DTU Library

Influence of bulk dielectric polarization upon PD transients

Pedersen, Aage; Crichton - Fratrådt, George C; McAllister, Iain Wilson

Link back to DTU Orbit

Citation (APA):
Pedersen, A., Crichton, G. C., & McAllister, I. W. (1995). Influence of bulk dielectric polarization upon PD transients. In Proceedings of the Conference on Electrical Insulation and Dielectric Phenomena (pp. 323-326). IEEE. DOI: 10.1109/CEIDP.1995.483729

Influence of Bulk Dielectric Polarization upon PD Transients

A. Pedersen   G.C. Crichton and I.W. McAllister
Physics Department   Electric Power Engineering Department
The Technical University of Denmark
2800 Lyngby
DENMARK

Abstract

From a field-theoretical approach, it has been possible to develop a physically valid theory of partial discharge transients. The theory is based upon the concept of the charge induced upon the detecting electrode by the partial discharge. This induced charge is shown to be composed of a component associated with the actual space charge in the void, and one related to changes in the bulk polarization brought about by changes in the field external to the void due to this space charge. The magnitude of the induced charge and its components are discussed in relation to a heterogeneous bulk dielectric system.

Introduction

The charge induced by a partial discharge on the the detecting electrode can be evaluated using either the λ-function, or the ϕ-function [1,2]. These functions take account of the dielectric polarization either implicitly (λ) or explicitly (ϕ). Hence by using the two functions it becomes possible to identify the influence of the dielectric polarization upon the induced charge. This influence is associated with the change in polarization $\delta\vec{P}$ due to the change in the electric field $\delta\vec{E}$ arising from the partial discharge space charge.

In the present paper, the influence of the bulk dielectric geometry upon $\delta\vec{P}$ is examined for a two dielectric system.

It is shown that the component of the induced charge due to $\delta\vec{P}$ may increase or decrease depending upon the ratio of the dielectric permittivities and within which medium the void is located. This increase/decrease is of course reflected in the Poissonian induced charge q.

The Poissonian Induced Charge

The induced charge can be described in terms of a Poissonian and a Laplacian component [3]. The Poissonian induced charge is that component of the induced charge which is rigidly linked to the space charge source, and which together with this source gives rise to the Basic Poisson Field [2]. Mathematically, the final value of the Poissonian induced charge q, due to a partial discharge, can be resolved into two components:

$$q = q_\mu + q_P \qquad (1)$$

where q_μ is the induced charge directly associated with the space charge in the void, and q_P represents the induced charge related to the change in dielectric polarization ($\delta\vec{P}$) due to the presence of this space charge [2]. With reference to induced charge, the effect of the void wall charges can be considered as the effect of an electric dipole of moment $\vec{\mu}$ located within the void [1]. The Poissonian induced charge arising from a dipole is given by

$$q = -\vec{\mu}\cdot\vec{\nabla}\lambda \qquad (2)$$

where λ represents the proportionality

323

factor between the charge in the void and the induced charge on the detecting electrode. The λ-function is a solution of the general Laplace equation [2]

$$\vec{\nabla} \cdot (\varepsilon \vec{\nabla} \lambda) = 0 \qquad (3)$$

in which ε denotes permittivity. The boundary conditions are $\lambda = 1$ at the detecting electrode, and $\lambda = 0$ at the surfaces of all other electrodes. In addition, the following condition must be fulfilled at all dielectric interfaces such as the walls of voids

$$\varepsilon_+ (\partial \lambda / \partial n)_+ = \varepsilon_- (\partial \lambda / \partial n)_- \qquad (4)$$

where λ is differentiated in the direction normal to the interface, and the signs + and - refer to each side of the interface, respectively. Any method of solving Laplace's equation can be used to determine λ.

If, however, the dimensions of the void are such that $\vec{\nabla} \lambda$ may be assumed constant within the void, then we can introduce another function, λ_0, which, in the absence of the void, represents the unperturbed λ-function. As λ is a solution of Laplace's equation, then by mathematical analogy with electrostatic fields, the relationship between the λ and λ_0 functions is given by

$$\vec{\nabla} \lambda = h \vec{\nabla} \lambda_0 \qquad (5)$$

For the voids under consideration, the parameter h is a scalar which depends on the void geometry and the relative permittivity of the bulk medium. Following the introduction of λ_0, the Poissonian induced charge on the detecting electrode may be expressed as

