Novel residual pollution layer model related to the arc propagation along the surface based on discretisation

Jian Li\(^1\)\(^2\) | Jun Zhou\(^3\) | Zhicheng Guan\(^4\) | Liming Wang\(^4\)

\(^1\)NARI Group Corporation Ltd., Nanjing, China
\(^2\)Wuhan NARI Limited Liability Company, State Grid Electric Power Research Institute, Wuhan, China
\(^3\)China Electric Power Research Institute, Beijing, China
\(^4\)Tsinghua University Graduate School at Shenzhen, Guangdong Province, China

Abstract
A concentrated treatment used on the residual pollution layer in the Obenau and its improved models is inappropriate for establishing the propagation model of an arc along the pollution layer surface. Therefore, discretising the residual pollution layer is innovatively proposed. The residual pollution layer is discretised into several infinitesimal pollution layer elements with various characteristics along the vertical direction from the arc root to the ground electrode. Quantitative relationships between the surface conductivity of a pollution layer element and several variables, including salt deposit density, water film thickness, temperature, and time, are concluded based on experimental data and relevant theories. A distribution factor that determines leakage current densities in a pollution layer is defined. A residual pollution layer surface resistance model based on the discretisation, relational expressions, and distribution factor is established. A comparison of the proposed model with the results observed in the experiments with and without a partial arc shows that the proposed model is reasonable.

1 | INTRODUCTION
Extra-high-voltage and ultra-high-voltage transmission projects are increasingly improving, especially in developing countries, such as China, India, and Brazil. The contamination flashover problem of insulators under high voltage must be sufficiently focused on in the project construction. A clearness study on the flashover mechanism is helpful for designing projects to avoid pollution flashover. The surface resistance of a residual pollution layer significantly influences the pollution flashover voltage. Lots of researchers and engineers have done some great work on this topic [1–6]. Surface resistance is generally expressed as a product of surface conductivity reciprocal and residual pollution layer form factor [4], which is related to insulator shape and arc length. Therefore, the research on surface resistance is translated into the study of surface conductivity and form factor [4–9].

The surface conductivity before the arc initiation was used to calculate the pollution flashover voltage in the models proposed by Chihani et al. [8]. The surface conductivity of the pollution layer was usually assumed to be constant, ignoring the influences of leakage current, arc heating, wetting and evaporation during the arc propagation. However, the influence of temperature on the surface conductivity should be considered due to the severe heating of the arc and leakage current [10]. The temperature distribution of the pollution layer over an insulator surface was measured using an AGA780 thermal infrared imager [11], and the temperature was the highest (~100°C) near the steel foot and rapidly decreased after the dry band formation. The pollution layer with a large leakage current density had a high temperature of nearly the boiling point, whereas that with a small leakage current density had a slightly increasing temperature. Therefore, neither using the surface conductivity before the arc initiation nor the value at the water boiling point was unsuitable for calculating the flashover voltage. The authors claimed that the surface conductivity variation during the arc propagation along the insulator should be introduced. Thus, the surface conductivity of the pollution layer was measured while the arc is developing from initiation to the critical length [11]. The results indicated that the surface conductivity varied similarly for various shed shapes of insulators with different pollution degrees under an AC or DC voltage. The surface conductivity gradually increased with the decrease of increase rate and finally approached saturation. Based on the research results, the authors defined a parameter called effective conductivity, which was the maximum surface conductivity in the development of arc. The effective conductivity was proposed as the key factor.

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of the pollution flashover and was 1.25 times of the surface conductivity before the arc initiation. However, effective conductivity, similar to the surface conductivity before the arc initiation and the value at the water boiling point, was also an approximation of the non-uniformly distributed surface conductivity to a certain extent. Because, the surface conductivity at various positions of the entire pollution layer was different in terms of different water contents, pollution degrees, and temperatures. Therefore, spatial and temporal distributions of the surface conductivity of the residual pollution layer should be considered.

