Adaptive numerical simulation of Streamer

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Schneider Electric

Tools: BDV from Drift diffusion calculation

Motivation:

- Streamer criteria works very well in moderately uniform field. But in highly non uniform field, like needle-plane electrode configuration (similar to sharp edges of nut-bolts or sharp edges of sheet metal inside switchgear tank),a new tool is needed
- Virtual experiments
- To understand the effect of space charges on the breakdown of medium.
- Introduction of solid dielectrics (barriers/coatings) in the hybrid insulation scheme needs the surface charge distribution to predict BDV
- The thermal effects dominates for very large distances, which can be incorporated in drift diffusion method.

Tools: BDV from Drift diffusion calculation

- The movement of electrical charges are approximated by convective-diffusive fluid flow model

  Application of the set of continuity equation as shown below to electrons, positive Ions, negative Ions:

$$\frac{\partial n_e}{\partial t} + \nabla \cdot (n_e \mathbf{w}_e - D_e \nabla n_e) = \alpha n_e |\mathbf{w}_e| - \eta n_e |\mathbf{w}_e| - \beta_{ep} n_e n_p + \nu_{\text{det}} n_n + R_0$$

$$\frac{\partial n_p}{\partial t} + \nabla \cdot (n_p \mathbf{w}_p - D_p \nabla n_p) = \alpha n_e |\mathbf{w}_e| - \beta_{ep} n_e n_p - \beta_{pn} n_p n_n + R_0$$

$$\frac{\partial n_n}{\partial t} + \nabla \cdot (n_n \mathbf{w}_n - D_n \nabla n_n) = \eta n_e |\mathbf{w}_e| - \beta_{pn} n_p n_n - \nu_{\text{det}} n_n$$

- Effect of electrical charges on the field distribution is estimated by Poisson equation

$$\nabla \cdot (\varepsilon_0 \varepsilon \nabla \phi) = -\rho = -q(n_p - n_e - n_n), \quad \mathbf{E} = -\nabla \phi$$

Tools: BDV from Drift diffusion calculation

- The photo ionization plays a critical role in the propagation of electric field by streamer

  The integral photo-ionization source term is converted to three separate helmholtz equation with coefficients determined by the gas properties and electron density

$$\nabla^2 a_1 u1 + b_1 u1 = c_1$$
$$\nabla^2 a_2 u2 + b_2 u2 = c_2$$
$$\nabla^2 a_3 u3 + b_3 u3 = c_3$$

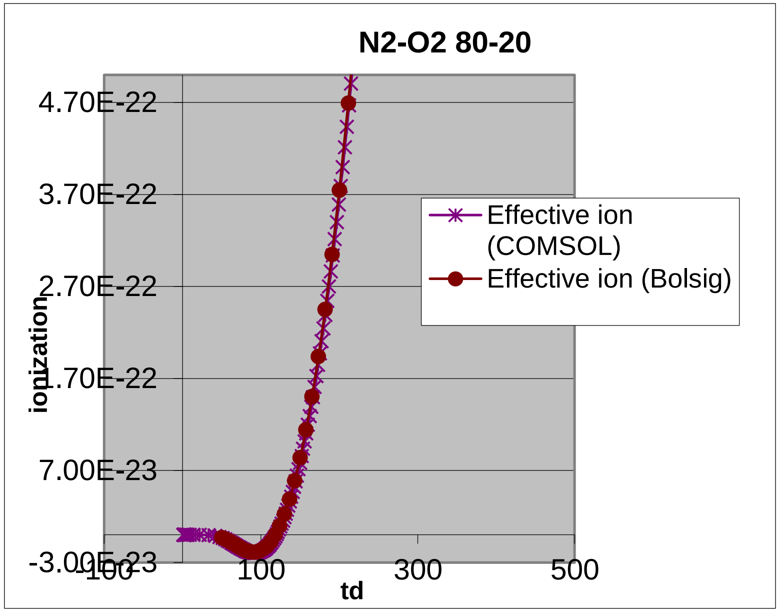
- The photo-ionization source is defined as

