Numerical Simulation of Onset Conditions for Corona Discharges on Stranded Conductors

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***Abstract*—Numerical simulations are presented for onset conditions of corona discharges on stranded conductors as found in high voltage transmission lines. The electric field in the vicinity of stranded conductors above a grounded plane are analyzed by two dimensional finite element method. Coupled with the classic corona onset criterion, the corona onset conditions are investigated. The predicted onset voltages agree well with the experimental data in the literature. The onset voltage for stranded conductor significantly decreases with the decrease of the relative air density. The radius of the ionization zone is about two times of the outer radius of the stranded conductor.**

I. Introduction

Corona induced effects, such as radio interference and audio noise, can limit the performance of high voltage transmission lines and other electrical conductors. T9. COUPLED MULTI-PHYSICS PROBLEMS onset is an important design consideration. The electrode configuration to be considered here is the stranded conductor, which is widely used to construct the overhead high voltage transmission lines.

A surface irregularity factor was introduced for Peek's formula [1] to evaluate the corona onset electric field for stranded conductors, but the surface irregularity factor is difficult to choose. Considering the electric field distribution in the vicinity of stranded conductors, the surface irregularity factor for stranded conductors inside a coaxial cylinder was investigated on the basis of the classic corona onset criterion [2]. However, the corona onset criterion should be modified for different electrode configurations and gas conditions [3].

The model presented in this paper is based on the modified classic corona onset criterion. The electric field in the vicinity of stranded conductors above a grounded plane is analyzed by two dimensional finite element method, which is more suitable for the electrode with complex geometry. The calculated results are compared with the experimental data in [4].

II. Numerical Simulation

A. Corona Onset Criterion

The arrangement of 7-stranded conductor with a outer radius R at a center height H above a grounded plane in calculation is shown in Fig. 1. The development line for either negative corona or positive corona is from the conductor surface at R to the position R_i where the electron ionization coefficient α equals to the electron attachment coefficient η. The classic corona onset criterion is given by

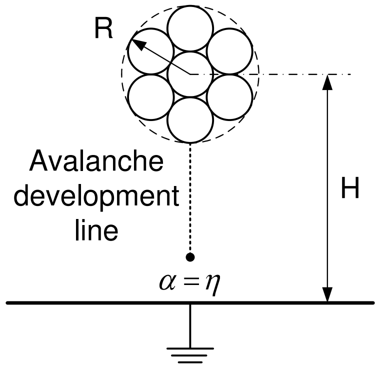

Fig. 1. Sketch of the avalanche development line in calculation for 7-strand conductor above a grounded plane.

$$Q = \exp\left[\int_R^{R_i} (\alpha - \eta) dl\right], \tag{1}$$

where l is the position in the avalanche development line and Q is a constant. The value of Q is given as 3500 by Yamazaki $et\ al.$ [2]. In this paper, the value of Q is modified as 500 for 7-strand conductor with an outer radius from 1 mm to 1.5 mm that the natural logarithm of Q is in the typical range 5-20 [3]. The electron ionization and attachment coefficients are given by [2], [5]

$$\alpha/\delta = \begin{cases} 3631.7\text{exp}(-167.960\delta/E) \text{ for } E/\delta \leq 45.6 \\ 7358.3\text{exp}(-200.792\delta/E) \text{ for } E/\delta > 45.6 \end{cases} \tag{2}$$

and

$$\eta/\delta = 9.8648 - 0.54(E/\delta) + 1.1447 \times 10^{-2}(E/\delta)^2, \tag{3}$$

where E is in kV/cm, α and η in cm^{-1}. The relative air density δ in (2) and (3) is given by

$$\delta = (P/P_0)/(T/T_0), \tag{4}$$

where P_0 is 101.325 kPa and T_0 is 298 T. The reference conditions are the same as that for Peek's formula.

