ELECTRIC FIELD COMPUTATION OF 400KV AC PORCELAIN STRING INSULATOR

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ABSTRACT

Satisfactory operation of outdoor porcelain insulators under polluted environment is immediately related to the electric field distribution along the insulator string. This paper presents results of the calculation of the electric field (E field) distribution for porcelain string or suspension insulators subjected to 400kV, 50Hz, AC, using PSPICE. Field distributions are calculated for three types of strings under dry, uniform pollution, non-uniform pollution distribution. The results obtained show that anti-fog and/or combination of anti-fog and standard disc insulator strings perform better under polluted & dry conditions.

Keywords: Arc, Electric Field, Flashover, Outdoor insulator, Porcelain and String/suspension.

1. INTRODUCTION

Pollution flashover, observed on insulators used in high voltage transmission, is one of the most important problems for power transmission. Pollution flashover is a very complex problem due to several reasons such as modeling difficulties of insulator complex shape, different pollution density at different regions, non-homogenous pollution distribution on the surface of insulator and unknown effect of humidity on the pollution. The performance of insulators under polluted environment is one of the guiding factors in the insulation coordination of high voltage transmission lines. On the other hand, the flashover of polluted insulators can cause transmission outage of long duration over a large area. Flashover of polluted insulators is still a serious threat to the safe operation of a power transmission system. It is generally considered that pollution flashover is becoming even more important in the design of high voltage lines.

Outdoor insulators are being subjected to various operating conditions and environments. The surface of the insulators is covered by airborne pollutants due to
natural or industrial or even mixed pollution. Contamination on the surface of the insulators enhances the chances of flashover. Under dry conditions the contaminated surfaces do not conduct, and thus contamination is of little importance in dry periods. As the surface becomes moist because of rain, fog or dew, the pollution layer becomes conductive because of the presence of ionic solids. The leakage current flows through the conducting surface film, generating heat which tends to increase the film temperature most rapidly at those points where the current density is high, i.e., at narrow sections of the insulator, such as the area around the pin. Eventually, the temperature in these areas approaches boiling point, and rapid evaporation of the moisture occurs producing dry bands.

The process of dry band formation has been analysed by William et al at [1]. They showed that if the evaporation rate exceeds the wetting rate then the electric field $E$ is sufficiently high causing dryband formation.

The basic phenomena of flashover is formation of dry bands due to the flow of leakage currents, initiations of arcs across dry bands and propagation of the arc on the wet pollution layer, finally triggering a complete flashover. Several models [2,3,4,5] have been developed to predict flashover voltage of polluted insulators and most of them depend directly or indirectly on arc voltage and or voltage across the pollution layers. It has been observed form the literature that, one of the major factor governing the electrical performance of the outdoor insulators is the electric filed distribution along the surface of the insulator string[6]. The resulting electric field concentration can lead to corona & accelerate several failure modes[7].

In the present paper 400 kV AC porcelain string insulator in PSPICE has been modelled & analysis of electric filed distribution under dry, uniform pollution and non-uniform pollution have been discussed for three different cases

i) standard disc

ii) Anti Fog

iii) Combination of standard and anti fog insulators.

2. MODELING OF PORCELAIN STRING INSULATOR

In the present work three different cases are considered for the study such as i) standard disc insulator ii)Anti-fog insulators iii)Combinations of standard & anti-fog insulators. The dimensional details of the insulators are given in Table 1.

<table>
<thead>
<tr>
<th>Case</th>
<th>Number of insulators in the string</th>
<th>Type of insulator/s</th>
<th>Leakage length / disc (cm)</th>
<th>Shed diameter (cm)</th>
<th>Height of insulator/ disc (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>26</td>
<td>Standard disc</td>
<td>3</td>
<td>25.4</td>
<td>14.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>I</td>
<td>Anti-fog disc</td>
<td>7</td>
<td>30.0</td>
<td>14.6</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>Combination of I &amp; II</td>
<td>3</td>
<td>25.4/30.0</td>
<td>14.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.3 &amp; 47.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

An electrical equivalent circuit shown in Fig.1 for string insulator reported in [8] has been adopted for the field analysis under dry conditions. The values for the different
capacitances are obtained from the field for a 400kV AC transmission system. The description and values for different capacitances used in present study are given below:

- $C_i$ - pin to line capacitance = 5pF
- $C_{oi}$ - section capacitance = 50 pF
- $C_{ig}$ - pin to ground capacitance = 4 pF

![Equivalent circuit for voltage/field distribution along insulator string](image1)

Fig. 1: Equivalent circuit for voltage/field distribution along insulator string

The mechanism of long strong flashover consists of different phases instantly, the contaminated insulator surface is completely dry and so the voltage/field distribution on the string can be regarded to be the same as that on a dry and clean insulator string. The equivalent circuit can be represented by network of capacitances only as shown in Fig. 1. As the wetting progresses, the surface impedance is a combined resistance, The equivalent circuit of contaminates insulator string is as shown in Fig. 2.

![Electrical Equivalent of Polluted String](image2)

Fig. 2: Electrical Equivalent of Polluted String
In order to calculate the pollution resistance of each unit, a dynamic model that takes into account the instantaneous change in the arc parameters employed [9, 10].