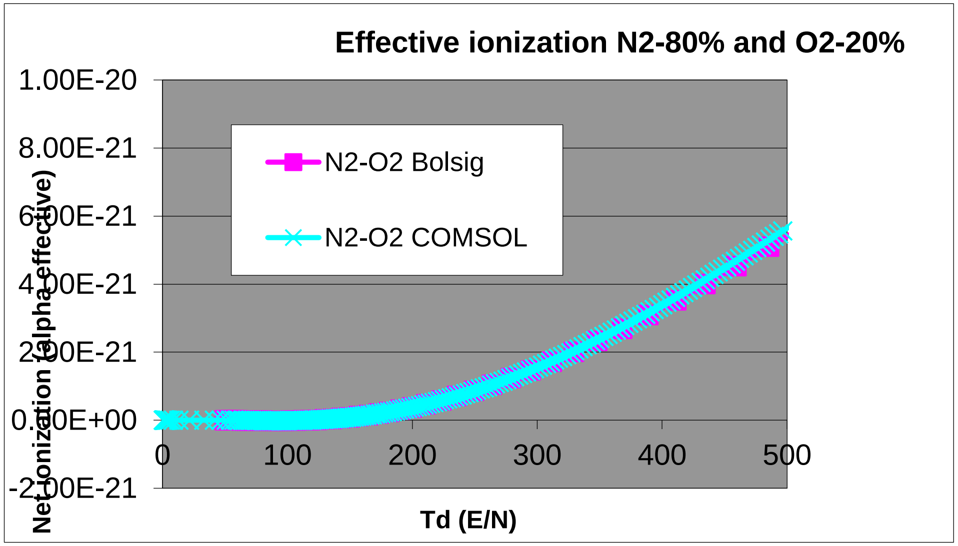
→ S=u1+u2+u3

Tools: Swarm parameters calculation

Calculation method to estimate effective ionization from electron cross section data for natural and synthetic gas

- The Boltzmann two term approximation was implemented in FE to calculate the ionization etc. to be used by both streamer criteria and drift diffusion method

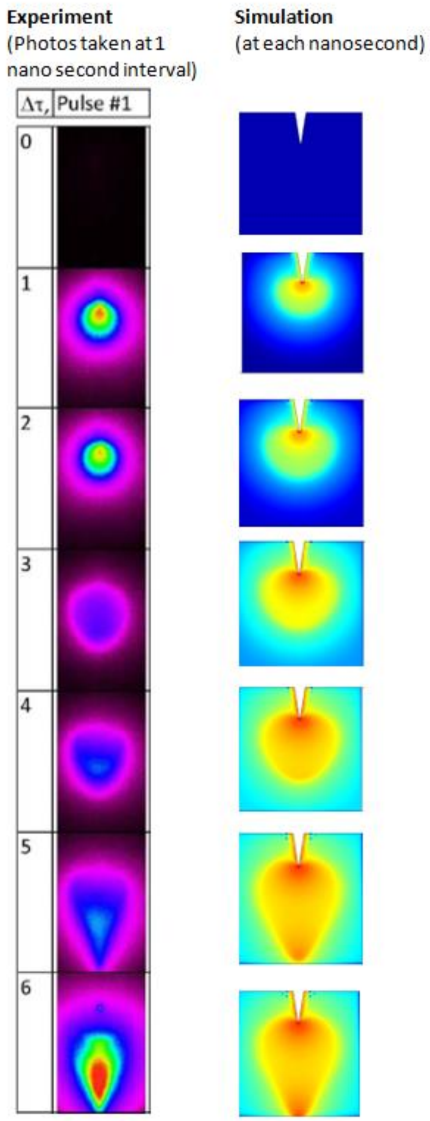




Alpha-ionization

Net alpha-ionization

Comparison of drift diffusion simulation with experiment (1mm electrode tip,separation 15 mm)