The form factor of an insulator was also researched, and the insulator surface was simply approximated as a rectangular; moreover, the residual pollution layer resistance was evaluated as a negative proportional linear relationship with arc length [4]. Wilkins et al. proposed an accurate but complicated expression of the residual pollution layer resistance considering the resistance increase caused by the current concentration at the arc root based on the above-mentioned rectangular model [4,10]. Guan and Zhang [11] provided a simple expression of the residual pollution layer resistance based on the above expressions. However, these improved expressions all treated the residual pollution layer resistance as a whole expressed as a resistance in series with the partial arc. The distribution characteristic of the residual pollution layer was not referred.

A novel resistance model of the residual pollution layer based on discretising the pollution layer is proposed considering the limitation of the above-mentioned treatment. The spatial and temporal distributions of the surface conductivity of the residual pollution layer in the process of leakage current heating and arc propagation are considered in the model. The model is experimentally verified on a plane triangular glass plate.

2 | MODEL OF THE POLLUTION LAYER

2.1 | Discretisation of pollution layer

The arc development is related to the characteristics of the pollution layer ahead of the arc root. The current density is large in the residual pollution layer near the arc root but small away from the arc root. The temperature of the pollution layer at various locations differs depending on the heating of various densities of current. Consequently, the water content and surface conductivity at various locations are also different. Thus, the resistance of the residual pollution layer cannot be treated as a lumped parameter, which is adopted in the Obenau model [12] and its improved models [10,11,13,14].

The pollution layer can be divided into a series of small enough elements of which the resistance can be comprehensively calculated. Some researchers use a finite element method (FEM) to calculate the resistance [15]. The static current distribution can be accurately considered in the FEM model. However, while the arc root is moving, the current distribution needs to be real-time calculated, as well as the parameters of the pollution layer, such as temperature, water content, etc. Due to a large amount of computation, this method will not be suitable for time-varying modelling for the pollution layer. Thus a simplified discrete model is adopted in this paper.

Because the complex geometric shape of real insulators makes it difficult to completely record the arc propagation process, a plane triangular glass plate is selected to investigate the residual resistance characteristics during arc propagation. Figure 1 illustrates the method to discretise the residual pollution layer over a plane triangular glass sample. The arc current flows onto the residual pollution layer through the arc root, and the current in the pollution layer is more concentrated near the arc root than away from the arc root. A conducting boundary is assumed to characterise the concentration degree of the pollution layer current at various locations. A large width \( w_i \) corresponds to a low and uniform current density. The trapezoid surrounded by the conducting boundary is divided into many mini-type trapezoid elements, starting from the arc root. Every mini trapezoid has an identical height \( \delta x_i \), but its waist width, denoted by \( w_i \), increases with its distance from the arc root. The surface resistance \( R_p \) of the residual pollution layer is

\[
R_p = \sum_{i=1}^{m} r_i \delta x / w_i
\]

where \( m \) is the number of the discretised elements, and \( r_i \) is the surface resistivity of the \( i \)th trapezoidal pollution layer element. Thus, the residual pollution layer is discretised into many mini pollution layer elements with various surface resistivity. For every position where the arc root moving to, the corresponding residual pollution layer must be discretised again; therefore, the discretisation is time-dependent given the propagation forward of the arc along the surface.

2.2 | Surface conductivity

2.2.1 | Surface conductivity versus salt deposit density (SDD) and water film thickness

When \( \delta x \) is small enough, then the mini-type trapezoid can be considered as a cuboid pollution layer element, as shown in Figure 2. The thickness, length, width, volume conductivity, SDD, and temperature of the \( i \)th element are denoted as \( h_i, \delta x_i, w_i, \sigma_i, \text{SDD}_i, \) and \( T_i \), respectively. For convenience, the subscript \( i \) is omitted for subsequent formula derivation.

