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Johansson, Torben; McAllister, Iain Wilson

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T. Johansson and I. W. McAllister
Department of Electric Power Engineering
Technical University of Denmark
Lyngby, Denmark

Abstract: The response of an electrostatic probe mounted in an electrode is examined with reference to eccentric charge distributions. The study involves using the probe λ function to derive a characteristic parameter. This parameter enables the response of the probe to different degrees of eccentricity to be quantitatively assessed.

Introduction

Bound electrostatic probes are typically employed to study electrical discharge activity along the surface of gas/solid-dielectric interfaces [1,2]. The word bound signifies that the probe is mounted in the electrode in contact with the solid dielectric, see Figure 1 [3]. Thus, as the probe is an integral part of this electrode, such probes lack the freedom of movement necessary to implement a scanning procedure which is required for a correct quantitative evaluation of the surface charge to be made [4,5].

In [1,2] the charge was deposited on the dielectric surface by a corona discharge from a point electrode. Thus although the bound probe itself is not free to move, the bounding (plane) electrode may be moved relative to the point electrode. Hence when this electrode and the probe are not coaxially aligned, an eccentric charge situation will arise.

Charges are electrostatically induced on the probe sensor plate by the presence of a source charge. The relationship between the induced charge and this interface source charge is expressible in terms of a general function, the λ function [6]. Using this function it is possible to examine the response of electrostatic probes.

In the present study, the response of bound probes to eccentric surface charge distributions is investigated. For a rotationally symmetric surface charge, the eccentricity refers to the fact that the axis of the probe and that of the surface charge are displaced from one other.

The probe responses are examined with reference to

the degree of eccentricity and compared with the associated concentric responses. In this way, the eccentricity of the charge distribution is shown to have a significant effect upon the probe response. For a given λ function, this response is controlled by the spatial dimensions of the surface charge.

Figure 1: Bound probe geometry.

The λ function

The λ function is the proportionality factor between the charge induced on the probe to any charge within the dielectric volume or at an interface [6]. If it is assumed that the volume charge density in the solid dielectric is zero, then this relationship can be expressed simply as

$$q = -\iint_{A_o} \lambda \sigma \mathrm{d}A \qquad (1)$$

where q is the Poissonian induced charge on the probe sensor plate, and σ is the surface charge density on the surface element $\mathrm{d}A$ of A_o, the surface of the solid dielectric.

The dimensionless parameter λ is a solution of the general Laplace equation for the complete system geometry:

$$\vec{\nabla} \bullet (\varepsilon \vec{\nabla} \lambda) = 0 \qquad (2)$$

The boundary conditions are $\lambda = 1$ at the probe sensor plate and $\lambda = 0$ at all other electrodes. In addition, at dielectric interfaces the normal derivatives of λ must obey the condition

$$\varepsilon_+ \left[\frac{\partial \lambda}{\partial n} \right]_+ = \varepsilon_- \left[\frac{\partial \lambda}{\partial n} \right]_- \qquad (3)$$

where the + and - signs refer to the opposite sides of the interface. As (2) is just Laplace's equation, any standard method of solving this equation can be employed to evaluate the variation of λ along the interface. On this occasion, solutions of Laplace's equation were obtained using a finite element software package. These solutions were then used to study the dependence of the probe response upon the surface charge distribution.

Probe/dielectric geometry

The geometry of the bound probe used in this study is shown in Figure 1, in which r is the radius of the sensor plate and x is the radial distance from the probe axis. The gap between the sensor plate and the remainder of the electrode is Δ. To minimise the influence of the probe length L on λ, the former parameter is set to $25\,r$.

The planar dielectric, of relative permittivity ε_r, has a thickness t in a direction normal to the plane electrode which, along with the probe shield, is grounded. In the direction normal to the probe axis, the extent of the solid-dielectric/plane-electrode is much greater than the probe lateral dimensions. With the present software this distance is made $250\,r$.