•Custom PDEs and transport solver

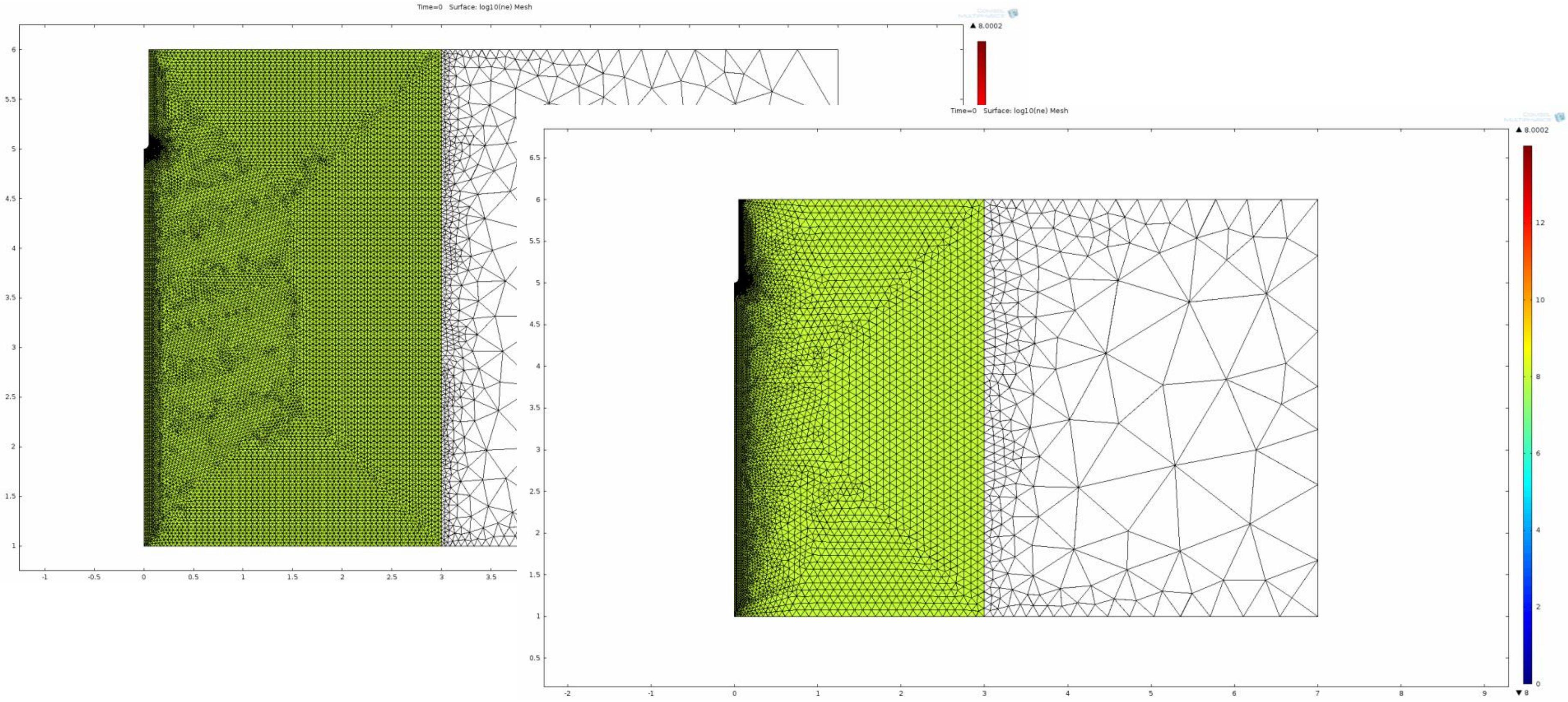
Steps

- Ionization of Gas at High Voltage
- Movement of Electrons and Ions
- Breakdown

Reduction in calculation time for practical solution

- Use of adaptive algorithm to reduce the calculation time

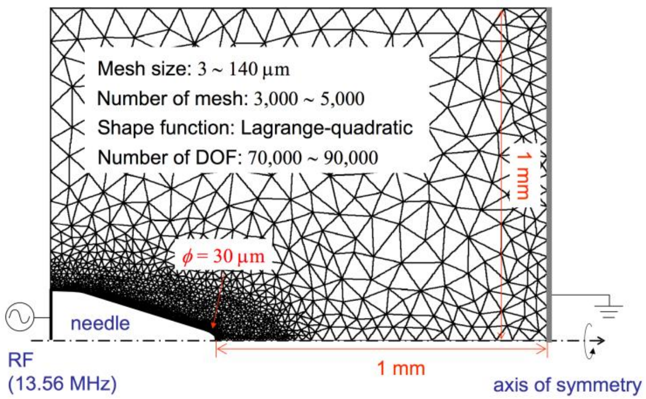
Coarse Mesh with AMR

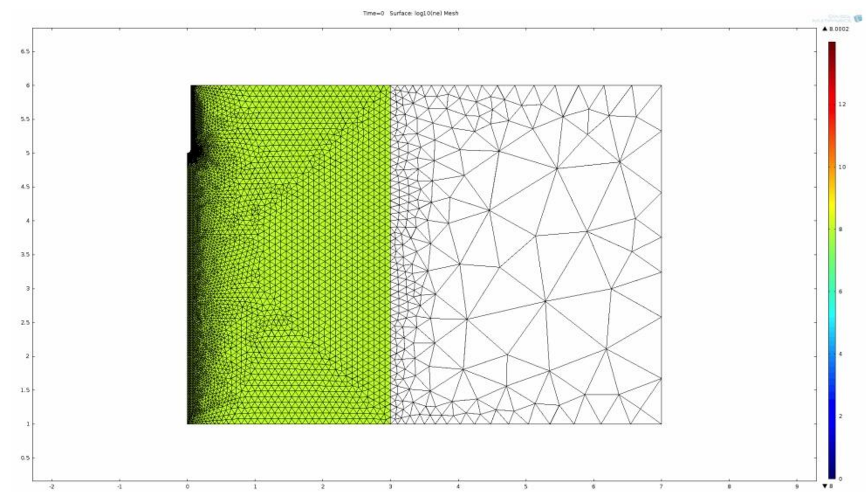


Tools: Drift –Diffusion comparison with tests

Efficiency comparison with existing models

- The existing models use 5000 elements for 1 mm separation, but with the use of mesh refinement algorithm @5000 elements are used for a distance of 40 mm