The salinity \( S_a \) (kg/m\(^3\)) of sodium chloride in the water film is

\[
S_a = \text{SDD} / h
\]

The nearly temperature-independent saturated solubility of sodium chloride is 352 kg/m\(^3\), which is the maximum of \( S_a \).
The relationship between the volume conductivity \( \sigma_{20} \) at 20°C of saline water and \( S_a \) can be expressed in (3) by fitting the experimental data from IEC Standard 60507-1991 [16, 17] with a fitting error below 3%.

\[
\sigma_{20} = \begin{cases} 
\frac{S_a^{1.03}}{5.7} & S_a < 10 \\
0.310 + 0.133S_a & 10 \leq S_a < 14 \\
25.252 - 25.338e^{-S_a/150.838} & S_a \geq 14 
\end{cases}
\]  

The surface conductivity \( K_{20} \) at 20°C of the pollution layer is

\[
K_{20} = b\sigma_{20} 
\]  

In Figure 3, the calculation using (2)–(4) indicates that the surface conductivity \( K_{20} \) rapidly increases initially and approaches saturation eventually with the increase of water film thickness for a given \( SDD \). Wilkins considered the wet-saturated pollution layer as ideally diluted. Thus, a surface conductivity of 97 \( \mu \)S at an \( SDD \) of 0.05 mg/cm\(^2\) was suggested [14]. However, in [18], the authors thought the wet-saturated pollution layer still having little water content, the saline solution on the surface remained saturated and surface conductivity of 40 \( \mu \)S at the same \( SDD \) was suggested. The calculated \( K_{20} \) shown in Figure 3 indicates that the surface conductivity varies with the thickness of the water film, which is neither the diluted value nor the saturated. A water amount of 0.007 ml/cm\(^2\) can make the pollution layer wet-saturated [19]. Therefore, the water film thickness \( h_s \) at saturated wetting is determined as 0.007 cm here.

The actual pollution layer contains an insoluble substance, and the surface conductivity must also be corrected. Linear calibration of (5) is performed here, i.e.

\[
K_{20} = 0.5b\sigma_{20} 
\]  

The surface conductivity \( K_{20} \) of the saturation wetted pollution layer with a non-soluble deposit density (NSDD) of 1.0 mg/cm\(^2\) is measured using a digital electric bridge to verify (5). The calibration result is demonstrated in Figure 4. The calculated data using (5) is in accordance with the measured data and the data from [19] with an average fitting error of 10.9%, which confirms the validity of (5).

### 2.2.2 Surface conductivity versus temperature

The temperature of the pollution layer will not constantly be at 20°C but vary while the arc develops or the leakage current flows. And the surface conductivity must be corrected. A transformational relation is given by IEC-60507 [16] as

\[
K_T = \frac{K_{20}}{1 - b(T - 20)} 
\]  

where \( K_T \) is the surface conductivity at temperature \( T \), and \( b \) is the temperature correction coefficient. An expression of \( b \) is...
on the time-dependent characteristic of surface conductivity is actually carried out to study the relationship between pollution layer temperature and water film thickness against the time. The wetting process of the pollution layer is disregarded here, given its longer time than that of the arc-developing process.

The time-dependent characteristics of temperature $T$ and water film thickness $b$ for a mini trapezoid of the pollution layer element are researched on the basis of the energy conservation law and described as follows.

Case I: $T < T_p$ ($T_p$: the water boiling point at gas pressure $p$, $T_p = 100^\circ$C for $p = 0.1$ MPa). The variation in water film thickness is mainly attributed to the evaporation process. According to Dalton’s evaporation law, the gradient of water film thickness $b$ is written as [20]

$$\frac{db}{dt} = \frac{-\Delta h_e}{K_e} = \frac{p(T) - p(T_s)}{\rho} \quad (8)$$

where $T_a$ (K) is the ambient temperature, $p_a(T)$ (MPa) is the saturated water vapour pressure at temperature $T$ with its value given in [21], $h_e$ (cm) is the evaporation capacity, $K_e$ (cm/s) is a constant coefficient related to air velocity, and $K_e = 0.07$ cm/s [18].

