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Determination of Partial Discharge Inception Voltage and Location of Partial Discharges by Means of Paschen's Theory and FEM

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Abstract—Determining the Partial Discharge Inception Voltage (PDIV) is a key point when designing electrical coils or busbars. In this paper, a method making it possible to calculate the PDIV as well as to locate Partial Discharges (PD) in windings of any shape is presented. It is based on a 2D finite element computation using both dual – *i.e.* scalar and vector potential – electrostatic formulations and a comparison of the obtained operating points with the Paschen's curve.

Index Terms—Finite element method, field lines, partial discharge inception voltage.

I. INTRODUCTION

The breakdown voltage V_b between two electrodes immersed in a gas is governed by [1]:

$$V_b = \frac{B p d}{\ln(A p d) - \ln[\ln(1 + \frac{1}{\gamma_{se}})]} \quad (1)$$

where p is the pressure (in Torr), d is the distance (in cm) between either the electrodes or the insulation layers if any, γ_{se} is the Townsend secondary electron emission coefficient and A and B are coefficients which depend on the considered gas and temperature. Then, it is possible to plot the so-called Paschen's curve $V_b = f(d)$ (in black in Fig. 1 for air at ambient pressure and temperature). This curve can be used as a criteria for the determination of the PDIV value. Indeed, if the point of coordinates (V, d) , where V is the electric potential difference between either the two electrodes or the insulation layers if any, is located below the curve, then no PD will appear. If this point is located above the curve – *i.e.* in the red zone in Fig. 1 – then PDs will appear. If the point is located on the curve, then the PDIV is equal to the electrodes supply voltage.

The aim of this paper is to provide a numerical method allowing to treat any 2D complex geometry – cables, motor/transformer windings or busbars – whether for the determination of the PDIV or the location of PDs. It will be shown that the use of both dual – scalar and vector potential – electrostatic formulations allows to account for the correct V and d parameters, which, to the author's knowledge, is an approach that has never been seen in the literature.

II. METHODOLOGY

During the avalanche breakdown process, the path followed by free electrons is an electric field line. Then, in the Paschen's theory, under certain assumptions that will be discussed in the extended paper, d can be assimilated to the field line length and V is equal to the electric potential difference between the two ends of this line. Hence, the proposed method consists in following these steps:

- perform an electrostatic finite element analysis using the vector potential formulation in order to evaluate the d length of each of a set of electric field lines – *i.e.* iso-values of the vector potential – in the air,
- perform an electrostatic finite element analysis using the scalar potential formulation in order to evaluate the V electric potential difference between the two ends of each of the aforementioned field lines,
- for each field line, compare the point of coordinates (V, d) (in blue in Fig. 1) to the Paschen's curve.

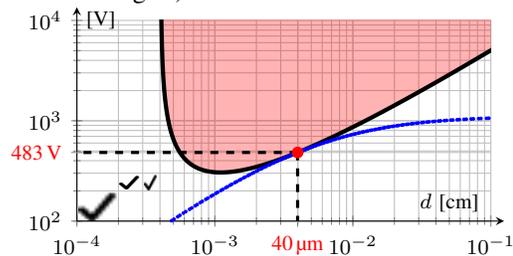


Fig. 1. Electric potential difference V as a function of distance d

As an example of validation, a twisted pair of copper wires with different radii and insulation layers has been modeled (Fig. 2). For this configuration, the curve $V = f(d)$ (in blue in Fig. 1) makes first contact with the Paschen's curve for $V = 483$ V and $d = 40$ μm . It corresponds to an electrodes supply voltage, and so a PDIV value, equal to 1135 V, which is in very good accordance with the experimental measurement (1184 V). As an illustration, the critical field line location is shown in Fig. 2.

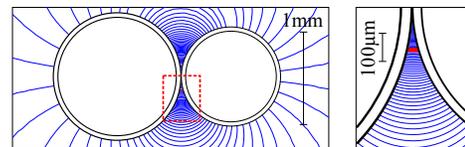


Fig. 2. (left) Electric field lines between the wires. (right) Field line from which the PDIV is determined and around which PD are likely to appear

In the extended paper the method will be applied to a standardized case – the mandrel test – and a busbar-like device. The problem of discontinuities undergone by the vector potential through cuts will be addressed. The robustness and the accuracy of the method with respect to the mesh size and the number of field lines to consider will also be discussed.

REFERENCES

- [1] F. Paschen, "Ueber die zum funkenübergang in luft, wasserstoff und kohlendioxid bei verschiedenen drucken erforderliche potentialdifferenz," *Annalen der Physik*, vol. 273, no. 5, pp. 69–96, 1889.