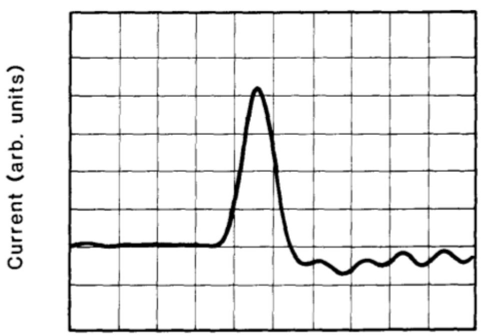
5000 elements in 1 mm

5000 elements in 40 mm

Tools: Drift –Diffusion comparison with tests

The validation of drift diffusion approach has been done with BDV tests performed in highly inhomogeneous field

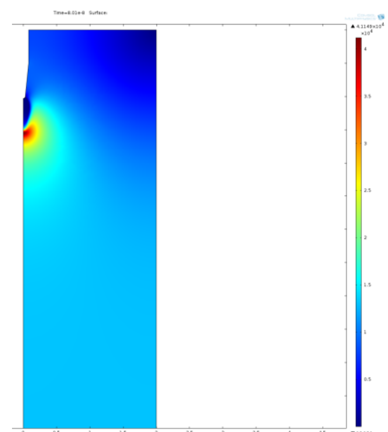
- The breakdown in simulation is predicted by the propagation of streamer to the ground electrode.Current in the external circuit is also calculated
- Comparison of Corona onset with experiments, since air data(in ns range) was not available so qualitative comparison was made with SF6

