Realistic 3D Particle Modelling of Discharge Inception near Ice Particles and other Dielectric Objects

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Prior to streamer formation, when the numbers of charged particles in the relevant region are still relatively low, a fluid discharge model is not appropriate. We have developed a particle model to study the initial phase, specifically the stochastic nature of positive streamer inception near dielectrics and other surfaces. The model is motivated by lightning initiation near ice particles in thunderclouds, but can be applied more generally to jitter in discharge inception. The model is designed such as to easily continue with 3D streamer simulations in the Afivo framework. This enables the first 3D streamer simulations that start with realistic initial distributions of electrons and ions.

1. Problem setting

In thunderstorms, streamers (as precursors for lightning leaders) can be initiated from hydrometeors (droplets, graupel, ice needles, etc.). These hydrometeors locally enhance the thundercloud electric field to values above electric breakdown; the initial electrons in the humid air of the cloud may be provided by extensive air showers [1]. Typically, streamers are modelled with a deterministic fluid model (i.e. drift-diffusion-reaction coupled with Poisson), which is now possible in full 3D with the Afivo framework [2].

However, under typical subcritical conditions electrons will only multiply in regions of local field enhancement to values above breakdown that can occur near a dielectric object. For typical hydrometeors this region is at most of the order of a cubic millimetre. Hence only individual electron avalanches – with their intrinsically random nature – are entering the breakdown area sequentially. On these scales, a deterministic fluid description is not valid**.** Therefore, we have developed a stochastic particle model to study the behaviour of the system described above, to calculate the probability of streamer inception for a given hydrometeor, electric field and initial electron density.

2. The DIPIC3D code

The DIPIC3D (Discharge Inception Particle in Cell 3D) code is a further development of the code used in [3] and assumes that initially space charge is not important, enabling fast parallel computation of the particle dynamics in the electric field. The initial electric field can be loaded from third party software packages like COMSOL®. In addition, the code can project particles into cells of the octree grids in the Afivo framework [2], which includes adaptive mesh refinement (AMR), a geometric multigrid solver, shared-memory (OpenMP) parallelism and it supports output in Silo and VTK file formats. In this manner, space charge effects can be included in the later stage of the discharge evolution, but currently still excluding polarization, which is fair for ice where the dielectric constant for fields changing on the nanosecond scale is relativity low (~3 compared to ~90 for stationary fields).

3. Results

First results show that the discharge starts with great jitter and usually off the symmetry axis, demanding a stochastic approach in full 3D for streamer inception in realistic thunderstorm conditions. We will present the latest developments of the DIPIC3D code and discuss our simulation results. After publication, the software will be made available as open source.

4. Acknowledgments

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5. References

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