.

6. Conclusions

CPRI, UHVRL, and Hyderabad has successfully established the test facility for conducting the following tests on HVDC insulators.

1. Artificial pollution test using solid layer method as per the standard
2. SF6 gas Puncture test.

- The HVDC source meets the requirement for conducting tests in EHV and UHV range for porcelain and glass DC insulators as per IEC standards.
- The repeatability of the test results is found to be OK
- The chamber/plastic tent, steam fog generator, and bushing are designed to meet the pollution testing requirement up to ±500kV DC.
- The test results obtained for pollution testing are compared with the available literature
- The puncture test facility confirms whether the insulator really gets punctured or not.

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