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Easy Evaluation of Streamer Discharge Criteria

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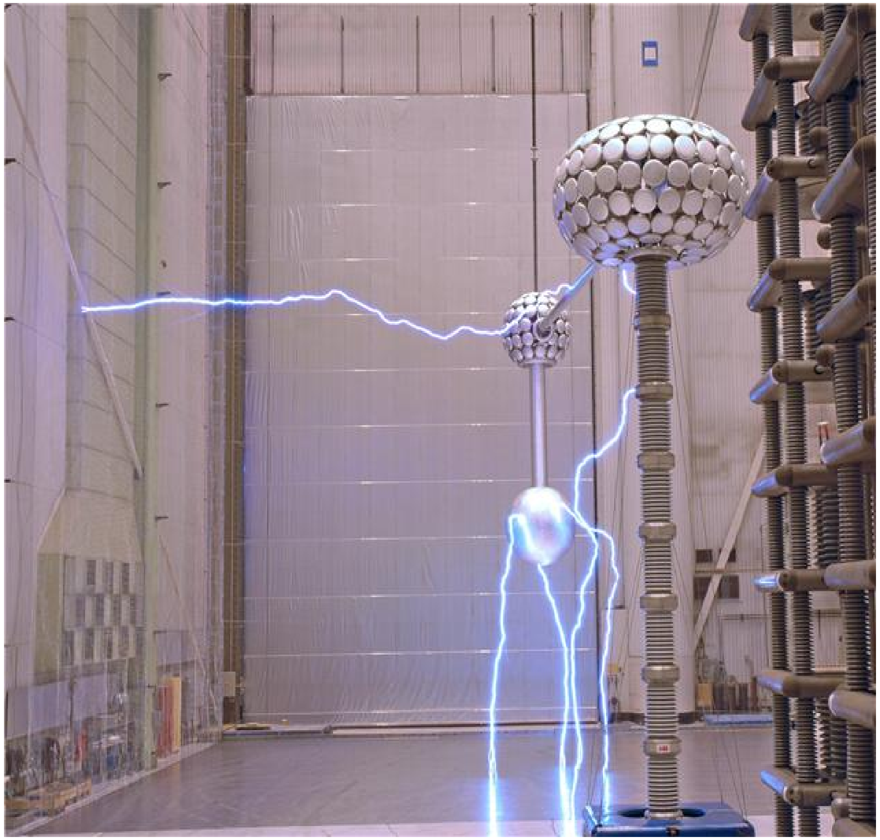
Flashovers and Breakdown in Power Equipment



Long discharges created with a high voltage test equipment

- Two important trends in power transmission technology are

  (i) Increasing voltage levels

  (ii) Compacting

- This implies inevitably an increasing risk for dielectric breakdown and flashovers
- Detailed *E*-field simulations are needed to avoid discharges and flashovers; simple rules of thumb are not sufficient

Discharge Theory

- An important quantity is the effective ionization $\alpha_{eff}(E)$, i.e. the net ionization rate in the gas (ionization rate minus the recombination and attachment rates)
- For a short gap with a homogeneous electric field breakdown occurs if $\alpha_{eff}(E) > 0$
- For air the critical field strength is E = 2.6 kV/mm
- In a longer gap with inhomogeneous field the criterion for localized streamer discharge to occur near an electrode is that the integral of $\alpha_{eff}(E)$ along a field line should be larger than $C_{crit} \approx$ 15-20

$$S = \int \alpha_{\text{eff}}(E)\,dl \; > C_{crit}$$

- Even if $\alpha_{eff}(E) < 0$ on parts of the field line, a streamer can propagate and bridge the gap provided the average field satisfies

$$\langle E \rangle = U / L > U_0 / L + E_0$$

where U is the voltage, L the length of field line, U_0 and E_0 are constants

Effective Ionization for Air

- The effective ionization function $\alpha_{eff}(E)$ is different for different gases
- For air it can be approximated by

  $$\alpha_{\mathrm{eff}}(E) = p\left[k\left(\frac{E}{p} - \Lambda\right)^2 - A\right]$$

  where E is given in kV/mm, the pressure p in bar, k equals 1.6 mm bar /kV^2, Λ equals 2.2 kV/(mm bar), and A is 0.3 1/(mm bar)
- Note that $\alpha_{eff}(E) > 0$ for $E/p > 2.6$ kV/mm