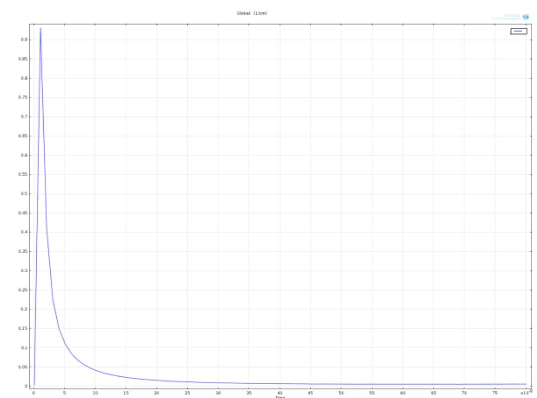


Time (1 ns per division)

Figure 8.

Experimental measurement of a corona onset pulse in SF_6 by Boggs [2] (reproduced with permission).





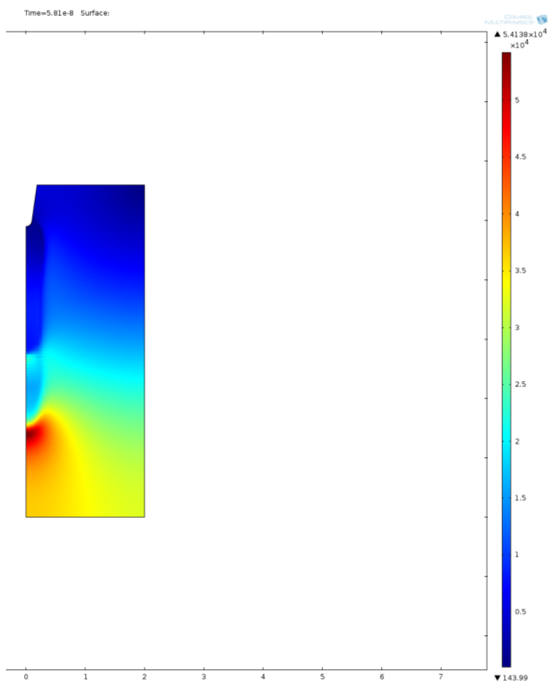
Test:50 kV applied to 5mm sphere, gap distance 65 mm in SF6

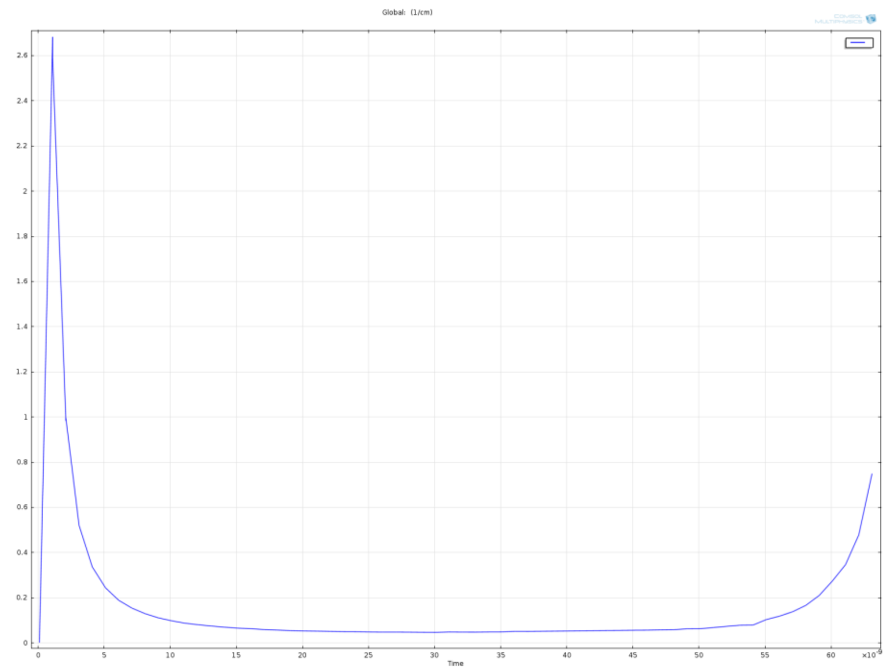
Simulation:300 microns 50 mm separation

Tools: Drift –Diffusion comparison with tests

Current in the external circuit

The rise in current density (sum of capacitive and convective component) can be seen when streamer is approaching the ground electrode





