Method for Estimating Equivalent Salt Deposit Density on Insulator Surfaces
Using Meteorological and Topographical Information Provided by Public Institutions

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Traditionally, the design and maintenance of electric power facilities of electric railways in bay areas have been carried out according to a uniform classification of pollution based on distance from the coast and other factors. In order to improve the safety of these facilities and save labor for maintenance, it is necessary to subdivide this uniform classification according to the actual pollution situation. Therefore, we propose a method for estimating the Equivalent Salt Deposit Density on insulator surfaces at any point on an open section using meteorological and topographical information provided by public institutions.

Key words: insulator, ESDD, estimating method, meteorological, topographical, open data

1. Introduction

An insulator is a component that provides electrical isolation between parts with different potentials, e.g. live parts and the earth. There are few cases of power transmission failures due to polluted insulation since an insulator is designed or maintained to ensure adequate insulation. On the other hand, if actual pollution is less than expected, an insulator may have been over-designed and over-maintained. It is therefore necessary to review current pollution classification from the viewpoint of both designing equipment suitable for the actual state of pollution and saving labor for maintenance. However, in order to achieve this, it would be required to measure pollution levels densely, and frequently over a wide area and accumulate data over several years.

A method for measuring the degree of pollution of an insulator widely used in Japan is to measure the amount of pollution (mainly sea salt) on the surface of an insulator by wiping it with gauze. However, it is difficult to obtain a sufficient amount of data for reviewing the pollution classification with the above-mentioned method, since a lot of labor is required for each data acquisition. In addition, there is an issue that the measurement results depend on the weather conditions immediately before the measurement and the proficiency of the measurer.

So far, the authors have surveyed reports [1-3] about measurements and simulations of sea salt particles on power transmission line insulators, conducted by electric utility companies in the past. Using these reports, we developed a method for estimating change in pollution over time for railway electric power facilities [4, 5], which are more sensitive to the surrounding environment as they are lower than transmission lines. In this proposed estimation method, meteorological information published by the Japan Meteorological Agency (hereinafter JMA) and topographical information published by the Geospatial Information Authority of Japan (hereinafter GSI) are used as input data. This method makes it possible to estimate changes in the Equivalent Salt Deposit Density (ESDD) as a degree of pollution over time at any point in an open section. This report provides an overview of the proposed methodology and the estimation accuracy.

2. Method for estimating ESDD on insulator surfaces

2.1 Model for transport and deposit of sea salt

Based on the investigations carried out by the Electric Technology Research Association on generation, transport, deposit and shedding of sea salt particles, as well as other literature reviews, we have developed a model for the transport and deposit of sea salt particles (hereinafter sea salt) as shown in Fig. 1. This model (Fig. 1) explains how sea salt generated at sea or along the coast is carried inland by wind, adheres to electrical equipment, and is washed away by rainfall. Each of the estimation equations corresponding to A) through E) in Fig. 1 is restated in equations (1) through (6).

A) density of sea salt in the air near the coast \( C_0 \)

\[
C_0 = \alpha \times W_0^2
\]

(1)

where \( C_0 \): the density of sea salt in the air per unit volume near the coast (mg/cm³); \( \alpha \): coefficient; and \( W_0 \): wind speed near the coast at 10m above sea level (m/s).

B) wind speed near the coast at 10m above sea level \( W_0 \)

\[
w = W \times \left( \frac{h}{H} \right)^\nu
\]

(2)

where \( w \): wind speed at local equipment height (m/s); \( W \): wind speed in meteorological data (m/s); \( h \): height of wind speed to be calculated (m) = 10 m; \( H \): height of wind speed measuring points in meteorological data (m); and \( \nu \): surrounding environment coefficient (big cities = about 0.5, general residential area and forest = about 0.25, on the sea = about 0.14).

\[
\therefore W_0 = W \times \left( \frac{10}{H} \right)^{0.14}
\]

(3)
C) salt density in the air $C$ decreases with distance from shore

$$C = C_0 \times l^x$$  \hspace{1cm} (4)$$

where $C$: density of sea salt in the air at a distance of $l$ (km) from the coast (m/s); $l$: distance from the coast (km); and $x$: coefficient.

D) density of salt deposit on equipment per unit time $M$

$$M = \beta \times C \times w$$  \hspace{1cm} (5)$$

where $M$: density of sea salt deposition per unit time (mg/cm$^2$); $\beta$: coefficient; and $w$: wind speed at local equipment height (m/s).

E) shedding by rain $R$

$$M' = M \times (1 - R^y)$$  \hspace{1cm} (6)$$

where $M'$: density of sea salt deposition per unit time subject to washing by rainfall (mg/cm$^2$); $R$: total rainfall in the last 1 hour (mm/h); and $y$: coefficient.

2.2 Algorithm for ESDD estimation

As shown in section 2.1, each of the equations given in Fig. 1 is simple. However, since they are interrelated, there are several possible estimation algorithms to derive ESDD estimates. Furthermore, some of the equations contain unknown coefficients. For this reason, the estimation algorithm and unknown coefficients were determined by repeating the calculation of each of the equations given in Fig. 1 until the correlation coefficient between measured ESDD values and the estimated ones reached the maximum. The main characteristics of the measured data used to determine the algorithm are shown in Table 1. The meteorological information used as input data was taken from the data of the JMA observation points closest to the estimated points from the JMA website. Note that topographical information was taken from the GSI website.