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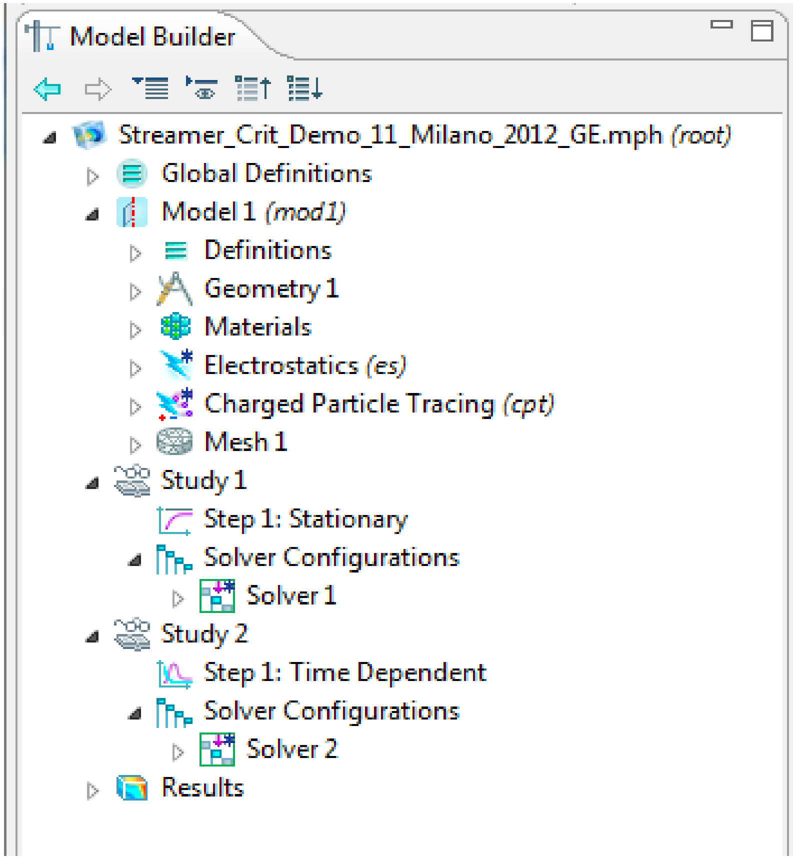
Solution Procedure

- We need to calculate the field line integrals S and $L = \int dl$
- To do this we:

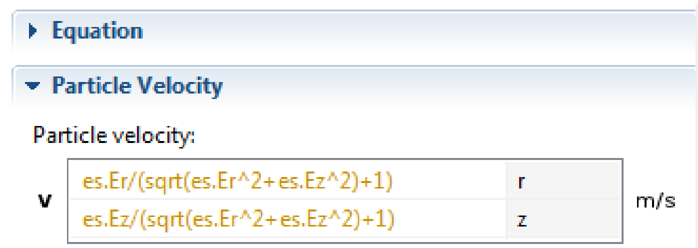
  1. Solve for the electric field using the *Electrostatics* interface

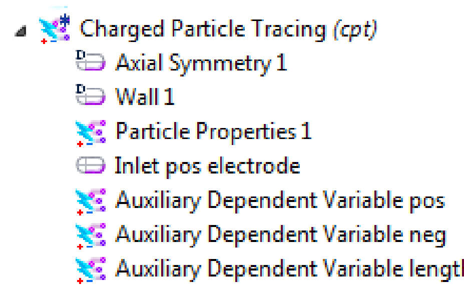
  2. Employ the *Particle Tracing* module to perform the field line integrals