B. Onset Field Calculation

The electric field is analyzed by two dimensional finite element method. The distances from the conductor center to

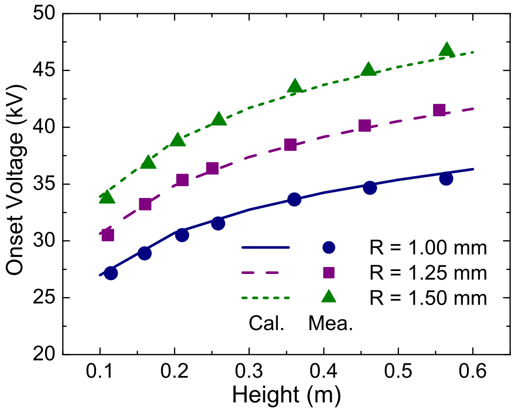

Fig. 2. Comparison of calculated and measured onset voltages [4] for 7-strand conductors with different outer radii at different center heights.

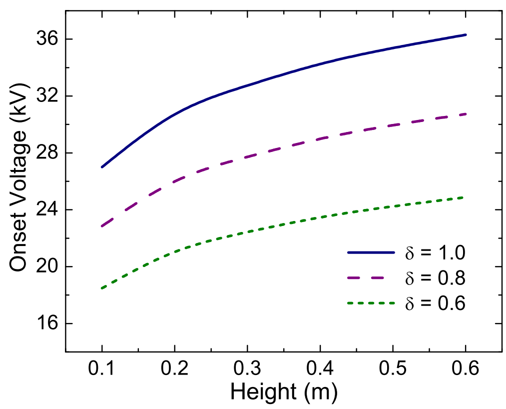

Fig. 3. The relationship between the calculated onset voltage and the relative air density for 7-strand conductors with an outer radius of 1 mm at different center heights.

the left boundary, right boundary, and up boundary of the computational domain are all set as $5H$. The sub-conductors are divided into 72 segments. The material of the stranded conductor is aluminum. The applied voltage on the stranded conductor is 1 kV and the grounded plane is 0 kV. The percent error is 1%. The calculation is carried out by a finite element analysis solver. The electric field distribution under the applied voltage 1 kV is obtained firstly.

If an onset voltage U_0 (in kV) is given, the onset electric field equals to the product of the electric field by finite element analysis and the value of U_0. The onset electric field should satisfy (1) and the onset voltage U_0 can be calculated. After then, the onset electric field is easy to obtain. When the value of Q is smaller than 10^8, the effect of space charges is negligible [3].

III. NUMERICAL RESULTS

The calculated and measured onset voltages for 7-strand conductors with different outer radii at different center heights are compared in Fig. 2. The calculated data agree well with the experimental data for negative corona discharges in [4]. It can be found that the predicted onset voltage with different conductor radii does not linearly increase with the increase of the center height. The onset voltage increases with the increase of the conductor radius.

The relationship between the calculated onset voltage and the relative air density for 7-strand conductors with an outer radius of 1 mm at different center heights is shown in Fig. 3. The predicted onset voltage at different center heights decreases with the decrease of the relative air density. It can be found that the decrease of the onset voltage under the low relative air density is significant.

The onset electric field distribution for 7-strand conductor with an outer radius of 1 mm at a center height of 0.1 m is shown in Fig. 4. The maximum electric field intensity on the conductor surface is located at the position R and the minimum intensity on the conductor surface is between the sub-conductors. As shown in Fig. 4, the electric field intensity at a radius of $2R$ is about 24.2 kV/cm where $\alpha = \eta$. It can be found that the ionization zone can not be neglected compared with the outer radius of the stranded conductor.

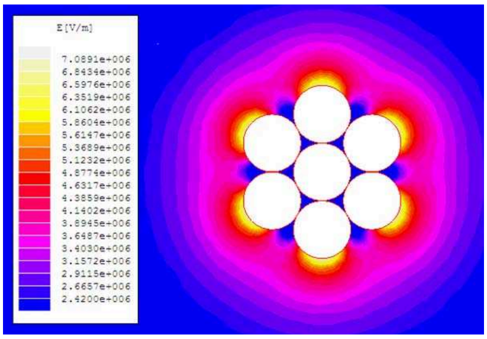

Fig. 4. Distribution of the onset electric field for 7-strand conductor with an outer radius of 1 mm at a center height of 0.1 m.

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