As the influence of the probe/dielectric geometry upon the λ function for a bound probe is discussed in [3], it is only necessary to illustrate the variation of λ along the gas/solid-dielectric interface for the probe geometry employed in the present study, viz. $\Delta/r = 0.5$, $\varepsilon_r = 4$, $t/r = 0.5$. The relevant λ function is shown in Figure 2.
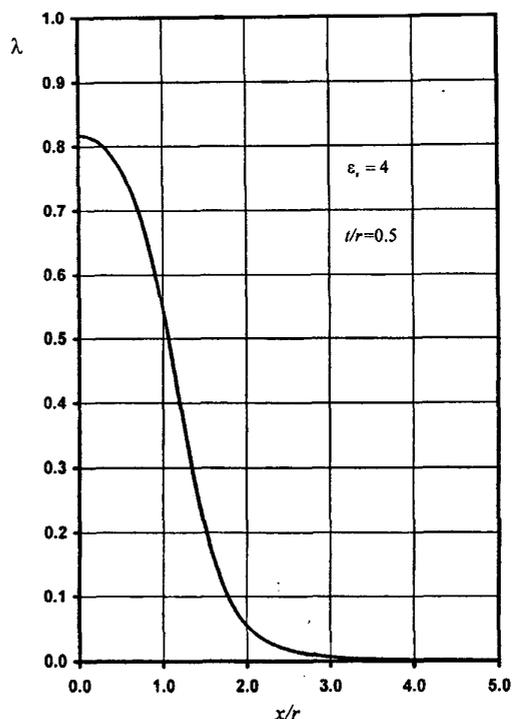

Figure 2: Variation of λ along the interface.

Surface charge distributions

Previous studies have considered the probe axis and the axis of a symmetrical surface charge to be concentric [3,7-11]. However if the probe is moved to another location, then these axes will be eccentric. Such situations may be represented as shown in Figure 3. The surface charge is represented by a circular disc of charge, of radius b. On this occasion, the charge density σ will be considered uniform, i.e. $\sigma = \sigma_0$. The extent of the charge distribution was altered by varying the value of b. The b values were selected such that the total charge per disc is in the ratio 1:2:5:10. This lead to $b/r = 2, 2\sqrt{2}, 2\sqrt{5}, 2\sqrt{10}$.

653

The significance of the eccentricity can be studied by examining the variations in the charge induced on the probe sensor plate. Owing to the lack of σ symme-try with respect to the probe, it is only meaningful to discuss the total induced charge q_T. A uniform charge density allows (1) to be expressed as

$$q_T(s) = -\sigma_0 \iint_S \lambda dA \qquad (4)$$

where s represents the probe offset, see Figure 3, while S is the surface charge area.

Traditionally, electrostatic probe measurements are interpreted as though the probe responds only to the charge directly subtended by the sensor plate, *i.e.* the value of charge Q assumed to be measured is given by

$$Q = \pi r^2 \sigma_0 \qquad (5)$$
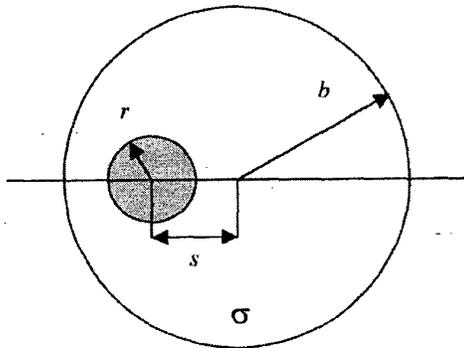
Figure 3: Probe/surface-charge geometry.

By using this charge value as a normalising factor, it is possible to examine the behaviour of the ratio $|q_T(0)|/Q$, *i.e.*

$$\frac{|q_T(0)|}{Q} = \frac{1}{\pi r^2} \iint_S \lambda dA \qquad (6)$$

This ratio represents a measure of the probe detection sensitivity. For $s = 0$, the charge and the probe axes are collinear, and thus $q_T(0)$ represents the maximum value of the charge induced on the probe by the disc of charge.

