Impact of sugar factory pollutants on the insulators’ impurity

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Abstract. This paper presents the impact of pollutants on the impurity of substation insulator around the sugar factory. We have conducted experiment and calculated the equivalent salt deposit density (ESDD) to determine pollutant’s level, which measure the conductivity of pollutants in insulators. Then synchronized with the weight of NaCl, so the conductivity is the same as the conductivity of pollutants. The results of experimental data from pollutants attached to the polymer isolator are in the medium category, with a value of 0.37 mg/cm².

1. Introduction
The purity of the insulating properties of substation insulators can be affected by pollutants. In industrial areas, it is undeniable that there are still levels of pollutants that escape into the air and then stick to the electrical network insulators. Certain pollutants can cause ionization, so that the corona discharge occurs in the insulator. Velásquez (2019) had tested the impact of pollutant agent, such as lime from a gold concentrator factory [1]. The impurity of insulator could make the insulation failure, which is dangerous for the power system equipment.

The insulation failure could start by repetitive corona effect, where the corona is the discharge current through ionized air surrounding the insulator. This corona discharge can be observed with visible eyes, in the form of a flash of fire/ light that strikes around the insulator (Figure 1). Thus, the insulator placed on the industrial area required schedule maintenance.

In this paper, we studied the impurity of the insulator in the area around the sugar factory. Based on data from the state electricity company, corona discharge incident reports were evidenced at the insulator at the substation adjacent to the factory site. This is what triggering us to conduct proof and test with an experimental approach, to find out how far the impact of these pollutants on the impurity of the insulators.

![Figure 1. Corona discharge](image-url)
State of the art on relevant studies can be found in [1-5]. Flashover voltage is predicted using an electric field measurement on the insulator, where a comparison is made between clean and polluted insulators [2]. Furthermore, in [3], a specific study on the quantity of ozone around corona region was predicted. In specific [4] used the two indices for predicting corona using irradiated rf spectrum on the overhead insulator.

Corona release occurs at atmospheric pressure, which is the flow of charged particles, i.e. electrons and ions which are accelerated by an electric field. Corona is produced when the space gap is filled with air or other ionized gas. Ionization that occurs around the insulator is caused by pollutants attached [5-7]. Corona occurs in high voltage insulators, usually in substations, transmission and distribution lines. Corona events can be seen with the naked eye like lightning streams. Corona can be an insulator failure parameter.

Industrial areas are very potential to produce continuous pollutants and accumulate in the insulator. the pollutant gets thicker the longer it sticks to the polymer insulator continuously and finally enough to reduce the resistance of the insulator polymer and the surrounding air, when high tension comes there will be electron jumps and the formation of more ions. A certain pollutant can be very dangerous to the insulation resistance of an insulator. Some previous researchers were very concerned with this [1-3]. Furthermore, the impurity of the insulator can be seen from the ESDD and NSDD indices [3].

Several other researchers tried to do modeling and circuit approaches for corona analysis. some make predictions of ozone content or other things related to corona. we have tried here to evaluate the potential of sugar factory pollutants and their potential to cause corona translucency.

2. Methods

We have conducted tests in the laboratory to simulate sugar factory pollutants and measure ESDD levels that have an impact on corona. We take sample of a polymer insulator from the nearest substation to the location of a sugar factory, that is GI kebonagung (150kV) — PT PLN APP Malang. Then, the pollutant was extracted from the insulator’s surface. The pollutant is weighted based on the IEC-60815 standard using the ESDD method. After that, the sample is dissolved in 150ml rain water and measured for conductivity in Laboratory. We compared the conductivity of rainwater without pulutan to find out the baseline. Figure 2 is an experimental process in the laboratory.
Finally, we calculate ESDD under 20 °C using the following equation.

1. Conductivity Measurement

Conductivity is the ability of a substance to conduct electric current. Conductivity value is used to determine the level of pollutants found on the surface of the insulator. Conductivity is calculated using the following equation:

\[
\sigma_{20} = \sigma_t \cdot [1 - K_t (t_s - 20)]
\]  

with,

- \(\sigma_{20}\): Conductivity at a temperature of 20 °C (S/m)
- \(\sigma_t\): Measured initial conductivity (S/m)
- \(K_t\): Temperature constant

\[
\sigma_{20} = -3.2 \times 10^{-8} \times t_s^3 + 1.032 \times 10^{-5} \times t_s^2 - 8.272 \times 10^{-4} \times t_s + 3.544 \times 10^{-2}
\]

\(t_s\): Solution Temperature (°C)

2. Calculation of Solution Salinity

With the value of conductivity at a temperature of 20 °C, the concentration of salt or salinity in the solution is determined using the equation:

\[
D = (5.7 \times \sigma_{20})^{1.03}
\]

where: \(D\) is Solution Salinity (grams)

3. Calculation of the ESDD method

\[
\text{ESDD} = V \times \frac{(D_2 - D_1)}{S}
\]

With:

- \(V\): Volume of water used (mL)
- \(S\): Contaminated Surface Area (cm²)
- \(D_1\): Equivalent concentration of salt in the water before pollutants (grams)
- \(D_2\): Equivalent concentration of salt in water after pollutants (grams)

The possibility of corona levels occurring in each phase. Then from a number of experiments we conducted an average and drew conclusions from the analysis.

