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# Methods for mapping salt pollution deposition in insulation


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***Abstract*— The present work proposes two methods for mapping the rate of pollution deposition on high voltage insulators over time: in the first method, it seeks to quantify the rate of deposition of pollution over time in a given region; in the second method, it seeks to determine how such pollution is deposited preferentially, considering spatial aspects, as in a given time interval. Both methods use small glass plates (test objects) as test samples and were tested at a 500 kV substation. In the first method, several glass plates are disposed in a place protected from rain, but not from the wind that brings pollution, and periodically one of them is extracted from the site and analyzed. In the second method, several glass plates are distributed throughout the substation, exposed to both pollution deposition and rain, removed after a determined period, several times. Both methods employ the equivalent salt deposit density for the quantification of salinity in the glass plates. As a result of a case study, it was possible to quantify the rate of saline pollution deposition (mg/cm³/day) in the equipment over the time of experimentation, as well as the spatial arrangement of pollution deposition in different areas of the substation, which has regions more prone to high salinity deposition.**

***Keywords*— *glass insulators, salt pollution, performance, equivalent salt deposit density***

## I. Introduction

A combination of busbar circuits, circuit-breakers, switches, fuse switches, disconnectors, earthing devices, terminations and associated control and protection equipment is referred to as a substation (SE). [1]. Insulators are key components for the efficient functioning of SE and electrical power systems (EPS) as a whole. Two important functions are assigned to these devices: firstly, to provide physical and electrical isolation of conductors from other structures with differing potentials; and secondly, to offer support to the conductors [2].

The contamination of such equipment is one of the most constant problems for the continuity of electrical service, due to the formation of a pollution conductive layer, under the presence of moisture, on the surface of the insulator [3]. This conductive layer compromises the insulators performance in terms of electrical supportability. Thus, this equipment is susceptible to failures that can result in interruptions in power supply and damage to various SE equipment, causing significant losses for companies. Such losses, in addition to financial, defame the company's image, reflecting its credibility with the public.

Therefore, managing the effects of pollution on insulation, especially natural salt pollution, is desirable. For this purpose, tests at different pollution levels designated as salt deposit equivalent density (ESDD) are commonly performed [4]. Therefore, mapping the rate of pollution deposition over time, and the way in which it is spatially deposited, is relevant information in the management of pollution impacts.

In this context, the present work proposes two methods: the first method aims to determine the rate of deposition of pollution over time in a given region; the second method seeks to determine how such pollution is deposited preferentially, considering spatial aspects, as in a given time interval.

In order to accomplish such objectives, glass plates (used as test objects) were distributed in a 500 kV substation of the Porto de Sergipe I Thermoelectric Unit (PSITU), owned by ENEVA S.A., in the city of Barra dos Coqueiros (Brazil). Depending on the method employed, the glass plates were removed from the substation and tested to determine their ESDD.

The ESDD measurement and calculation followed IEC 60815-1 (2008) [5]. The results obtained were evaluated by the classification of pollution levels produced by Electric Power Research Institute (EPRI) (1975) [6] and adapted by Bezerra (2004) [7].

## II. Methodology

The glass plates are divided into two groups (A and B), so that the rate of deposition of pollution and the identification of preferential regions of pollution deposition are addressed separately. Flowcharts outlining the procedures for both groups are shown in Fig. 1.