The variation of this ratio is shown in Figure 4. With respect to Q, $q_T(0)$ is seen to increase with b/r to some asymptotic value, which for the present probe is about $1.5Q$. This implies that, depending on the b/r value, the outer lying areas of charge $(b/r>1)$ can contribute more than 50% of the probe signal.
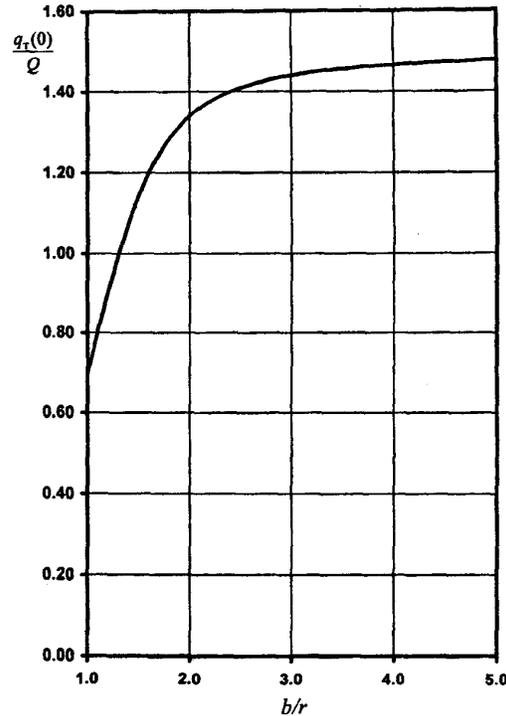

Figure 4: Variation of $q_T(0)/Q$.

The effects of charge eccentricity can be assessed by considering the variation of the ratio $q_T(s)/q_T(0)$. This is illustrated in Figure 5 for several values of b/r. As the degree of eccentricity (s/r) increases, the initial rate of decrease of the induced charge is controlled by the relative dimensions of the charged area. Thereafter the induced charge decreases rapidly as the probe tra-verses the edge of the charge region, *e.g.* for (b/r)-1 ≤ s/r ≤ (b/r)+1, the value of $q_T(s)/q_T(0)$ falls from about 0.85 to 0.1. This decrease is essentially indepen-dent of the relative disc size, *i. e.* b/r.

For $s/r ≥ (b/r)$+1, no charge is directly subtended by the probe sensor. However Figure 4 indicates the probe responds to the non-local areas of charge. This is

654

confirmed in Figure 5. However the existence of a probe signal is traditionally taken to imply the presence of charge directly above the sensor plate.

Such an interpretation will lead to the wrong conclusion with respect to the spatial extent of the surface charge. The degree of error associated with this aspect is presently under study.
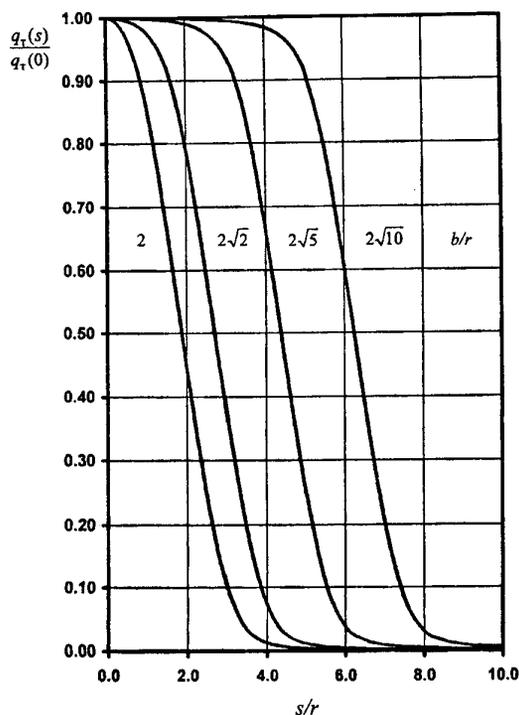

Figure 5: Variation of $q_T(s)/q_T(0)$.

Conclusions

The response of the probe to eccentric charge distributions is controlled by the spatial dimensions of the surface charge. Nevertheless the response to the transition region from charge to no-charge is essentially independent of these dimensions.

As the probe responds to non-local charge, this characteristic will invariably lead to errors in any assessment of the spatial extent of the surface charge.

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655