3. Results and Discussion

This study used an experimental method in which the data obtained from the measurement by the parameters set previously.

3.1. Conductivity Levels

The conductivity testing of this solution was carried out under five conditions such as in weights of 0g NaCl, 25 g NaCl, 50 g NaCl, 100 g NaCl, and 200 g NaCl. In Table 2, it is known that the highest conductivity value occurs when rainwater is mixed with 200 g NaCl. When the conductivity of rainwater without pollutants is measured, a value of 199 µs is obtained. Meanwhile, when rainwater mixes with pollutants, the conductivity value changes to 660 µs. After calculating the conductivity of pollutants, ESDD was calculated. Conductivity calculation in the standard conditions of \(t = 20 \, ^\circ\text{C}\) using Equation 1 shows in Table 1.

Corona is the main factor causing degradation and failure in isolation. Corona events are characterized by the smell of ozone, buzzing sounds, and flashes of light on the surface of the insulator. Corona can occur on the surface of a clean insulator or the surface of a polluted insulator. When the insulator surface is polluted, the insulator surface resistance will decrease, so that the leaky current that flows will be greater than when the insulator is clean. This leaky current causes the formation of a conductive path, so that a corona event occurs. Data from the corona test on the SUTT Lawang 150 kV - polymer isolator are shown in Table 4.
Table 1. Conductivity Measurement

| Solution Composition | Clean Rainwater | Polluted Rainwater |
|----------------------|-----------------|-------------------|
|                      | Temperature (ºC) | Conductivity (σ1) | Temperature (ºC) | Conductivity (σ1) |
| NaCl 0 gram          | 27.8            | 72 μs             | 27.8             | 72 μs             |
| NaCl 25 gram         | 27.8            | 89 μs             | 27.8             | 150 μs            |
| NaCl 50 gram         | 27.8            | 101 μs            | 27.8             | 190 μs            |
| NaCl 100 gram        | 27.8            | 150 μs            | 27.8             | 360 μs            |
| NaCl 200 gram        | 27.8            | 199 μs            | 27.8             | 660 μs            |

Table 2. Corona and Thermo Vision Test

| Conductors          | Phase | Brand       | Type         | Serial Number | Corona Value (count rate/edit) | Thermovision (ºC) |
|---------------------|-------|-------------|--------------|---------------|-------------------------------|-------------------|
| Kebonagung – Lawang 1 | R     | Proteksindo | FXBW4-150kV/120K | S418003108    | 150                           | 25.0              |
|                     | S     | Proteksindo | NSPLN T5.010-1 | S418003108    | 30                            | 26.1              |
|                     | T     | Proteksindo | S418003108    | S418003108    | 100                           | 25.9              |
| Kebonagung – Lawang 2 | R     | Proteksindo | NSPLN T5.010-1 | S418003108    | 30                            | 26.1              |
|                     | S     | Proteksindo | S418003108    | S418003108    | 20                            | 25.6              |
|                     | T     | Proteksindo | S418003108    | S418003108    | 100                           | 25.9              |

Based on the data above, the 150kV SUTT polymer isolator Kebonagung - Lawang 1 in the R phase experienced a corona event with a value of 150 kW / km with an isolator temperature of 25 ºC. Phase S experiences corona events with a value of 120 kW / km with an insulator temperature of 25.5 ºC, while phase T experiences corona with a value of 30 kW / km with an insulating temperature of 26.1 ºC. Kebonagung - Lawang 2 Pathway in phase R experiences corona event with a value of 30 kW / km with an isolator temperature of 25.9 ºC. Phase S experienced a corona event with a value of 20 kW / km with an insulator temperature of 25.6 ºC while the T phase experienced a corona event with a value of 100 kW / km with an isolator temperature of 25.9 ºC. In addition, the corona value of SUTT Polymer Isolator 150kV - Lawang Kebonagung is still in normal condition. The results of temperature measurements on the Kebonagung - Lawang 1 pathway and the Kebonagung - Lawang 2 pathway has an average value of 25.5 and 25.8 ºC. The following is the follow-up set by PT PLN (Persero):

