A study of field enhancement from semiconductive protrusions in power cables

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ABSTRACT

Protrusions from semiconductive layers in extruded high voltage cables will cause localised enhancement of the electric field. Two formulas for calculating the field enhancement at the tip of protrusion are described in the scientific literature: The Larmor and Mason formulas.

The paper provides evidence that the Mason formula is not applicable. The Larmor formula has been extended to spheroidal-shaped protrusion of arbitrary aspect ratio.

The impact of protrusion size on dielectric performance of power cables is discussed.

KEYWORDS

Power cables; Semiconductive protrusions; field enhancement

INTRODUCTION

Protrusions from semiconductive layers in extruded high voltage cables will cause localised enhancement of the electric field. Two formulas for calculating the field enhancement at the tip of protrusion are described in the scientific literature, e.g. in [1]: The Larmor formula assuming spheroidal shape of the protrusion and the Mason formula assuming hyperboloidal shape.

Although the two equations can give values that differ with several magnitudes, there has not been a comparative study addressing the validity of the formulas prior to a recent conference article from the author [2].

The intention with the current paper is to present the proper mathematical algorithms for calculation of the electric field at semiconductive protrusions of any aspect ratio and to discuss possible mechanisms for cable degradation caused by protrusions.

COMPARISON LARMOR - MASON

Fig. 1 compare the shapes of spheroidal and hyperboloid protrusions with the same height (100 µm) and same radius of curvature at the tip, the tip radius r (50 µm).

The Larmor formula for the field enhancement factor (FEF) - the ratio of the actual field to the field without defect - at the tip:

$$FEF_{tip} = \frac{2n^3}{m\ ln\left(\frac{m+n}{m-n}\right) - 2n} \quad (1)$$

where

$$m = {}^{a}/_{c} \quad (2)$$

$$n = \sqrt{m^2 - 1} \quad (3)$$

The parameter a is the height and c is the half width of the protrusion.

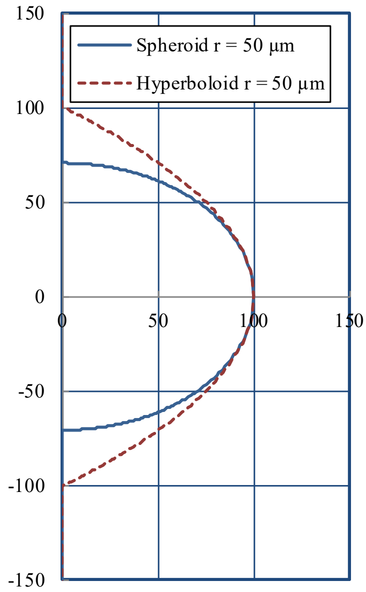

Fig. 1: Comparison between spheroidal and hyperboloidal geometry of a protrusion of height 100 µm and tip radius 50 µm. The unit of the axes is µm.

Note that Larmor equation 3 in reference [1] has an erroneous exponent, but it is evident from the graphs in the paper that the correct version of the formula has been used for the calculations.

The Mason equation:

$$FEF_{tip} = \frac{2L}{r \cdot ln\left(1 + \frac{4L}{r}\right)} \quad (4)$$

Parameter L is the insulation thickness (distance between the tip and the plane) and r is the radius of the tip.

The two formulas are compared in Fig. 2 plotting the field enhancement factor versus tip radius for protrusions with 100 µm height. Two lines are included for the Mason formula; one for a medium voltage cable and one for an EHV cable as the insulation thickness is a parameter in the Mason formula.

It is obvious that the calculated values can differ with several orders of magnitude although the difference in shape is not very sizeable. Another peculiarity is the fact that the insulation thickness is a parameter in the Mason equation but not in the Larmor equation.