$$q = -h \vec{\mu} \cdot \vec{\nabla} \lambda_0 \qquad (6)$$

The component of the Poissonian induced charge related to the void space charge alone may be obtained from

$$q_\mu = -\vec{\mu} \cdot \vec{\nabla} \phi \qquad (7)$$

where ϕ, another proportionality factor, is a solution of the reduced Laplace equation [2]

$$\nabla^2 \phi = 0 \qquad (8)$$

The boundary conditions are $\phi = 1$ at the detecting electrode, and $\phi = 0$ at the surfaces of all other electrodes. Hence, from (1), (6) and (7), the polarization component q_p of the Poissonian induced charge may be expressed as

$$q_p = -\vec{\mu} \cdot (h \vec{\nabla} \lambda_0 - \vec{\nabla} \phi) \qquad (9)$$

The λ_0 Function

For a homogeneous dielectric system, λ_0 is a solution of the reduced Laplace equation, and hence in such situations λ_0 and ϕ are synonomous. Consequently (9) would reduce to

$$q_p = -(h - 1) \vec{\mu} \cdot \vec{\nabla} \lambda_0 \qquad (10)$$

In practice, nearly all dielectric insulation systems are heterogeneous. However, for a very restricted class of dielectric geometries, e.g. a coaxial disc spacer, λ_0 is also a solution of the reduced Laplace equation, and thus λ_0 and ϕ are again synonomous. The behaviour of q_p in this case has been studied in [2].

To examine a situation in which λ_0 is a solution of the general Laplace equation, we consider a planar electrode geometry with a two layer dielectric. If in rectangular coordinates, the electrodes are represented by $z = 0$ and $z = d$, then the dielectric interface is taken as $z = s$, with $s < d$. The permittivity of the upper dielectric is ε_2 for which $s \leq z \leq d$, while that of the lower is ε_1, for which $0 \leq z \leq s$.

324

If the lower electrode is used as the detecting electrode, then the boundary conditions for the λ-function are $\lambda = 1$ for $z = 0$ and $\lambda = 0$ for $z = d$. Hence the λ functions of the two media are given by

$$\lambda_0 1 = \frac{\varepsilon_1(d - s) + \varepsilon_2(s - z)}{\varepsilon_1(d - s) + \varepsilon_2 s} \tag{11}$$

for $0 \le z \le s$, and

$$\lambda_0 2 = \frac{\varepsilon_1(d - z)}{\varepsilon_1(d - s) + \varepsilon_2 s} \tag{12}$$

for $s \le z \le d$, where the λ_0 subscripts, 1 & 2, refer to the lower and upper regions, respectively.

On differentiating with respect to z, we obtain the relevant expressions for the associated λ-gradients:

$$\vec{\nabla}\lambda_0 1 = \frac{-\varepsilon_2 \vec{e}}{\varepsilon_1(d - s) + \varepsilon_2 s} \tag{13}$$

and

$$\vec{\nabla}\lambda_0 2 = \frac{-\varepsilon_1 \vec{e}}{\varepsilon_1(d - s) + \varepsilon_2 s} \tag{14}$$

where $\vec{e}$ is a unit vector in the positive z direction.

For a homogeneous medium, $\lambda_0 = \phi$ and thus for a planar system we have

$$\vec{\nabla}\lambda_0 = \vec{\nabla}\phi = - \frac{\vec{e}}{d} \tag{15}$$

Both (13) and (14) reduce to this expression for $\varepsilon_1 = \varepsilon_2$.

Heterogeneous Dielectric System

To undertake a comparative assessment of the influence of the dielectric geometry upon PD transients we will assume that the dipole $\vec{\mu}$, associated with the charge which accumulates at the void wall following a partial discharge, is considered a constant in this study. Furthermore, it will be assumed that the void is more than 10 times its greatest linear dimension from the dielectric interface, such that the $\vec{\nabla}\lambda$ distribution within the void is effectively uniform: i.e. the existence of the interface does not perturb $\vec{\nabla}\lambda$ in the void. This assumption implies that the concept of h is valid and that (5) may be employed.

Variation of q_{Pn}

With respect to the component of the induced charge related to $\delta\vec{P}$, we have upon combining (9) and (6)

$$\frac{q_{Pn}}{q_n} = \frac{-\vec{\mu}\cdot(h_n\vec{\nabla}\lambda_0 n - \vec{\nabla}\phi)}{-\vec{\mu}\cdot h_n\vec{\nabla}\lambda_0 n} \tag{16}$$

where q_n is the Poissonian induced charge of the heterogeneous system, with $n = 1,2$ depending in which dielectric medium the void is located.