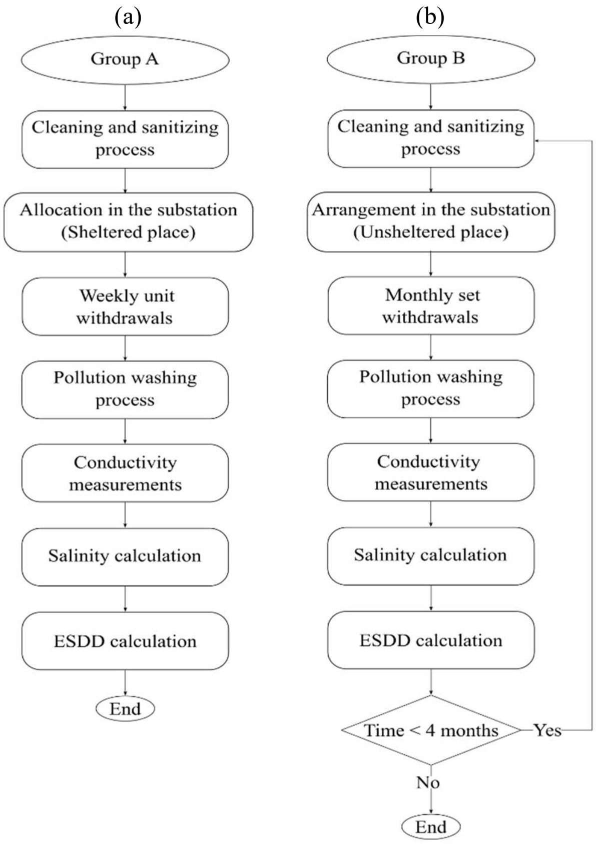


Fig. 1. Methodology flowchart: (a) group A; (b) group B.

The glass plate, illustrated in Fig. 2, had a rectangular shape with dimensions of 12x8 cm, representing respectively the width and length, and a thickness of 0.5 cm. Each plate has two 0.7 cm perforations located in the center. These perforations were strategically used to fix screws and washers (electrodes), to establish a direct contact between the surface of the glass plate and the screw. The pair of screws across the plates are used as electrodes in tests of superficial leakage current, which are not presented in this paper.

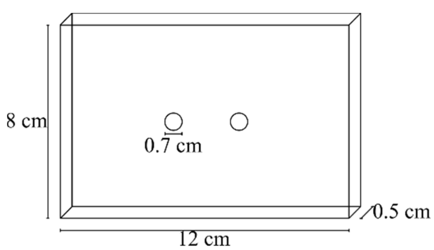


Fig. 2. Glass plate (test objects).

The cleaning of the plates is performed using neutral detergent and tap water. In the test site both groups are distributed in different arrangements:

- Group A: the plates are positioned in a location sheltered from the rain, but exposed to the wind, in order to accumulate salt pollution over time. Then, a plate is removed periodically (weekly, e.g.) for the ESDD measurements. The removed plates do not return to the substation;
- Group B: several plates are uniformly arranged along the SE, covering the entire area of interest. The number of plates may vary according to the area evaluated and the desired spatial distribution. After a determined period (days or weeks, e.g.), all plates are removed for the ESDD measurements. After that, the plates may be again disposed in the area, depending on the time windows of interest.

The pollution washing procedure followed guidelines stablished by the IEC 60815 standard [5], employing distilled water with conductivity ($\sigma$) below < 0.001 S/m. With the aid of the pisseta nozzle, the washing of the deposits present in the entire plate is performed, and the solution placed in a container that allows to verify the volume. The volume of the solutions is fixed in 500 cm³.

For efficient cleaning gloves and brushes are used, as presented in Fig. 3. The collected solutions are kept in agitation for 2 minutes, and then the conductivity measurement is done.

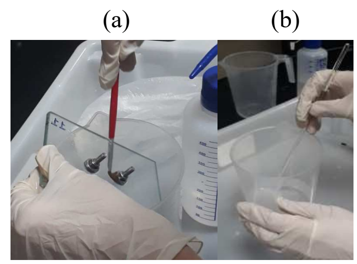


Fig. 3. Pollution washing. (a) plate cleaning; (b) solution stirring process.

Then, the conductivity and temperature of the solution are measured. The conductivity meter used is an Instrutherm model CD-850 [8]. After obtaining the necessary data (conductivity and volume), the salinity and, finally, the ESDD are calculated.