Tools: Drift –Diffusion comparison with tests

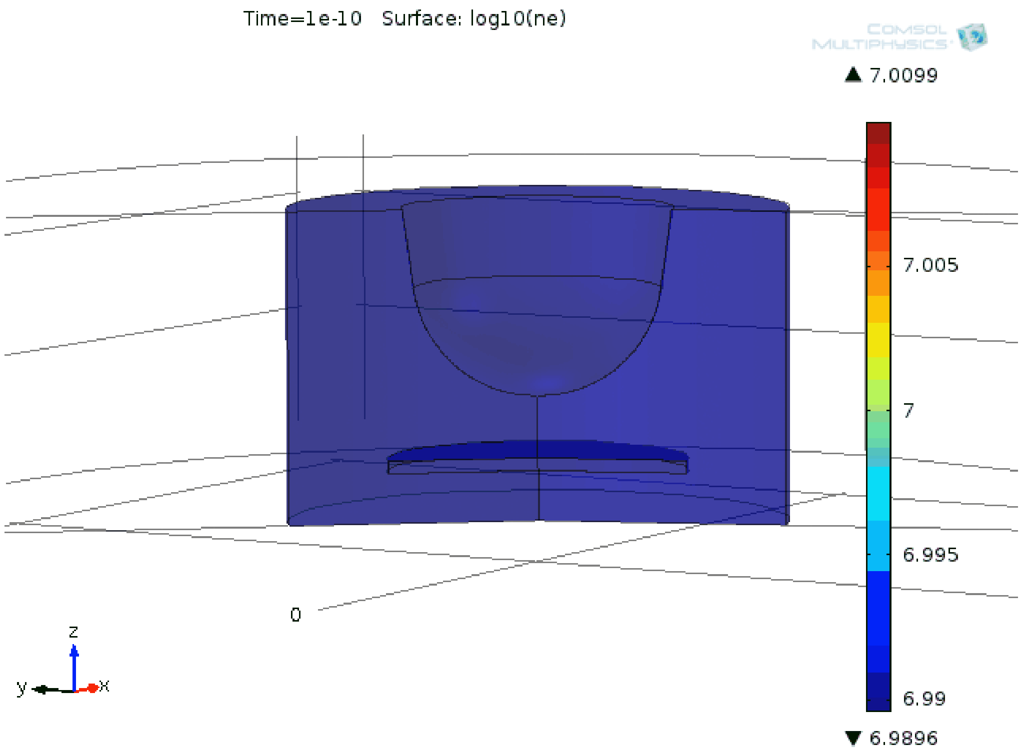
Breakdown prediction for highly inhomogeneous field

- The 1mm electrode tip geometry was modelled in drift diffusion simulation tool.
- The voltage is applied in the increment of 10 kV
- The breakdown voltage is calculated as average of largest step voltage at which streamer has stabilized and the lowest step voltage at which streamer propagates to the ground electrode

	BDV from tests (kV)	BDV from simulation (kV)
1mm tip,40mm separation	39.8	40 kV
1mm tip,50mm separation	52(questionable result)	45 kV
1mm tip,60mm separation	46.4	50 kV

Tools: Implementation of drift diffusion for barriers

- Basic investigation done for floating dielectric barrier at small distances 1mm separation 1mm electrode tip 4kV applied Voltage



Electrons during a discharge

- The charge deposition on both sides of the barrier was calculated,which act as input for streamer criteria

Conclusions

- Transport phenomena of charges can be solved efficiently with mathematical simplification
- The simulation results are encouraging when compared to experiments
- Implementation of floating barriers is in progress
- Other physics can be implemented to expand the regime of electric discharge simulation

Thank You