The algorithm for ESDD estimation is shown in Fig. 2. The algorithm uses meteorological and topographical data to estimate the degree of ESDD at any point in an open section at any given time in the past. The meteorological and topographical information used as input are as follows:

Wind speed, wind direction: average of last 1 hour
Rainfall: total rainfall in last 1 hour, and
Topographical information: 16 azimuthal distances from the coast at estimated point, surrounding environment coefficient.

Table 1 Main characteristics of the measured data used to determine the algorithm

<table>
<thead>
<tr>
<th>Measuring location</th>
<th>5 places in Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measuring period</td>
<td>2 to 5 years</td>
</tr>
<tr>
<td>Number of data</td>
<td>About 120</td>
</tr>
<tr>
<td>Min. ESDD (lower side)</td>
<td>0.0022 mg/cm$^2$</td>
</tr>
<tr>
<td>Max. ESDD (lower side)</td>
<td>0.2119 mg/cm$^2$</td>
</tr>
</tbody>
</table>

3. Verification of estimation accuracy

3.1 Verification of estimation accuracy at multiple locations

In order to obtain estimates of the ESDD densely over a wide area, it is necessary to verify that the application of the same method is effective at any point. Table 2 shows the locations where the ESDD for verification was measured with the actual insulator. Note that the locations in Table 2 are different from the location where the data for algorithm determination were obtained. The upper and lower sides of the insulator are shown in Fig. 3. Measurements of ESDD were carried out on both sides using conventional methods (wiping the pollution with gauze).
Ref. 2, and Fig. 4 shows measurement results of ESDD. Even the maximum ESDD on the lower side, which is prone to pollution, had a measured value classified as Grade 3. Figure 5 shows a comparison of the estimated values with the measured values shown in Fig. 4. The determination coefficient between the measured and estimated values $R^2$ for the upper side is 0.62, while the determination coefficient $R^2$ for the lower side is 0.72. As a result, it was found that there is a high correlation between the measured and estimated values. Furthermore, since the slope of the approximate straight line for the lower side is almost 1, the estimation of the ESDD up to Grade 3 is generally appropriate.
3.2 Verification of estimation accuracy by using ESDD of the Anti-Salt Testing Station

As described in section 3.1, it was confirmed that the proposed method is generally correct. However, it was not possible to verify the method in a way which included highly polluted areas. In order to verify the accuracy of the proposed method in highly polluted areas, we attempted its verification using data obtained at the anti-salt testing station where we can obtain a large amount of data on high levels of pollution.

The locations of the anti-salt testing station and the JMA station closest to the test site are shown in Fig. 6. Both of them face the Sea of Japan and are about 10 km apart in a straight line. Figure 7 shows the estimated values (lower side) and measured values (lower side) in 2019 at the anti-salt testing station. At the testing station, high levels of ESDD are expected in winter and the estimated results showed a peak in ESDD in winter, so that the trend is consistent.

Plots of the measured values and estimated values for the three-year period 2018 to 2020 at the anti-salt testing station, by frequency of occurrence, are shown in Fig. 8(a). In Fig. 8(a), it was confirmed that the 5% frequency of occurrence value of the approximate line of the measured values and the 5% frequency of occurrence value calculated from the estimated values roughly match. In addition, the same estimation method was used to verify the results at another location (facing a bay). The results are shown in Fig. 8(b). In the same way as the results of the anti-salt testing station, the 5% frequency of occurrence measured ESDD and the 5% frequency of occurrence estimated ESDD also roughly matched. Therefore, it is concluded that the proposed method has an estimation accuracy applicable to ESDD setting at any point.

4. Examples of the use of estimation methods

By using this method, it is possible to obtain the frequency of occurrence of ESDD for any point as shown in Fig. 8. Therefore, areas with a wide range of uniform pollution categories can be subdivided into categories that match the actual situation of pollution. This will lead to carrying out design and maintenance in accordance with the actual situation. As a result, this can contribute to optimization of insulation co-ordination and labor-saving maintenance.

An example of pollution category subdivision using the proposed method is shown in Fig. 9. First, select the point you want to estimate. Here, the estimation point is the location closest from the coast between one station and the next station. Second, collect topographical information on the estimated point and meteorological information for any period. Here, we have collected about 10 years...
of meteorological information. Third, calculate ESDD (5% frequency of occurrence) at the selected point. And fourth, classify the estimated results (ESDD) according to the categories shown in Table 3. Figure 9(a) shows the current categories where all sections are currently set as “sections where salt pollution is considered”. On the other hand, the results of subdividing the classification into areas with a low and high risk of pollution according to the estimated degree of pollution by the proposed method are shown in Fig. 9(b). In this case study, the estimated point was closest from the coast between one station and the next station. The proposed method can estimate the ESDD on each mast instead of between one station and the next station.

5. Conclusions

We proposed an estimating method of ESDD on insulator surface at any point in an open section using meteorological and topographical information provided by public institutions. The research findings are as follows:

- Results confirmed that estimated values using the proposed method roughly matched measured values.
- It was confirmed that the proposed estimation method can be applied to any point.
- The measured and estimated ESDD (5% frequency of occurrence) roughly matched. Therefore, it is concluded that the method has the estimation accuracy that is applicable to the ESDD setting at any point in an open section.
- By using the proposed method, it is possible to design and maintain insulators according to actual pollution conditions. This makes it possible to improve safety, as well as optimize insulation coordination and save labor for maintenance.
References


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