On account of the planar geometry, we may regard the dipole moment as being directed away from the coordinate origin. This moment can then be expressed as

$$\vec{\mu} = \mu\vec{e} \tag{17}$$

On performing the vector operations, (16) simplifies to give

$$\frac{q_{Pn}}{q_n} = 1 - \frac{d\phi/dz}{h_n d\lambda_0 n/dz} \tag{18}$$

Hence using (13), (14) and (15) we obtain for a void in medium 1

$$\frac{q_{P1}}{q_1} = 1 - \frac{\varepsilon_1(d - s) + \varepsilon_2 s}{\varepsilon_2 h_1 d} \tag{19}$$

and for medium 2

$$\frac{q_{P2}}{q_2} = 1 - \frac{\varepsilon_1(d - s) + \varepsilon_2 s}{\varepsilon_1 h_2 d} \tag{20}$$

325

As both (19) and (20) contain h, this implies that q_{Pn} is dependent upon the void geometry. In this study we will assume the void to be spherical, in which case we have

$$h = \frac{3\varepsilon_r}{1 + 2\varepsilon_r} \qquad (21)$$

where ε_r is the relative permittivity of the dielectric containing the void.

The variation of q_{Pn}/q_n with $\varepsilon_2/\varepsilon_1$ is shown in Fig.1 for $\varepsilon_r = 4$ and several values of s/d. From the figure it is seen that q_{Pn} is increased when the void is located in the medium of lower permittivity. Likewise a decrease occurs when located in the medium of higher permittivity. This reduction can be of such a degree that the polarity of q_{Pn} is reversed.

When the void is in the lower medium, the nearer the dielectric interface is to the detecting electrode, the greater are the relative changes in these induced charges. The opposite behaviour occurs when the void is in the upper medium; i.e., the further the interface is from the detecting electrode, the greater is the effect.

Owing to the simple geometry under discussion, the behaviour of q_{Pn} is symmetrical with respect to s/d and $(1 - s/d)$.

For a fixed void location q_μ is dependent only on $\vec{\mu}$, which we assumed constant. Hence variations in q_p will be directly reflected in the magnitude of the Poissonian induced charge q, see (1).

Conclusion

It is demonstrated that changes in dielectric polarization arising from a partial discharge can significantly affect the magnitude of the Poissonian induced charge. For a two dielectric system, this influence is dependent upon the ratio of the dielectric permittivities and within which medium the void is located. Hence the interpretation of partial discharge transients in terms of discharge phenomena within the void is even more complicated when heterogeneous systems are involved.

References

[1] A. Pedersen, G.C. Crichton and I.W. McAllister, "The Theory and Measurement of Partial Discharge Transients", IEEE Trans. Elect. Insul.,Vol.26, pp.487-497, 1991.

[2] A. Pedersen, G.C. Crichton and I.W. McAllister, "The Functional Relationship Between Partial Discharges and Induced Charge", submitted to IEEE Trans. Diel. & Elect. Insul., 1994.

[3] A. Pedersen, G.C. Crichton and I.W. McAllister, "Partial Discharge Detection: Theoretical and Practical Aspects", IEE Proc.- Sci. Meas. Technol., Vol.142 pp.29-36, 1995.
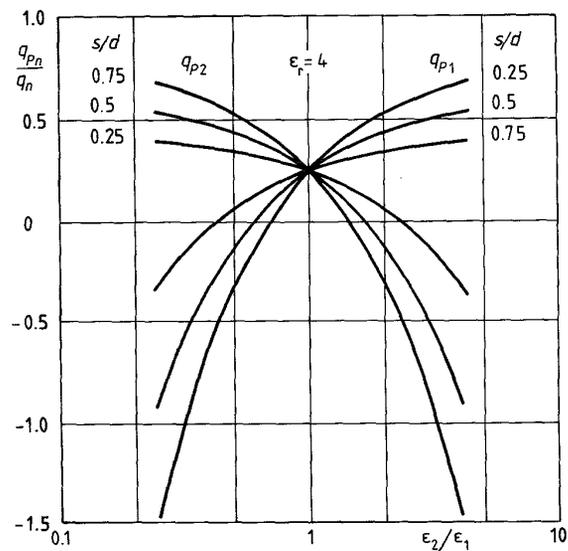
Fig.1 Variation of the polarization component of the Poissonian induced charge.

326