The calculation of ESDD is done with the equations presented below. Based on sections 16.2 and 7 of IEC 60507 (2013) [9], (1) deals with the correction of the volumetric conductivity of the solution for 20°C, due to non-standard ambient temperature.

$$\sigma_{20}= \sigma_{\theta}[ 1 - b(\theta - 20)], \quad (1)$$

where $\theta$ is the temperature of the solution [°C]; $\sigma_\theta$ is the volumetric conductivity at temperature $\theta$ °C [S/m]; $\sigma_{20}$ is the correction of the conductivity to 20 °C [S/m]; $b$ is the dependent factor of $\theta$, obtained in (2).

$$b=3.200\times10^{-8}\theta^3+1.032\times10^{-5}\theta^2-8.272\times10^{-4}+3.544\times10^{-2}. \quad (2)$$

After the value of $\sigma_{20}$ is obtained, the salinity is calculated from (3) and the density of salt deposit is calculated from (4).

$$S_a=(5.7\times\sigma_{20})^{1.03}; \quad (3)$$

$$SDD=S_a\times V/A, \quad (4)$$

where $S_a$ is salinity [kg/m³]; $V$ is the volume of the solution [cm³]; $A$ is the area of the pollutant collection surface, the whole plate, calculated by dimensions [cm²]; $SDD$ is the density of salt deposit [mg/cm²].

The classification of pollution levels produced by EPRI [6] and adapted by Bezerra [7] are presented in TABLE I. Listed from 1 (minimum) to 5 (maximum), these levels represent the degree of contamination according to the calculated ESDD value.

TABLE I. CHARACTERIZATION OF POLLUTION LEVELS ACCORDING TO EPRI (1975)

| *Levels* | *Classification* | *ESDD range (mg/cm²)* |
|---|---|---|
| 1 | Clean atmosphere. | 0.00 – 0.032 |
| 2 | Very light contamination. | 0.032 – 0.038 |
| 3 | Light contamination. | 0.038 – 0.056 |
| 4 | Heavy contamination. | 0.056 – 0.123 |
| 5 | Very heavy contamination. | Higher than 0.123 |

In order to demonstrate the applicability of the proposed methodology, a case study was carried out at the PSITU, owned by Eneva, S.A., located in the city of Barra dos Coqueiros, Brazil.

## III. RESULTS

The results obtained with the application of the described methodology are presented in the next subsections, for the case study.

### A. Group A

The results expected for Group A must allow the evaluation of the accumulation of salt pollution over time. Group A had 10 plates, that were positioned in a location sheltered from the rain but exposed to the wind. A plate was removed after the period of approximately 10 days, for ESDD measurements (in fact, on days 8, 22, 34, 41, 48, 56, 63, 71, 84 and 91).

Based on the ESDD values found for each Group A plate, as graphically presented in Fig. 4, and considering the observed time window, it is possible to describe this periodic behavior with a linear equation.

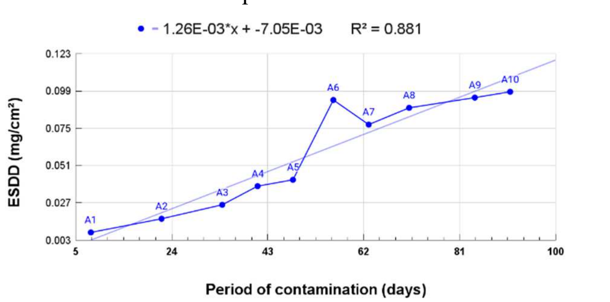


Fig. 4. ESDD (mg/cm²) accumulation over days.

The ratio between the pollution present in the plates and the time of exposure to the saline atmosphere in the observed periods is represented by (5).

$$ESDD = 1.26\times10^{-3}days - 7.05\times10^{-3}. \quad (5)$$

The adjustment presented a coefficient of determination ($R^2$) of 0.88 for data observed over approximately 100 days, which indicates a good adherence of the curve fitting.

### B. Group B

The results expected for Group B must allow the evaluation of the deposition of salt pollution spatially over the substation. Eight plates were disposed over the substation, in approximately even distribution, and after a period between two and three weeks, all of them were removed for ESDD measurements.

