ELECTRIC FIELD IMPACT ON CAVITY DEFORMATION AND DYNAMICS IN MI INSULATION

Mikael **UNGE**, Sarath **KUMARA;** NKT HV Cables AB, Technology Consulting, Västerås, Sweden, mikael.unge@nkt.com, sarath.kumara@nkt.com

Adeep **SANTOSH**, NKT HV Cables AB, R&D, Karlskrona, Sweden, adeep.santosh@nkt.com

ABSTRACT

Partial discharges in mass impregnated insulation is connected to the dimension of gas cavities. Here impact of electrical forces on the deformation of cavities is investigated by simulations using Maxwell stress tensor and two phase modelling of gas oil mixture. It is shown that initially cavities are stretched in the field direction but after some time they are compressed to oblate shape. The oblate shape can be understood from polarization of charges at the cavity surface and the resulting coulomb force. It is illustrated that inhomogeneous field can give a net force and movement of the cavities.

KEYWORDS

Gas cavities, Electrical forces, MI Cables

INTRODUCTION

The insulation system in Mass Impregnated (MI) cables is built up of cellulose based papers and impregnated with a high viscosity insulating oil. The insulation thickness is built up by helically winding paper strips on the conductor, a gap is kept between adjacent paper strips forming so called butt gaps in between the paper strips. During the impregnation the butt gaps will be oil filled which may contain gas cavities. When the conductor temperature increases due to load current the temperature in the insulation increases, this in turn increases the pressure and impacts the gas solubility of the oil. Partial discharges (PDs) that may occur in gas cavities can impact ageing and are potential starting point for electrical breakdown. In literature PDs are primarily studied for AC cases but also under DC for example during load cycling [1].

The electrical forces that impact the cavity can be described by Maxwells stress tensor in combination with Navier-Stoke equations which describes the motion of the fluid. To be able to simulate changes in the cavity form a phase-field method based on Cahn-Hilliard equation can be applied [2, 3].

In this study, we simulate the shape of gas cavities in high viscosity insulating oil and how it dynamically depends on the applied voltage. Oil properties used are typical values for impregnation oil in MI cables. Small model geometries as well as full radial representation of a MI cable are used.

METHOD

Single Cavity

A simple geometry relevant to MI Cables are used for the initial calculation. Fig. 1 show an illustration of the 2D geometry. A gas cavity, which initially is circular, with a radius *r* is placed in an oil volume (grey), two papers are included (orange) and periodic boundary conditions are applied in 7the x direction. Electrically the bottom paper is grounded and high voltage is applied on the top paper. Laplace equation is then solved for this geometry. Material properties used are listed in Table 1. Due to the difference in dielectric properties of the gas and the oil there will be electrical forces acting upon the cavity. The electrical forces are calculated from

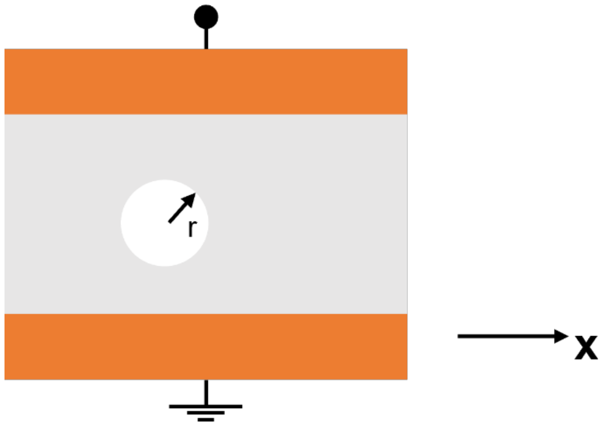

Fig. 1 Illustration of gas cavity embedded in oil (grey) and surrounding paper (orange). Periodic boundary conditions are applied in the x-direction.

$$\boldsymbol{F}_{\mathrm{el}} = \boldsymbol{\nabla} \cdot \boldsymbol{T} \qquad [1]$$

where $\boldsymbol{T}$ is the Maxwells stress tensor which is

$$\boldsymbol{T} = \varepsilon_0 \varepsilon_r \boldsymbol{E}\boldsymbol{E}^T - \frac{\varepsilon_0 \varepsilon_r}{2}(\boldsymbol{E} \cdot \boldsymbol{E})\boldsymbol{I}. \qquad [2]$$

where $\boldsymbol{E}$ is the electric field and $\boldsymbol{I}$ is the unit matrix. Thus, from equation [1] and [2] it is seen that the electrical forces are small in a homogenous electric field but can be large at interfaces between dielectric materials if the dielectric constant differ between the materials. The resulting electrical forces can be taken into account when solving the fluid dynamics problem. In this study we have considered Stoke flow, i.e. excluding the inertia term in Navier Stokes equation. Thus, the following equation is used

$$\rho \frac{\partial \boldsymbol{u}}{\partial t} = \boldsymbol{\nabla} \cdot [-p\boldsymbol{I} + \mu(\boldsymbol{\nabla}\mathbf{u} + (\boldsymbol{\nabla}\mathbf{u})^{\mathrm{T}})] + \boldsymbol{F} \qquad [3]$$

$$\boldsymbol{\nabla} \cdot \boldsymbol{u} = 0 \qquad [4]$$

where ρ is the density, $\boldsymbol{u}$ the velocity, p the pressure and μ the viscosity. The volume forces are summed in the term $\boldsymbol{F}$. The gravity is not taken into account so the volume force in our case is only the electrical forces.

Here we also would like to address the impact of the electrical forces on the cavity and how the forces may change the shape. For this a two phase model is used which is based on Cahn-Hilliard equation [4]. A function ϕ is introduced that separate the phases. In this study the gas