Central Power Research Institute

Vol. 18(2)/133-138, December 2022
ISSN (Print) : 0973-0338
DOI : 10.33686/pwj.v18i2.1091

Power Research

Experimental Analysis of Ceramic Insulators with Different Profiles Under Very High Pollution Zone by Solid Layer Method

Shyam Agarwal*, V. Mohan Babu, G. Gobinath and G. Pandian

High Voltage Division, Central Power Research Institute, Bengaluru, India; sagarwal@cpri.in, mohanvasu@cpri.in, gobinath@cpri.in, gpandian@cpri.in

Abstract

The outdoor insulators in service are exposed to marine, agricultural waste and industrial pollution. These pollutants get deposited on the insulator surface and lead to flashovers under fog conditions. There has been an abnormal increase in pollution levels due to rapid industrialization in the past two decades. This exponential increase in pollution levels causes frequent flashovers of insulators, leading to the tripping of transmission lines consecutively may result in blackouts, which severely affects the reliability of the power systems. The ESDD and NSDD measurement on the insulator surface are critical parameters for determining the pollution severity levels. This paper discusses ESDD and NSDD measurement procedures. In this paper, field pollution severity has been simulated in the Artificial Pollution Lab. In addition, the Non-Soluble Deposit Density (NSDD) component of pollutants for designing the creepage distance of ceramic insulators under heavy pollution conditions has been emphasized.

Keywords: Creepage Distance, ESDD, NSDD

1. Introduction

Electrical power is transmitted over long distances. This Electrical power system is expanding daily worldwide, so situations of unscheduled power supply interruptions can cause problems ranging from simple inconveniences to significant losses. The insulators are a significant and populous component in this power transmission network. These insulators under the pollution condition lead to the formation of a contamination layer on the insulator's surface, allowing leaking currents that will facilitate the conditions of flashover and consequent power outages[1].

Three main types of pollution can be distinguished: industrial, desert, and marine pollution. The first appears with industrial development producing contaminants (metallurgical, chemical substances, dust, carbon and cement etc.) into the atmosphere in both dry and gas forms, leading to flashover during wet conditions. These solid pollutants are deposited by the wind onto the insulator surface. Desert pollution occurs due to a gradual accumulation of dust, sometimes salty, on the insulators, resulting in reduced efficiency and possible supply interruption. Marine pollution exists in coastal environments where a conductive layer may be formed on the insulator's surface due to the salted dew. When large birds and groups release their excrement on the transmission line's ceramic insulators, it forms a long continuous length of highly conductive fluid droppings, leading to the intensification of layer conductance of insulators. Due to this, the insulators are covered with bird excrement, which is a pollution layer with a very high salt content. If the birds utilize the tower frequently, this may become a thick layer. This pollution becomes conductive when wetted during fog conditions.

In dry conditions, these contaminants generally do not cause the flashover of high-voltage insulators. However, when a contaminated high-voltage insulator gets wet due to operation in fog and mist, the contaminated layer

*Author for correspondence

conducts and causes a leakage current to flow on the surface of the insulator. Due to the heating effect associated with the leakage current, dry regions are formed across the different regions on the surface of the insulator. It results in electrical discharge across these dry regions. In certain favourable conditions, these discharges elongate over the whole surface of the insulator and ultimately may cause a flashover[2,3]. To avoid these flashovers, the creepage distance of the Porcelain insulator has to be designed based on the severity of pollutants in the pollution area as suggested by IEC 60815-2: 2008[4]. Creepage distance is the shortest distance measured along the surface of the insulator between conducting parts. For larger creepage distances, the leakage current path is increased; therefore, flashover chances get reduced. The Specific Creepage Distance (SCD) in mm/kV is the creepage distance of an insulator divided by the maximum operating voltage across the insulator[4].

2. ESDD and NSDD

Pollutants on the insulator's surface can be divided into two categories. Equivalent Salt Deposit Density (ESDD) is one part, while Non-Soluble Deposit Density (NSDD) is the other. These pollutants can be collected from existing transmission lines or field testing stations to assess ESDD and NSDD[5]. The ESDD part is water-soluble, and the NSDD part is non-soluble or inert materials. The soluble component, expressed in the Equivalent Salt Deposit Density (ESDD), has been used widely in artificial pollution tests to describe the outdoor pollution severity. This quantity is obtained by measuring the volume conductivity of the solution containing pollutants removed from the insulator surface and then calculating the equivalent amount of NaCl having the same volume conductivity per unit area[6,7].

