Fast Calculation Tool for Breakdown Voltage in a setup with a Dielectric Surface

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1 Introduction

At a setup's breakdown voltage (BDV), a transient non-stationary discharge will develop, where a high current flows between the electrodes. It is of considerable interest to be able to estimate, in a simple, fast and reliable way, the minimum voltage that causes breakdown for any given setup. It is a common engineering practice to evaluate the BDV resorting to the Townsend criterion, which only requires the specification of the ionization coefficient, the cathode emission coefficient and evaluating path integrals in the electrostatic field distribution. This criterion actually gives the self-sustainment voltage (SSV) of the discharge, i.e. the minimum voltage at which particle gain and loss mechanisms are balanced. Though in some cases this criterion can be extended[1] it isn't generally applicable, namely when diffusion, or photoimission are important. Furthermore, in setups which are more complicated than plane to plane the general relation between SSV and BDV is unknown.

In this work we present a quite accurate and fast tool to calculate the BDV of a generic setup based on the resonance method[2]. The tool is applied to a setup consisting of a dielectric disc spacer of 4 mm height close-stacked between two disc electrodes of 7.5 mm radius in air at 1 atm.

2 The Tool

The tool is described in detail in previous work [2]. It is based on a drift-diffusion description of the gas employing numerical modeling of transport and conservation of one positive species, electrons and three negative ions. The Poisson equation and equations for photoionization source terms are also solved. The tool employs only stationary calculations and follows a 5-step flowchart for the determination of the setup's SSV/BDV, 6-step in the case a dielectric is present.

3 Results and Discussion

In the studied setup, shown in the figure, the electric field distribution has a weak non-uniformity at ignition. Calculation of the BDV starting from a given initial state and using the drift-diffusion equations for its time-evolution, will be called the standard tool. Results for the BDV calculated using the new and the standard tool are given in the following table for three dielectric radii, two permittivities and two boundary/initial conditions. An experimental value of 10kV[3], confirms the calculated values for the case R=3mm. Calculations with the standard tool were actually 'informed' by the new tool's results regarding the tried initial voltages and the initial surface charge distribution (case j_n=0).

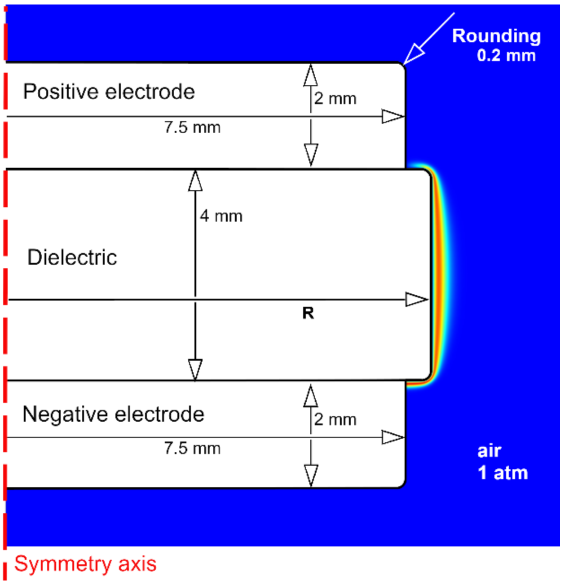

Figure: Schematic of setup. Calculations were performed for R=3mm, R=7.5mm and R=8.2mm.

<table>
<tr><td colspan="2"></td><td colspan="2">Tool's stationary calculations</td><td colspan="2">Standard non-stationary calculations</td></tr>
<tr><td rowspan="2">R (mm)</td><td rowspan="2">ε_D</td><td colspan="2">Self-Sustainment Voltage, Diel. BC</td><td colspan="2">Breakdown Voltage, initial σ_s from</td></tr>
<tr><td>σ_s=0</td><td>j_n=0</td><td>σ_s=0</td><td>j_n=0</td></tr>
<tr><td>3</td><td>1</td><td rowspan="2">9.9kV</td><td rowspan="2">9.9kV</td><td rowspan="2">10.0kV</td><td rowspan="2">10.0kV</td></tr>
<tr><td>3</td><td>12</td></tr>
<tr><td>7.5</td><td>1</td><td>9.4kV</td><td rowspan="2">6.8kV</td><td>9.5kV</td><td rowspan="2">6.9kV (+2%)</td></tr>
<tr><td>7.5</td><td>12</td><td>11.9kV</td><td>12.0kV</td></tr>
<tr><td>8.2</td><td>1</td><td>14.0kV</td><td rowspan="2">11.5kV</td><td>14.2kV</td><td rowspan="2">11.6kV</td></tr>
<tr><td>8.2</td><td>12</td><td>8.3kV</td><td>8.7kV (+5%)</td></tr>
</table>

Table: Comparison of the new tool's calculated SSV versus the standard tool's calculated BDV. Shown are results for the dielectric radii (R) of 3mm, 7.5mm, and 8.2mm, for the dielectric constants (ε_D) of 1 and 12 and for two dielectric surface boundary/initial conditions used in the new/standard tool. σ_s=0 means no surface charge in both tools; j_n=0 means no normal current density in the new tool, while in the standard tool it means that the initial surface charge is that of the steady state as calculated by the new tool with boundary condition(BC) on diel. j_n=0.

The standard tool was seen to lead to discharge extinction at the SSV as calculated by the new tool, this voltage was then successively increased by 1% until the standard tool produced breakdown (cases where an overvoltage of more than 1% was needed, are indicated in the table). In the columns for boundary/initial condition σ_s=0, the SSV/BDV is seen to increase with the dielectric radii and with the dielectric constant. A notable exception occurs for the protruding dielectric with higher permittivity, this was seen to be due to the strong electric field generated close to the cathode triple junction. When the boundary condition, in the new tool, is that of zero current density across the dielectric surface (steady-state case j_n=0), or when for the initial surface charge, in the standard tool, the surface charge distribution of the steady-state is used (last column j_n=0), results confirm that breakdown is facilitated when close to the active discharge path there is a dielectric. The reason why the voltages in the columns for boundary/initial condition j_n=0 don't depend on the dielectric constant, is related to the fact that the surface charge on the dielectric screens the effect of the dielectric, resulting on the gas side in near-parallel electric fieldlines along the dielectric surface. With the stated exception, the BDV of the pre-stressed setup(j_n=0) was generally lower than the unstressed setup(σ_s=0).

4 Conclusion

The developed tool for calculating BDVs based on stationary numerical modeling, has produced results to within 5% of those obtained through standard non-stationary modeling. Unlike the standard tool, where the BDV has to be obtained by a very computationally intensive and time-consuming trial and error procedure, the new tool provides a systematic procedure to calculate the SSV, which is seen to be very close to the BDV as calculated by the standard tool. It should be clear that, for the purpose of evaluating the performance in calculating BDVs, the here employed new and standard tools, cannot be compared. No other tools with the same general scope of application were found for comparison with this new tool.

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