The rise of the pollution layer temperature results from the heat difference between the Joule heat of the leakage current $I$ and the evaporative and air convection heat losses, provided that the conduction heat loss to the glass sample is neglected [21]

$$C \rho \beta \frac{dT}{dt} = \left( \frac{I}{w} \right)^2 \frac{1}{K_T} - H_p \frac{dh_e}{dt} - H_e(T - T_a) \quad (9)$$

where $C (= 4.2 \text{ J·kg}^{-1}·\text{°C}^{-1})$ is the specific heat of water; $\rho$ is the pollution layer density, which is nearly equal to the water density of 1 g·cm$^{-3}$; $K_T$ (S) is the surface conductivity at temperature $T$; $H (= 2256.6 \text{ J·g}^{-1}$ [21]) is the water evaporation enthalpy; $w$ is the conductive width of the pollution layer element; and $H_e (= 2.5 \times 10^{-4} \text{ W·cm}^{-2}·\text{°C}^{-1})$ is the free convection heat transfer coefficient of the air.

Case II: $T = T_p$. The pollution layer temperature does not continue to rise under the heating action of the leakage current when it reaches the water boiling point. The water film thickness will gradually decrease under boiling. At this stage, the gradient of the water film thickness $b$ is expressed as

$$\frac{db}{dt} = \frac{-\Delta h_e}{K_e} = \frac{(I/w)^2/K_T - H_e(T - T_a)}{\rho(H + C(T - T_s))} \quad (10)$$

Figure 6 shows an example of the time-dependent pollution layer temperature $T$, water film thickness $b$, and surface conductivity $K_T$ obtained through the numerical computation of combining (2)–(10). The $SDD$ is fixed at 0.05 mg·cm$^{-2}$, and a fixed leakage current $I$ of 0.1 A is applied; the ambient temperature $T_a$ and initial pollution layer temperature are 20°C,
and the initial water film thickness $b$ is 0.007 cm; furthermore, the width $w$ of the pollution layer element is fixed at 1 cm.

As shown in Figure 6, the surface conductivity $K_T$ increases rapidly at the beginning, then slowly decreases, and finally rapidly decreases to approximately zero. At the initial stage, the pollution layer temperature $T$ rapidly rises, given the leakage current heating, and the surface conductivity $K_T$ rapidly increases. The water evaporation is strengthened with the increase in the pollution layer temperature; thus, the evaporative heat loss becomes rapid, thereby leading to a slowly increasing of temperature $T$. The competition between the water evaporation and this slowly increasing $T$ results in a slowly decreasing of $K_T$. The saline water reaches saturation, and then the sodium chloride separates out while the water evaporates. The temperature at this time reaches the water boiling point, and the water rapidly decreases because of the boiling, which causes the rapid decrease in $K_T$ until zero, i.e. a kiln-dried pollution layer.

2.3 | Current distribution factor

The surface conductivity of the residual pollution layer is non-uniform and time-dependent, thereby resulting in the calculation complicity of its leakage current distribution. The calculation of the leakage current distribution here is only aimed at acquiring the electric field distribution on the pollution layer surface for judging whether the arc develops or not. Hence, the peak electric field intensity is considered here. For the plane triangular glass sample displayed in Figure 1, the maximum field intensity is located at the shortest leakage path between the arc root and the grounding electrode after the arc formation, provided that the current uniformly distributes in the width direction $w$. Therefore, the 2D leakage current distribution on the pollution layer surface is simplified as a unidimensional distribution along the shortest leakage path.