ESDD variations were observed in each plate when relocated in the SE, due both to the pollution deposition and the precipitation that occurred in the SE during test period. Thus, individually, the values obtained for 22, 13, 15 and 22 days of exposure are presented in Fig. 5.

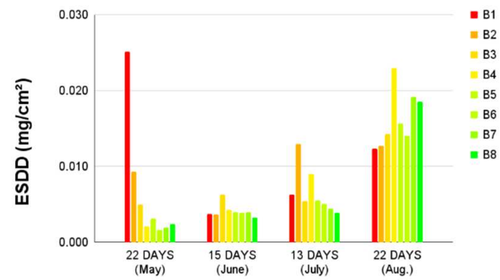


Fig. 5. ESDD (mg/cm²) spatial accumulation over days.

It is noted that the ESDD values for each month observed behaved in different ways. Among them, the month of May, in which the plates were exposed for 22 days, highlights plate B1 for presenting 0.0251 mg/cm². However, in subsequent months it was found 0.0037 mg/cm² (June), 0.0063 mg/cm² (July) and 0.0123 mg/cm² (August). The change in the pollution disposal over the substation during the observed time window may be justified by the occurrence of rain (months of June and July) and change in the direction of the winds in the region, due to the change of seasons (winter to spring).

In Fig. 6, the color map is synthesized based on the results obtained for this case (May, 2023), considering the location of the plates and the classification of pollution levels according to TABLE I.

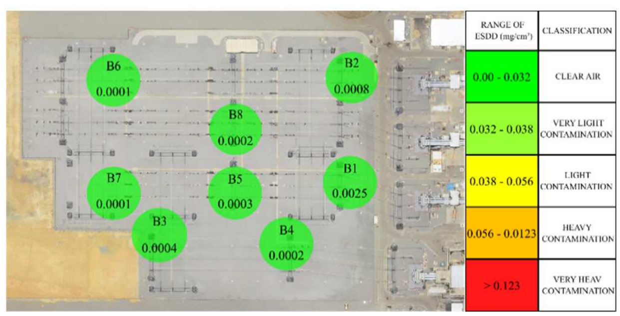


Fig. 6. Mapping of PSITU plates and pollution level.

The plates B1 and B2, positioned in a front line, have the highest values of ESDD, being those of 0.0025 mg/cm² and 0.0008 mg/cm², respectively. Such line of equipment composes the first obstacle for the wind that carries the pollution. It is also noticeable from Fig. 6 that all Group B plates presented ESDD values in the clean atmosphere classification. Therefore, although uniform deposition is potentiated in the regions where the B1 and B2 plates are placed.

## IV. CONCLUSION

The results of these tests yielded significant findings regarding the spatial distribution of pollution and the rate of deposition in the insulation. For this, the methods applied to

Group A and B aimed to quantify and map the pollution deposited in this equipment in certain periods.

The method proposed for Group A allowed the assignment of a linear equation to this group, which expresses the deposition of pollution over time. Therefore, presenting $R^2 = 0.881$, the result was consistent with the expected. In contrast, the classification of Group B at level 1 exposes the influence of climate, rainfall and wind on the density of salt found. Therefore, the method and objective applied in Group A would not be appropriate.

However, through the experimental arrangement of Group B, it was possible to show a spatial analysis of contamination, given the designated purpose. Therefore, this method was effective to identify that the region of the plate B1 and B2 suffers greater salt deposition. In addition, the calculated ESDD presented values in the clean atmosphere range. Therefore, the spatial distribution in the different areas of the substation presented a heterogeneous saline deposition, but with regions more prone to a high level of salinity.

Finally, the application of the presented methodology proved to be promising in the periodic determination of the degree of pollution of the insulators and in the mapping of critical regions of pollution deposition. Thus, an annual analysis (e.g.) can provide, through the verification of recurrences, data to the company that allows it to optimize washing cycles.

## Acknowledgment

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