In most outdoor locations, the representation of pollution severity by ESSD is appropriate for ceramic and glass insulators. However, in certain areas close to industries such as cement and paper plants, heavy machinery and significant roadways, the pollutants are not soluble therefore giving low ESDD values. These pollutant depositions can be substantial enough to cause a thick water film and a large leakage current, leading to a flashover. So far, inert material put on an insulator surface was thought to have only a minor and indirect effect on the withstand voltage. However, the greater the inert material deposit is, the more the water film will be thicker and retained on the insulator surface, so the amount of soluble material dissolved in the water film will be higher. The non-soluble part of the pollution is denoted in the literature as NSDD[5]. Because the NSDD affects the insulator's flashover voltage under pollution conditions, it is important to consider NSDD values during insulator selection. It has been observed that the insulator Flashover Voltage (FOV) reduces with increasing NSDD for the same ESDD, primarily due to the thicker water film supported by the inert material. Both ESDD and NSDD are expressed in mg/cm2 of the insulator surface Area[6,7].

3. ESDD and NSDD Measurement at Site

The pollution level in India's NCR region comes under a very high pollution zone. For the Selection of insulators on the Dadri-Khurja route, the pollution mapping study was carried out. The site pollution severity was determined by measuring both ESDD and NSDD. The swab technique method has been used to calculate ESDD and NSDD values[5]. The condition of the sample is shown in Figure 1.

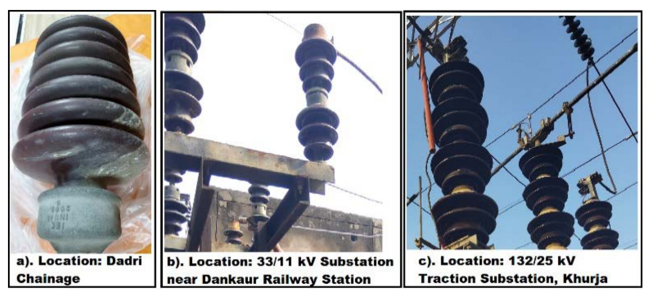

Figure 1. Photographs of sample insulators in field condition.

For measuring the ESDD and NSDD values, De-ionized water of 300 mL was poured into the container. White, Clean and absorbent cotton was immersed in the water. Volume Conductivity of the water with the immersed cotton was recorded. Then the pollutant from the sample was wiped with the squeezed cotton from top to bottom. Cotton with the pollutant was put back into the labelled container. Wiping was repeated until no further pollutants remained on the insulator surface. The pollutants were dissolved into the water by shaking and squeezing the cotton in the water. The volume conductivity and the temperature of the water containing the pollutant were recorded. The measurements were made after enough stirring of the water. Volume Conductivity correction factors were applied as per clause 5.2 of IEC 60507: 2013[8].

The ESDD was calculated using Equations 1 and 2.

$$Sa = (5.7 \times \sigma_{20})^{1.03}\ in\ \text{kg/m}^3 \quad (1)$$

Where:

Sa is the salinity of water solution containing pollutants in kg/m^3.

σ_{20} is the measured and corrected volume conductivity at a temperature of 20°C in S/m.

$$ESDD = \frac{Sa\ X\ V}{A}\ in\ \text{mg/cm}^2 \quad (2)$$

V is the volume of de-ionized water in cm^3.

A is the surface area of the insulator cm^2.

The surface area of the insulator is calculated from the procedure as mentioned in RDSO standard[9]. The water containing pollutants, after computing ESDD, has been filtered out using a funnel and pre-dried and weighed filter paper with a grade of GF/A. The filter paper containing pollutants (residuum) shall be dried and weighed. The NSDD shall be calculated by Equation 3.

$$\text{NSDD} = \frac{(Wf - Wi)}{A}\ in\ \text{mg/cm}^2 \quad (3)$$

Where:

W_f is the weight of the filter paper containing pollutants under dry conditions in mg.

W_i is the initial weight of the filter paper under dry conditions in mg.