Its leakage current is considered uniform for a given trapezoidal pollution layer element. A larger trapezoid width $w_i$ means a more uniform current distribution. The linear increase in the width $w_i$ with the increase of distance from the arc root is assumed, i.e.

$$\begin{align}w_i = w_0 + k_w \delta x \\
\text{if } w_i > (w_i)_{\text{max}} \quad w_i = (w_i)_{\text{max}}\end{align}$$

where $w_0$ (cm) is the width at the arc root; $w_i$ is the width of the $i$th trapezoidal pollution layer element; $\delta x$ (cm) is the distance of the $i$th element from the arc root; and $k_w$ is defined as current distribution factor, which is assumed to be $\pi$ here. $(w_i)_{\text{max}}$ is the maximum conducting width limited by the physical boundary, hence, $(w_i)_{\text{max}} = W$. The radius $r_{\text{root}}$ of the arc root is related to the arc root current $I_{\text{root}}$ [10]

$$r_{\text{root}} = \sqrt{\frac{I_{\text{root}}}{1.45\pi}}$$

The width $w_0$ at the arc root is considered half of the arc root perimeter because the arc root current unidirectionally flows into the residual pollution layer

$$w_0 = \pi r_{\text{root}}$$

2.4 | Simulation flowchart of the model

Figure 7 gives the simulation flowchart of the pollution layer surface resistance $R_s$ and the leakage current $I$ using (1)–(11) in the absence of an arc for a given voltage. The simulation is conducted on MATLAB through self-programming based on the time-step iteration method. The simulation process is as follows:

i. Starting calculation, and discretising the pollution layer.

ii. Initialising the water film thickness $b(0)$ ($=0.007$ cm), pollution layer temperature $T(0) = T_0$, conducting width $w(0)$ of the first trapezoidal pollution layer element, leakage current $I(0)$, and surface conductivity $K_T(0)$. The initial surface conductivity $K_T(0)$ of every trapezoidal pollution layer element is calculated using (2)–(7), the initial surface resistance $R_s(0)$ of the entire pollution layer is obtained using (1), and the initial leakage current $I(0)$ is determined according to Ohm’s law; calculating the conducting widths $w(0)$ of all the trapezoidal pollution layer elements in accordance with (11) for a given discrete-element length $\delta x$.

iii. Calculating $b(t + \Delta t)$ and $T(t + \Delta t)$ in accordance with (8) and (9) if $T(t) < T_p$ and calculating $b(t + \Delta t)$ in accordance with (10) if $T(t) = T_p$ for a given time step $\Delta t$.

iv. Calculating $K_T(t + \Delta t)$ using $b(t + \Delta t)$ and $T(t + \Delta t)$ in Step (c) in accordance with (2)–(7).

v. Calculating the surface resistance $R_s(t + \Delta t)$ of the entire pollution layer in accordance with (1).
vi. Calculating the leakage current $I(t + \Delta t)$ according to Ohm's law for a given voltage $U(t + \Delta t)$.

vii. Judging whether $t + \Delta t > t_{\text{end}}$ or not, calculating circularly according to Steps (b)–(f) if $t + \Delta t < t_{\text{end}}$ and ending the calculation if $t + \Delta t > t_{\text{end}}$, the parameters ($R_p$ and $I$) are obtained.

Figure 8 presents the simulation flowchart of the residual pollution layer surface resistance $R_{p0}$ using (1)–(13) in the presence of an arc with a given arc length $L_0$. All the frames of the arc before developing to the given arc length recorded by a high-speed camera must be considered. The lengths of these frames of the arc are set as $L_1$, $L_2$, …, and $L_k$. The measured time-dependent leakage current through a current sampling resistance and an oscilloscope (Figure 9) and the corresponding time related to every frame of arc serves as the input parameters of the simulation. The leakage currents and
times that correspond to these frames of the arc are set as $I_1$, $I_2$, ..., and $I_k$ and $t_1$, $t_2$, ..., and $t_k$, respectively. The arc root current $I_{\text{root}}(i = 1, \ldots, k)$ is assumed as the leakage current $I$.