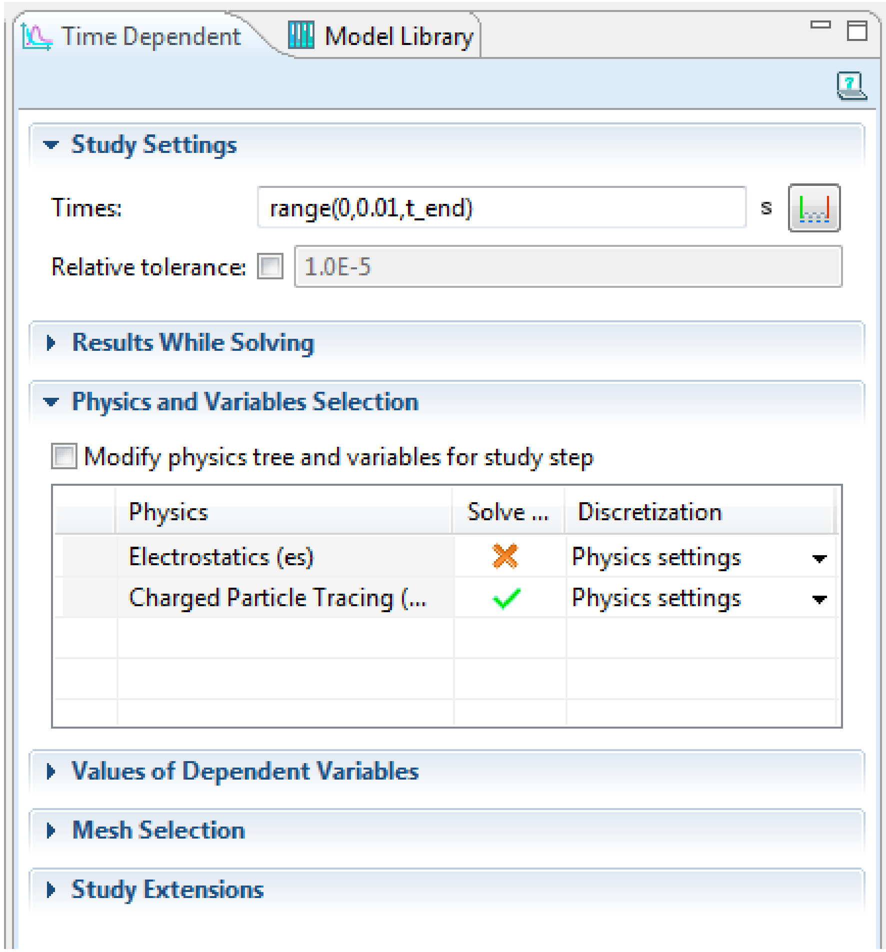
Particle Tracing

- The field lines are traced by assuming *Massless Particles* moving with a velocity parallel to **E**
- Field line integrals are computed as *Auxiliary Dependent Variables*
- A large number of field lines can then be analyzed by injecting ”particles” distributed over one of the electrodes