A is the surface area of the insulator cm^2.

With this procedure, the calculated ESDD and NSDD are tabulated in Table 1.

Table 1. Field pollution level

Location details	Rated Voltage of service Insulator	ESDD in mg/cm^2	NSDD in mg/cm^2	Design Severity
a. Dadri Chainage: 1417/4	25	0.96	0.68	Very High
b. 11 kV substation, Near Dankaur Railway Station	11	0.56	0.65	Very High
c. 132 kV/25kV Traction Substation, Khurja	132	0.72	0.18	Very High

Table 2. Specific Creepage Distance (SCD) for an insulator based on pollution severity

S.No.	ESDD At 20°C in mg/cm^2	Pollution Level	SCD to be used in mm/KV
1	<0.10	Low	16
2	0.10 to 0.30	Medium	20
3	0.30 to 0.60	High	25
4	>0.60	Very High	31

As per the standard IEC 60815-2: 2008[4], the pollution level falls under a very high pollution zone, and the recommended SCD shall be 31 mm/kV, as mentioned in Table 2.

4. Experimental Results

The field conditions as mentioned in Table 1 were simulated. The artificial pollution test using the solid layer method (procedure B) as per IEC 60507:2013[8] is adopted. The typical profile selected for the test sample is mentioned in Figure 2.

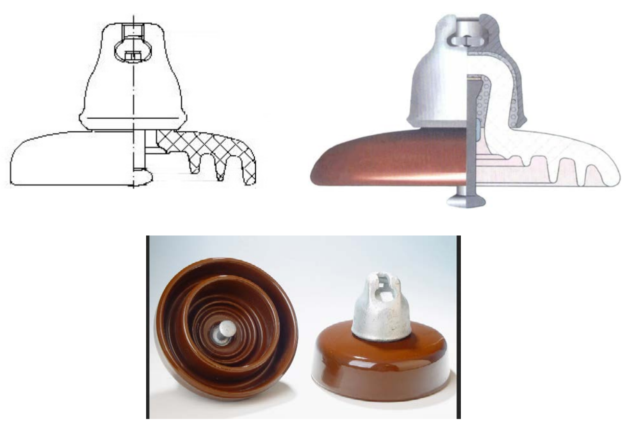

Figure 2. Typical profiles of porcelain disc insulators.

As per Table 1 maximum observed value of NSDD is 0.68 mg/cm^2, and ESDD is 0.96 mg/cm^2. Therefore, these values are considered reference values for the experiment purpose. For this experiment, three different creepage distances disc insulators of 11kV were selected, as shown in Figure 3. The SCD of these disc insulators is 24 mm/kV, 31 mm/kV and 38 mm/kV, respectively.

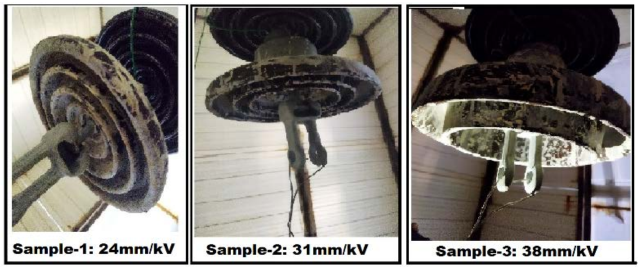

Figure 3. Photographs of test samples during experiment.

The salinity of the water solution is obtained with the following Equation 4 deduced from Equation 2.

$$\text{Sa} = \frac{SDD\ X\ A}{V}\, in\, \text{kg/m}^3 \qquad (4)$$

In this experiment, 25 mL of tap water with a volume conductivity of 0.9 mS/cm is used; the recommended value is within limits as per IEC 60507: 2013[8]. The surface area of the insulator is calculated with the procedure mentioned in RDSO standard[9].

$$\sigma_{20} = \frac{\sqrt[1.03]{Sa}}{0.57}\, in\, \text{mS/cm} \qquad (5)$$

The corresponding value of volume conductivity of the water solution is mentioned in Table 3 calculated from Equation 5.

With the above value of Kaolin and the volume conductivity of the water solution, the sample was coated with this solution. Each sample was then subjected to 100 minutes test with a constant voltage of 6.9 kV. The circuit diagram of the test setup is shown in FIG.4. For the measurement of leakage and current 11Ω resistor was chosen along with 10 volt Zener diode for protection of the measuring circuit.