The leakage current heating in the time interval from the voltage beginning ($t = 0$) to the arc initiation ($t = t_1$) is also considered because the heating causes the pollution layer parameters at the moment of the arc initiation to be probably different from those before the voltage beginning. The water film thickness, pollution layer temperature, and surface conductivity of the residual pollution layer that corresponds to arc length $L_0$ are denoted as $b_0(t_1)$, $T_0(t_1)$, and $K_{\text{TS}}(t_1)$, respectively, and are similar to the arc lengths $L_1$, $L_2$, ..., and $L_k$. For a given arc length $L_0$, the simulation process is as follows:

i. Starting calculation.
ii. Determining the water film thickness $b_0(t_1)$, pollution layer temperature $T_0(t_1)$, and surface conductivity $K_{\text{TS}}(t_1)$ of the residual pollution layer in accordance with Figure 7; these parameter values are set as the initial values of the following calculation.
iii. Discretising the residual pollution layer starting from the arc root linked with the first frame of arc $L_1$, and calculating the conducting widths $w(t_i)$ of all the trapezoidal pollution layer elements in accordance with (11)–(13) for a given discrete-element length $\delta x$ assuming that $I_{\text{root}}(t_i) = I_i$; the abovementioned two parameter values are also set as the initial values of the following calculation.
iv. Calculating $b_0(t + \Delta t)$ and $T_0(t + \Delta t)$ in accordance with (8) and (9) if $T(t) < T_p$, and calculating $b_0(t + \Delta t)$ in accordance with (10) if $T(t) = T_p$; for a given time step $\Delta t$, $t_{i+1} - t_i = \Delta t$.
v. Calculating $K_{\text{TS}}(t + \Delta t)$ using $b_0(t + \Delta t)$ and $T_0(t + \Delta t)$ in Step (d) in accordance with (2)–(7).
vi. Calculating the surface resistance $R_{\text{pol}}(t + \Delta t)$ of the residual pollution layer that corresponds to arc length $L_0$ in accordance with (1)
vii. Judging whether $t > t_k$ or not, calculating circularly according to Steps (b)–(e) if $t < t_k$, and ending the calculation if $t > t_k$; the parameters $R_{\text{pol}}(t_k + \Delta t)$ are obtained.

3 | VERIFICATION OF THE POLLUTION LAYER MODEL

Figure 9 illustrates the experimental setup for measuring the leakage current in a pollution layer over a plane triangular glass sample. The applied negative DC high voltage is monitored using an HV probe (IWATSU HV-P60) connected to an oscilloscope (Tek TDS2024C). The leakage current is collected through a non-inductive current sampling resistance ($10,503 \, \Omega$) and the oscilloscope. The mixed slurry of sodium chloride ($SDD$) and kaolin ($NSDD$) is uniformly coated on the glass surface in accordance with the solid layer method recommended by the IEC-60507 standard. The pollution layer is wetted by spraying distilled water rather than applying a fog because the fog lowers the visibility and hinders the clear recording of the high-speed camera on the arc propagation process. The photographic method as well as the measurement method of partial arc length were described in the authors’ another paper [22].

The purpose of the experiment is to obtain the resistance of the pollution layer. Before the arc initiates, the load of the power source is just the resistance of the pollution layer. Thus, the resistance, can easily be obtained through dividing the applied voltage with leakage current, i.e. $R_p = U/I$. However, if the partial arc exists, the resistance of the pollution layer will be hard to measure due to the uncontrollable arc root movement. Because the resistance of arc is much smaller than the resistance of the pollution layer in series with the arc, the change characteristic of the residual resistance of the pollution layer can be approximately represented by the load resistance which can be calculated through $U/I$. So the residual pollution layer resistance is calculated in the situations with and without a partial arc. The results calculated from the model are also treated in the same way.

The proposed pollution layer model is verified from the following two perspectives.

