FLOATING POTENTIAL BOUNDARY CONDITION IN OPENFOAM

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In power transmission and distribution systems, high voltage bushings (Figure 1) are essential components to insulate conductors that carry high voltage current through a grounded enclosure [1]. A condenser bushing (Figure 2) is constructed by arranging metallic conductive layers within the insulating material with the purpose to control the distribution of the electric field by capacitive grading.

Figure 1: 600 kV HVDC transformer bushings.

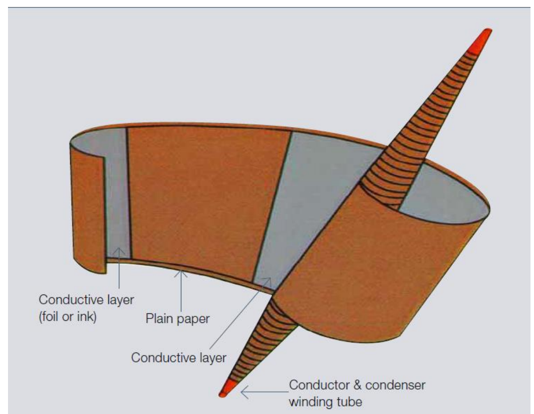

Figure 2: Condenser bushing construction principle.

As for all high voltage components, the reliability of a bushing is of extreme importance. The degradation of insulation material is a slow process which depends both on temperature and electric field strength. A proper description thus requires a multiphysics approach that includes the numerically challenging natural convection cooling. By using OpenFOAM, the powerful CFD solver can be combined with an electrostatic solver, allowing the problem to be solved on the same mesh within the same numerical framework. The missing functionality in OpenFOAM is a boundary condition for the electrostatic solver that can apply a floating potential on the metallic conductors of the bushing condenser core, which the present work aims to address.

The proposed implementation is an iterative method. Assuming at step n a known electric potential Φ_k^n for each conductor i, the charge can be evaluated using Gauss' law

$$Q_i^n = \oint \varepsilon \boldsymbol{E}^n \cdot \mathrm{d}\boldsymbol{S}_i = \oint \boldsymbol{D}^n \cdot \mathrm{d}\boldsymbol{S}_i \qquad (1)$$

and by comparison to the actual charge Q_i a new value Φ_i^{n+1} can be assigned. In the general case there will be a strong cross coupling between the floating potentials as they screen each other which may lead to instabilities and poor convergence if each conductor is considered separately. Instead it is preferable to compute the capacitance matrix C of the system [2] and calculate

$$\Phi^{n+1} = \Phi^n + C^{-1}(Q^n - Q^{n+1}) \qquad (1)$$

A boundary condition type for OpenFOAM has been implemented derived from the fixed value boundary condition, including a class that handles calculation of capacitances and adjustment of the floating potential values. The capacitance matrix is decomposed using LU factorization from the GNU scientific library.

The accuracy and grid sensitivity of the method is demonstrated by solving a problem of concentric spheres (Figure 3) where the analytical solution is available. A test geometry (Figure 4) pertinent to the case of a condenser bushing is also investigated.

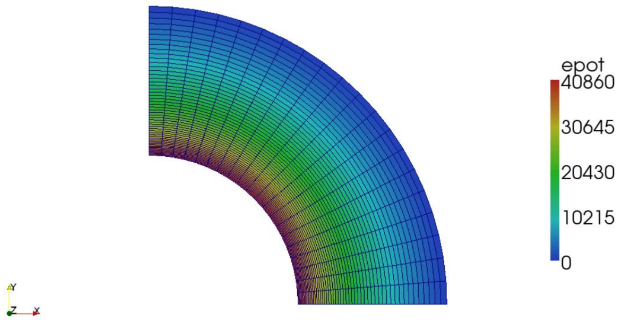

Figure 3: Floating potential between concentric spheres

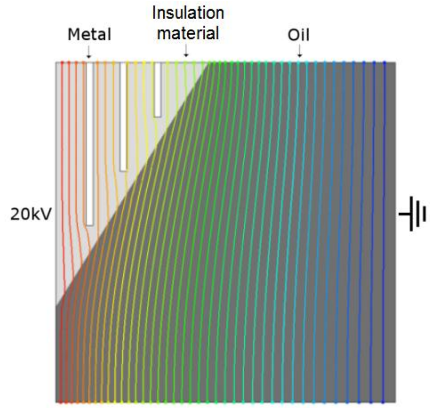

Figure 4: Test problem

References

[1] Lars Jonsson, Rutger Johansson, High-voltage bushings – 100 years of technical advancement in ABB Review 03/2009, ABB Ltd

[2] John David Jackson, "Classical Electrodynamics, Third Edition", Wiley, 1999