Table 3. Experiment parameters

Sample No.	Surface Area in cm^2	Inert material (Kaolin) weight at the NSDD value of 0.68 mg/cm^2	Volume Conductivity in mS/cm of water solution at 20°C
Sample-1	1286	875 mg	77.33
Sample-2	1802	1226 mg	107.30
Sample-3	2330	1585 mg	137.71

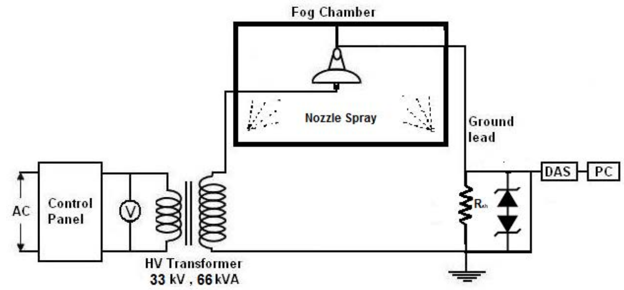

Figure 4. Schematic diagram for test setup.

The leakage current waveforms were recorded and shown in Figures 5, 6, and 7. For each test specimen, the maximum recorded value of leakage current and test voltage is mentioned in the Table 4.

Table 4. Test results

Sample No.	Test Voltage	Maximum Leakage Current	Flashover Incident
Sample-1	6.9 kV	NA	Flashover
Sample-2	6.9 kV	400 mA	Withstood 100 minute
Sample-3	6.9 kV	120 mA	Withstood 100 minute

With the above experimental observation and leakage current values, the sample with 24mm/kV SCD did not withstand the test voltage at ESDD and NSDD values of 0.96 mg/cm^2 and 0.68 mg/cm^2, as shown in Figure 5.

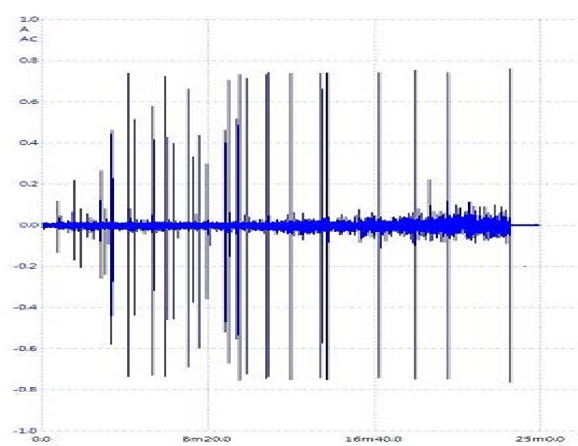

Figure 5. Waveform of leakage current measured for sample 1.

The sample with SCD of 38 mm/kV saw leakage current up to 120 mA, as shown in Figure 6. The scintillation was minimal in sample 3 during the study.

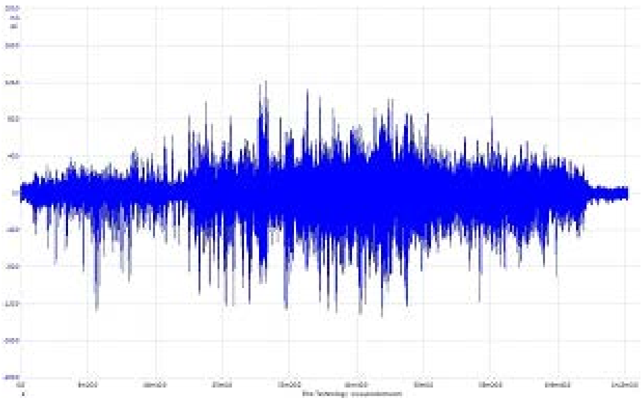

Figure 6. waveform of leakage current measured for sample 3.

The sample with SCD of 31mm/kV saw leakage current up to 400 mA as shown in Figure 7. The scintillation in the case of sample 2 was high compared with sample 3, as shown in Figure 7.