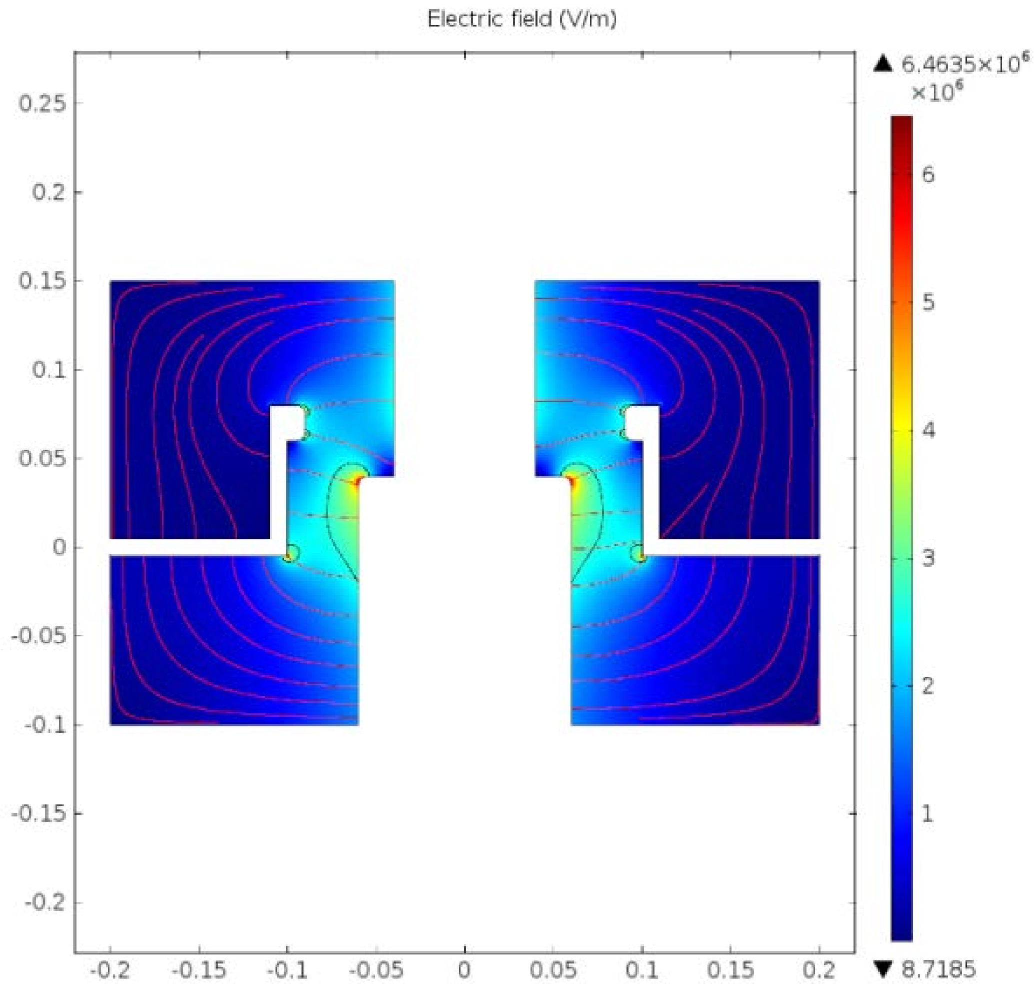


Running the Simulation



- The procedure is executed by first running the electrostatic field solver and then the time dependent particle tracing for a sufficiently long time for all ”particles” to reach the opposite electrode

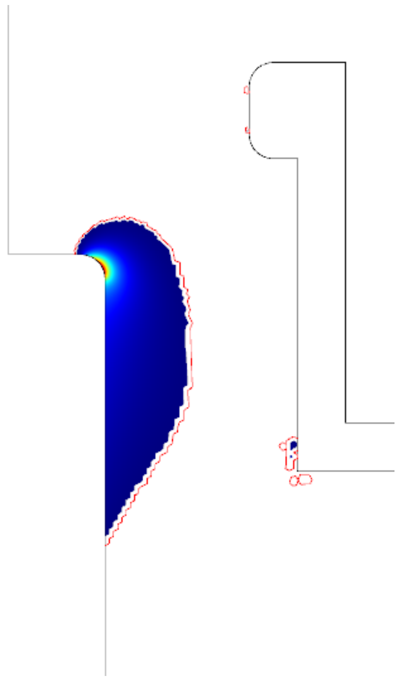
2D Axisymmetric Example



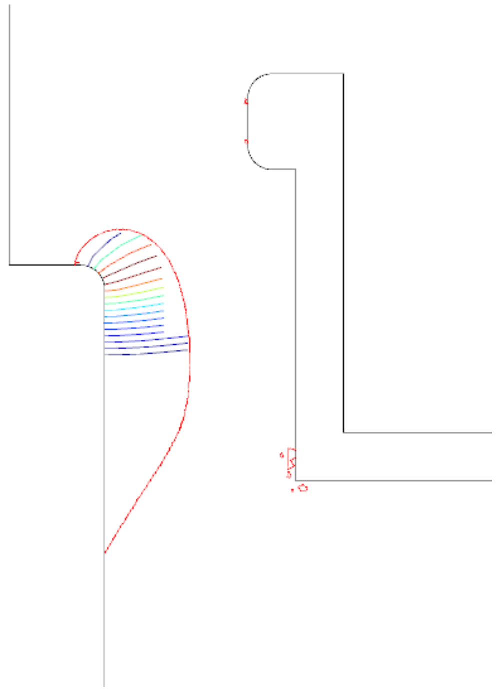
- A cylindrical central conductor at high voltage penetrating a flanged opening in a grounded wall