A: 0-10 ºC = Good Condition  
B: > 10-25 ºC = Measure 1 more month  
C: > 25-40 ºC = Improvement Plan  
D: > 40-70 ºC = Immediate repairs

3.2. Salinity and ESDD  
The following data are the solution salinity calculation and ESDD value:

Table 3. Conductivity Calculation of Standards, Salinity Value, and ESDD Value

| Kt     | σ₁ S/m | D₁ mg/cm³ | Kt     | σ₂ S/m | D₂ mg/cm³ | ESDD mg/cm² |
|--------|---------|-----------|--------|---------|-----------|-------------|
| 0.0197 | 0.0061  | 0.0314    | 0.0197 | 0.0061  | 0.0314    | 0           |
| 0.0197 | 0.0075  | 0.0391    | 0.0197 | 0.0127  | 0.0669    | 0.04636     |
| 0.0198 | 0.0086  | 0.0448    | 0.0198 | 0.0016  | 0.0080    | 0.07333     |
| 0.0198 | 0.0128  | 0.0673    | 0.0198 | 0.0307  | 0.1658    | 0.164193    |
| 0.0198 | 0.0168  | 0.0894    | 0.0198 | 0.0558  | 0.3074    | 0.363258    |
Based on the salinity solution calculation using the ESDD method, the highest pollutant level was obtained when the solution was mixed with 200 grams of NaCl with an ESDD value of 0.3632 mg/cm². Additionally, the level of pollutants found in the 150 kV SUTT Polymer Isolator of Kebonagung-Lawang during the lifetime is included in the medium category with a value of 0.3632 mg/cm².

### 3.3. Validation

Based on the research on the level of the intensity of SUTT 150 kV Kebonagung - Lawang in several parameters, after calculating the salinity solution using the ESDD method, it can be concluded that the highest pollutant level was obtained when the solution was mixed with 200 gram NaCl with an ESDD value of 0.3632 mg / cm². Thus, the level of pollutants attached to the 150 kV Kebonagung - Lawang polymer isolator during its lifetime is included in the moderate category with a value of 0.3632 mg/cm².

Arrester Transformer II isolator was contaminated in the weight category with a value of 0.66 mg/cm². In this process, found pollutants in the Transformer Arrester II Insulator are included in the weight category because this arrester has been installed from 1993 to 2014 which is then placed in a warehouse. Meanwhile, the 150 kV SUTT Polymer Isolator is maintained in 2017. Pollutants can make the surface resistance of the insulator decrease so that the leakage current that flows will be greater than when the isolator is clean. This leakage current causes the formation of conductive pathways so that corona events occur.

Based on corona data from PT PLN (Persero), it was observed that the corona values in the Kebonagung - Lawang 1 pathway and phase R and phase S were still in the normal category. Meanwhile, in the T phase, the corona rate is 30 kV, this can mean that the corona occurs below the working voltage limit. In addition, on the Kebonagung - Lawang 2 Line, the corona value in the R phase is 30 kV and in the S phase is 20 kV, the corona also occurs below the working voltage limit. While in the T phase, the corona is 100kV, so it is still in the normal category.

The higher the ESDD value (pollutant deposits) is, the faster the corona will occur and the faster the low voltage is. In the SUTT Isolator 150 kV, the ESDD value of 0.3632 mg/cm² is included in the medium category. Furthermore, the corona in the Kebonagung line - Lawang 1 phase R has a rate of 150 kV, phase S with 120 kV and phase T with 30 kV. It can be concluded that on the Kebonagung - Lawang 1 line only phase T has a corrosion rate below the working voltage limit. This is hazardous since the insulator does not function properly and will cause interference such as leakage currents on the transmission line.

### 4. Conclusion

Based on the test results, the calculation and analysis of the level of pollutants attached to the 150 kV SUTT polymer isolator using the ESDD method can be summarized as follows. The level of pollutants attached to the SUTT polymer isolator is 150 kV, causing the insulator to be contaminated in the medium category, with an ESDD value of 0.3632 mg/cm². Based on tests conducted in several parameters, the heavier the NaCl content mixed into the rainwater solution at the time of the study, with the higher conductivity values causing an increase in ESDD values. Corona values on 150kV SUTT polymer isolators Kebonagung - Lawang 1 in the R phase have a level of 150 kV with an S phase 120 kV, and a T30 kV phase. It can be concluded that in the Kebonagung - Lawang 1 pathway, the T phase has a corrosion rate below the working stress limit. It is perilous because the isolator is not functioning properly and will cause interference such as leakage currents on the transmission line. The higher the ESDD (pollutant deposit) value will produce the corona and the lower the voltage.

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