However, minimal scintillation was observed in SCD of 38 mm/kV. It is evident that SCD of 31mm/kV may not be sufficient under these pollution conditions. Therefore for better reliability and to minimize chances of flashover for these pollution levels, the SCD used shall be 38 mm/kV. Further to minimize any chances of pollution flashover, the following measures also may be taken. The RTV (room temperature vulcanize) coated samples also may be recommended. It is further suggested that line washing may be performed three times a year.

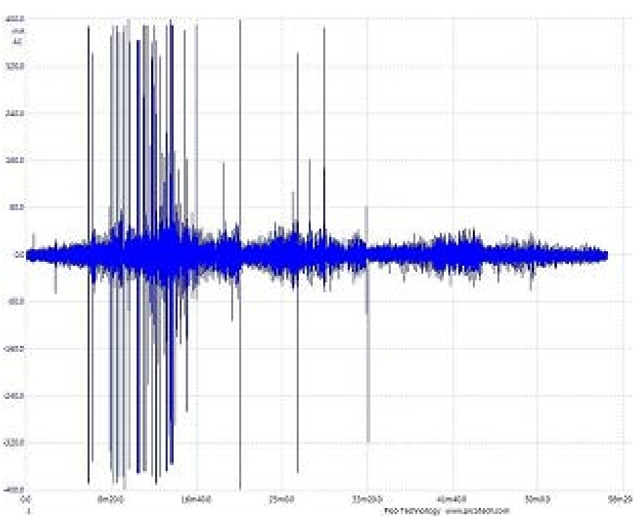

Figure 7. Waveform of leakage current measured for sample 2.

5. Conclusion

Based on the CPRI's experiences of pollution mapping study in the field, to compare the field study results, an attempt has been made to conduct the experiment on three 11kV ceramic disc insulators of different creepage distances for their pollution performance. In the laboratory, the Kaolin powder has been used to simulate the contribution of Non-soluble components of pollutant deposits on insulators. The maximum ESDD and NSDD values of the field study have been considered for the experiment.

In light of field study and the prevailing limitations of the IEC standard's recommendations of SCD for pollution severity of 0.6 mg/cm^2 and higher is found meagre. The detailed site survey is the only available alternative to identify the pollution severity and aptly design the creepage distance of the insulator. Therefore, further research is required to address these issues and the standardization of SCDs and ESDD & NSDD values.

6. Acknowledgement

The authors thank CPRI Management for giving us the opportunity in publishing this paper. The authors also thank L&T CP 105 project team for their support during measurement.

7. References

1. Holtzhausen JP, Vosloo WL. The pollution flashover of ac energized post type insulators. IEEE Transactions on Dielectrics and Electrical Insulation. 2001; 8(2):191-194. https://doi.org/10.1109/94.919925
2. Rahal AM, Huraux C. Flashover mechanism of high voltage insulators. IEEE Transactions on Power Apparatus and Systems. 1979 Nov; PAS-98(6):2223-2231. https://doi.org/10.1109/TPAS.1979.319421
3. Muhsin T, Mehmet C. The pollution flashover on high voltage insulators. Electric Power Systems Research. 2008; 78:1914-1921. https://doi.org/10.1016/j.epsr.2008.03.019
4. IEC Technical Specification 60815-2, Selection and dimensioning of high-voltage insulators intended for use in polluted Conditions-Part 1: ceramic and glass insulators for a.c. systems; 10 2008.
5. IEC Technical Specification 60815-1, Selection and dimensioning of high-voltage insulators intended for use in

polluted Conditions-Part 1: ceramic and glass insulators for a.c. systems; 10 2008.
6. CIGRE WG C4.303- Outdoor insulation in polluted conditions: Guidelines for Selection and dimensioning - Part 1: General principles and the a.c. case, CIGRE Technical Brochure N° 361; 2008
7. Sundararajan R, Gorur RS. Role of non-soluble contaminants on the flashover voltage of porcelain insulators. IEEE Transactions on Dielectrics and Electrical Insulation. 1996; 3(1):113-118. https://doi.org/10.1109/94.485522
8. IEC-60507, Artificial pollution tests on high-voltage ceramic and glass insulators to be used on a.c. systems; 2013.
9. RDSO's Special Maintenance Instruction (SMI) to measure the severity of pollution by brush wash method. Specification No. TI/MI/040, Rev.0, dated: 05/04/2005