2D Axisymmetric Example

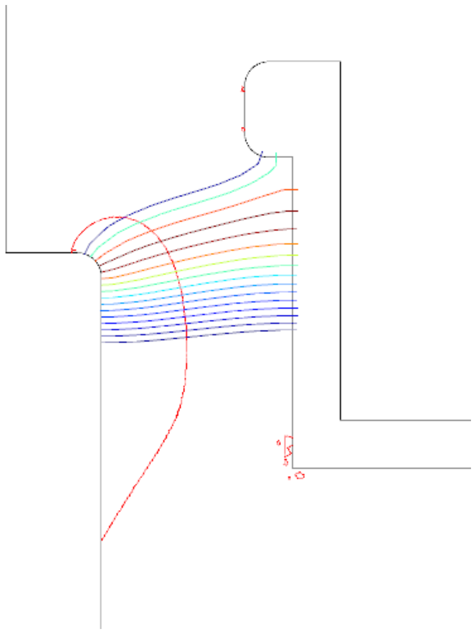
- Discharges starting from the inner high voltage electrode



Region with positive net ionization



Field lines satisfying the inception condition $S > C_{crit}$



Field lines satisfying the propagation condition

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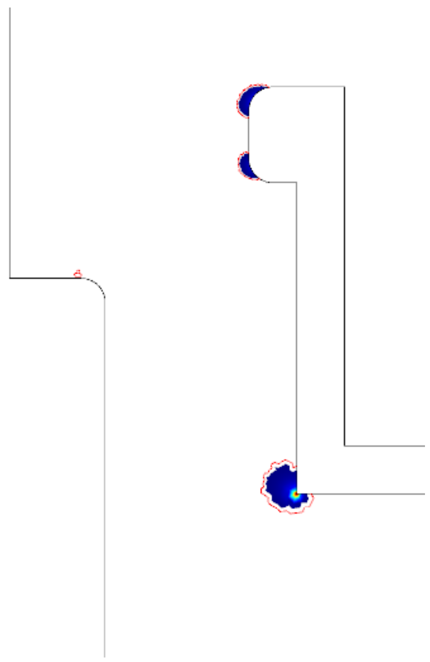
2D Axisymmetric Example

- Discharges starting from the grounded wall



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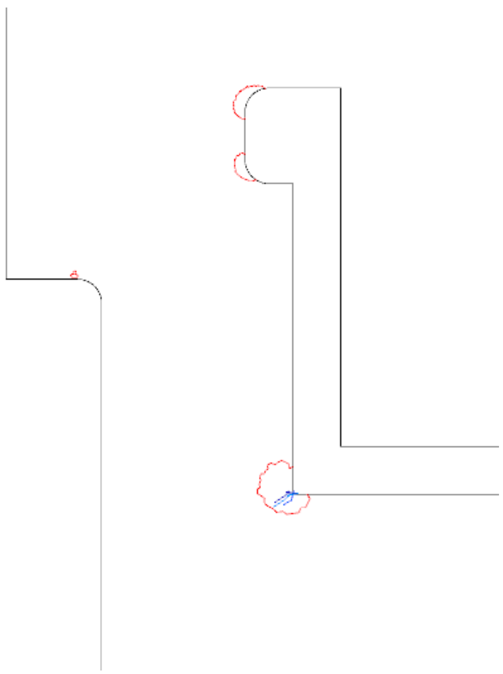