Case I: In the absence of an arc. A negative DC high voltage is applied after the pollution layer is wet-saturated, which corresponds to a water film thickness $b$ of 0.007 cm. At the initial stage, the dry band is not formed; thus, the partial arc will not be produced. Figure 10 shows the measured time-dependent leakage current and the applied voltage. The initial zigzag rise of the voltage is caused by the voltage instability that is attributed to the large initial leakage current.

The voltage demonstrated in Figure 10 is set as the input voltage of the calculation using the pollution layer model according to the simulation flowchart exhibited in Figure 7. It is shown in Figure 11 that the calculated leakage current agrees with the measured leakage current regardless of the SDD. The fitting error is 6.63% when $SDD = 0.05 \, \text{mg/cm}^2$ and 2.03% when $SDD = 0.02 \, \text{mg/cm}^2$. The results confirm the validity of the pollution layer model in the absence of an arc.

Figure 12 presents the calculated and measured time-dependent surface resistances of the pollution layer. The calculated surface resistance agrees with the measured surface resistance with a fitting error of 1.84%, thereby confirming the validity of the pollution layer model. The pollution layer temperature rises due to the leakage current heating with the increase in voltage action time, and the rise results in the increased surface conductivity and the decreased surface resistance.

Case II: in the presence of an arc. In this case, the concentration effect of the leakage current at the arc root must be considered in calculating the residual pollution layer resistance. The presence of an arc in front of the ground electrode leads to the excessive difficulty in measuring the surface resistance of the residual pollution layer. Therefore, the series resistance of the residual pollution layer and the arc is measured here.

Figure 13 illustrates the variation in the calculated surface resistance of the residual pollution layer and the measured series resistance with an arc. The arc length is determined
through the real-time recording of a high-speed camera on the arc propagation process in accordance with the method in [22]. The calculated and measured resistances gradually decrease while the arc length increases, and they are adjacent with an average fitting error of 10.35%. The slight difference between them for a given arc length may results from arc length measurement error in [22] that measure the straight distance from the HV electrode to the arc root ignoring the part floating into the air. Thus, the calculated value is smaller than the measured one. This finding further confirms the validity of the pollution layer model. Owing to the arc propagation, the long pollution layer is bridged by the arc, thereby resulting in a gradual decrease in series resistance.

In brief, the proposed pollution layer model based on discretising the residual pollution layer is confirmed to be valid for predicting the influences of leakage current heating, water evaporation, and boiling on the residual pollution layer resistance regardless of the absence or the presence of an arc over the pollution layer. The model and calculation flowchart remain effective, except for setting different SDD and water film thickness $b$ at various locations when the surface is non-uniformly polluted and wetted.

### 4 | CONCLUSIONS

A novel residual pollution layer model based on discretisation is proposed in this study. The discretised treatment of the residual pollution layer is significantly different from the concentrated treatment used in the Obenaus model and its improved models. The residual pollution layer is discretised into successive mini-type trapezoidal pollution layer elements, starting with the arc root, over the plane triangular polluted glass sample. Every mini trapezoidal element has its own SDD, water film thickness, temperature, conducting width, leakage current density, and surface conductivity at any given moment.
The value of a given parameter at various locations is identical in a given mini element. The quantitative relationships between surface conductivity and several variables, including SDD, water film thickness, temperature, and time are concluded on the basis of the experimental data and relevant theories. The conducting width \( w_0 \), which determines the leakage current density, at any given residual pollution layer location, is assumed as a linear-varying relationship of the location with a proportionality coefficient of \( \pi \).

The simulation flowcharts of the residual pollution layer model in the absence and presence of an arc are given, and the simulation is conducted in MATLAB through self-programming. Comparing the calculated results with an experiment in the absence and presence of an arc show that the changes of surface resistance and leakage current of the polluted layer can be well simulated using the proposed pollution layer model which will take a significant role in building a time-varying model to calculate the flashover voltage which will be discussed in the future work.

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