Equation of the computation of the pollution resistance \( R_{oi} \) for a given conductivity \( \sigma \) of pollution layer are given below.

\[
R_{oi} = \frac{1}{\sigma} \cdot FF
\]

\[
FF = \int_{L_{arc}}^{L} \frac{dL}{2\pi r}
\]

Where, \( dL \) is the movement of the arc in time \( dt \).
\( r \) is the radius of the insulator at creepage distance \( L_{arc} \).
\( L_{arc} \) is the arc length.
\( L \) is the creepage length of the insulator string.
\( FF \) is the form factor.
\( \sigma \) is the conductivity of the pollution layer.

3. ESTIMATION OF ELECTRIC FIELD

In the present work a 400kV porcelain string insulator is considered and E field has been estimated for three different strings
i) standard disc
ii) Anti Fog
iii) Combination of standard and anti fog insulators.

Each string has been analysed under dry, uniform pollution and non-uniform pollution. The following section explains the estimation of E field for the three conditions mentioned above.

3.1 Electric field under dry conditions

The electric field have been calculated after performing the analysis in PSPICE for string model shown in Fig.1. Number of insulators used in string is 26, 17 and 20 respectively for strings of standard disc, anti-fog and combination of standard and anti-fog insulators.

The electric field has been calculated along the string length from the energized line and up to the ground end. Figure.3 shows the variation of E field as a function of length of the string. The maximum of about 7.5kV/cm near the pin of the first insulator or near high voltage line end. This field is less than the field required to initiate the arc under dry conditions.
3.2 Electric field under uniform pollution condition

The surface of porcelain insulator is assumed with a uniform pollution of 10µS and corresponding pollution resistance of all the 26 insulators are calculated using (1) and simulation is carried out in PSPICE with string model shown in Fig.2. The same procedure is repeated for anti-fog & combined insulator strings.

Figure 4 shows the electric field along the length of the strings for 231 kV (line to ground) system voltages. The electric field required to initiate the arc/scintillation along the polluted porcelain insulator has been reported in the range of 2.1 to 2.8 kV/cm[11] and 1.45 to 2 kV/cm[12].

From Fig.4, it can be observed that field across the insulator disc 1 and 2 are higher than the minimum field required for the arc initiation in case of string with standard discs. In the case of string with anti-fog discs insulators and combined anti-fog & standard disc insulator, only across the first insulator from the line end exceeds the minimum field for arc initiation.
3.3 Electric field under non uniform pollution condition

In practice the accumulation of the pollution on the surface of the insulator is not uniform because of the reason i)non uniform distribution of the voltage across the string and ii) partially washing of some pollutants on the surface of the insulator surfaces. To mimic this present work also considers non uniform pollution of string from high level(5µS) to heavy level (30 µS). Heavy pollution has been consider on the line end insulators and decreased pollution near the ground end. Again using (1) ,the pollution resistance were calculated for all the three cases mentioned earlier and simulation has been performed to estimate the electric field.

Figure 5, shows the plot of electric field as a function of length along the string for standard disc string, string of anti-fog and string of combination of anti-fog & standard disc insulators. It can be observed from the Fig.5 that across the first insulator from the line end ,the field is about 3kV/cm in case of standard disc string & it is about 2.3kV/cm in case of anti-fog insulators.
As mentioned earlier, the field across the first unit of the insulator string exceeds the threshold field of the arc initiations leading to flashover of the first disc which in turn redistributes the voltage causing high field across the second and/or third insulator. This process continues until the arc reaches the critical length and finally bridging the whole insulator leading to a complete flashover.

From the above discussion, it is observed that, the strings of anti-fog insulator and combined insulator perform better that gives lesser field compared with strings of standard disc insulators. To get more insight, string efficiency has been calculated for all the three cases under dry conditions and tabulated in Table 2.

### Table2: Calculated string efficiency under dry condition

<table>
<thead>
<tr>
<th>Insulator type in the string</th>
<th>Percentage efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard discs</td>
<td>27.8</td>
</tr>
<tr>
<td>Anti-fog discs</td>
<td>42.2</td>
</tr>
<tr>
<td>Combination of standard &amp; anti-fog discs</td>
<td>46.0</td>
</tr>
</tbody>
</table>

Table 2 shows that combination of anti-fog and standard disc insulator string yields better string efficiency.

### 4. CONCLUSIONS

Paper describes the estimation of electric field of porcelain insulator string used in 400kV transmission systems. For this purpose three insulator string has been modelled as RC network and used in PSPICE to find the node potential/potential difference across the each insulator disc. The values of the node potential are further used to calculate the electric field along the length of the string.

Anti-fog insulator and combination of anti-fog and standard disc insulator string not only performs better in polluted environment, it also yields better string efficiency under dry conditions. Using anti-fog disc insulators and/or combinations of anti-fog and standard disc insulators, results in increased creepage length and reduced leakage current.

Electric field analysis plays a critical role in the design, selection and application of ceramic insulators to ensure better performance under polluted environment.

### REFERENCES

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