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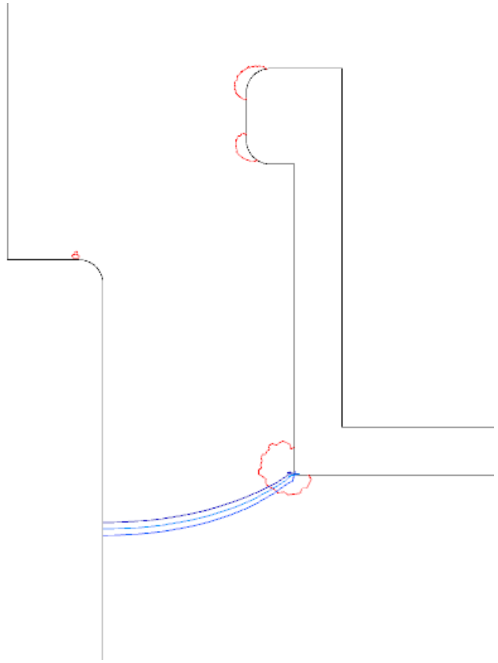

Field lines satisfying the propagation condition

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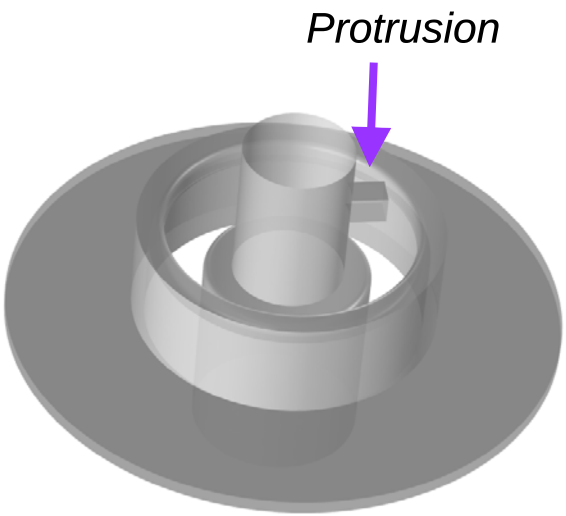
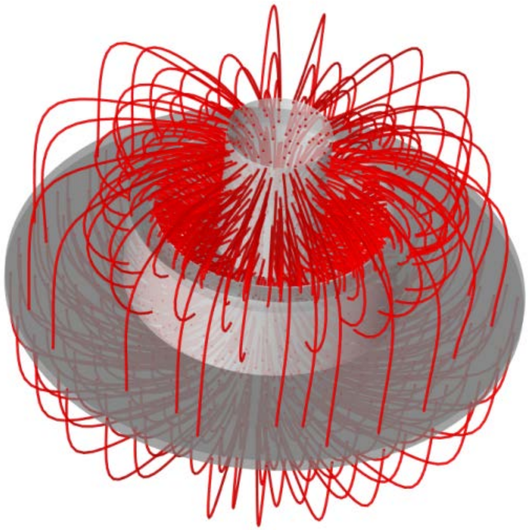
3D Example

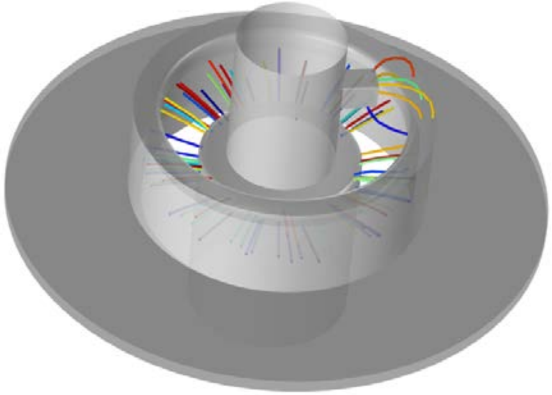
- Same as the 2D case but with an added protrusion on the inner conductor



3D geometry



1000 field lines being analyzed



Field lines satisfying the propagation condition from the inner conductor

Conclusions

- The new Particle Tracing Module enables an easily implemented way of calculating integrals along field lines and hence the evaluation of discharge criteria
- The method works in both 2D and 3D
- Thousands of field lines can be analyzed simultaneously with reasonable computational effort

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