



Model created in COMSOL Multiphysics 6.4

# Dielectric Barrier Discharge in Air

## *Introduction*

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Dielectric barrier discharge (DBD) is a non-thermal plasma phenomenon that occurs between two electrodes separated by a dielectric layer. It is widely employed in applications such as ozone generation, surface modification, and plasma medicine. The presence of the dielectric barrier significantly influences the discharge process by altering the electric field distribution and controlling the motion of charged species. In particular, the accumulation and relaxation of surface charges at the dielectric interface play a crucial role in determining discharge dynamics.

This model simulates DBD in air under an applied AC voltage. As the voltage amplitude increases, the discharge becomes more intense, and the dominant contribution to the total current shifts from displacement current to conduction current.

## *Model Definition*

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The Electric Discharge interface is used to simulate the DBD. The built-in charge transport model is used:

$$\frac{\partial n_i}{\partial t} + \nabla \cdot (\mathbf{w}_i n_i - D_i \nabla n_i) = R_i$$

where

$$i = e, p, n$$

$$z_{e, p, n} = -1, +1, -1$$

$$\mathbf{w}_i = z_i \mu_i \mathbf{E}$$

$$R_e = \alpha |\mathbf{w}_e| n_e - \eta |\mathbf{w}_e| n_e - \beta_{ep} n_e n_p$$

$$R_p = \alpha |\mathbf{w}_e| n_e - \beta_{ep} n_e n_p - \beta_{pn} n_p n_n$$

$$R_n = \eta |\mathbf{w}_e| n_e - \beta_{pn} n_p n_n$$

where

- e, p, n denote electrons, positive ions, and negative ions
- $n_i$  is the number density of the charge carrier (SI unit:  $1/\text{m}^3$ )
- $\mathbf{E}$  is the electric field (SI unit:  $\text{V}/\text{m}$ )
- $z_i$  denotes the carrier charge (SI unit: 1)
- $\mu_i$  denotes the carrier mobility (SI unit:  $\text{m}^2/(\text{V}\cdot\text{s})$ )
- $\mathbf{w}_i$  is the drift velocity in the electric field (SI unit:  $\text{m}/\text{s}$ )
- $D_i$  is the diffusion coefficient (SI unit:  $\text{m}^2/\text{s}$ )
- $R_i$  is the reaction rate (SI unit:  $1/(\text{m}^3\cdot\text{s})$ )
- $\alpha$  is the ionization coefficient (SI unit:  $1/\text{m}$ )
- $\eta$  is the attachment coefficient (SI unit:  $1/\text{m}$ )
- $\beta_{ep}$  is the electron-ion recombination coefficient (SI unit:  $\text{m}^3/\text{s}$ )
- $\beta_{pn}$  is the ion-ion recombination coefficient (SI unit:  $\text{m}^3/\text{s}$ )

The above transport equations are fully coupled with Poisson's equation through the electric field and the space charge:

$$\nabla \cdot (\epsilon_r \epsilon_0 \mathbf{E}) = \rho$$

$$\rho = e \sum_i z_i n_i$$

where  $e$  is the elementary charge.

The Gas–Solid interface is modeled with the dedicated *Dielectric Interface, Surface Transport* feature described in the *Electric Discharge Module User's Guide*.

### Results and Discussion

Figure 1 shows the discharge current as a function of time from the first study. The total current consists of the displacement current superimposed with the gas discharge current. Figure 2 shows the surface charge density at the inner and outer surfaces as a function of time.

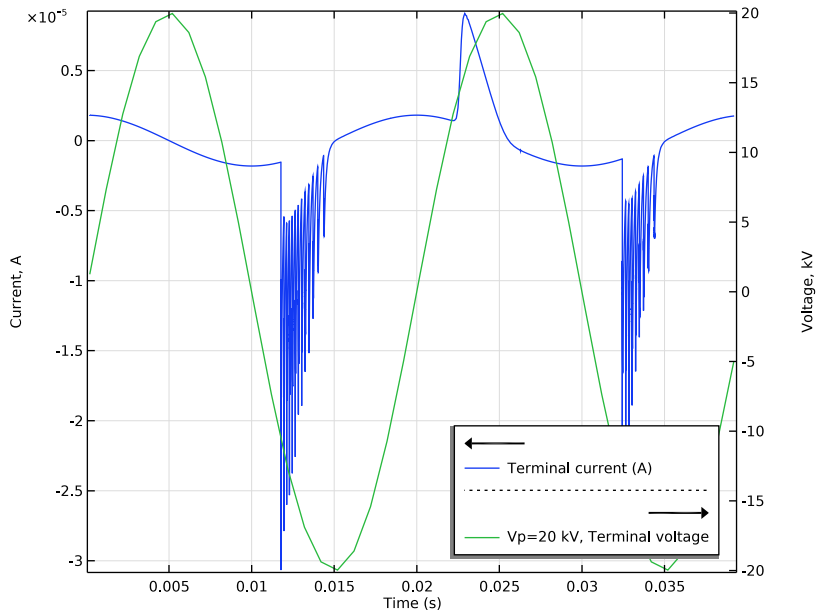


Figure 1: The discharge current as a function of time.

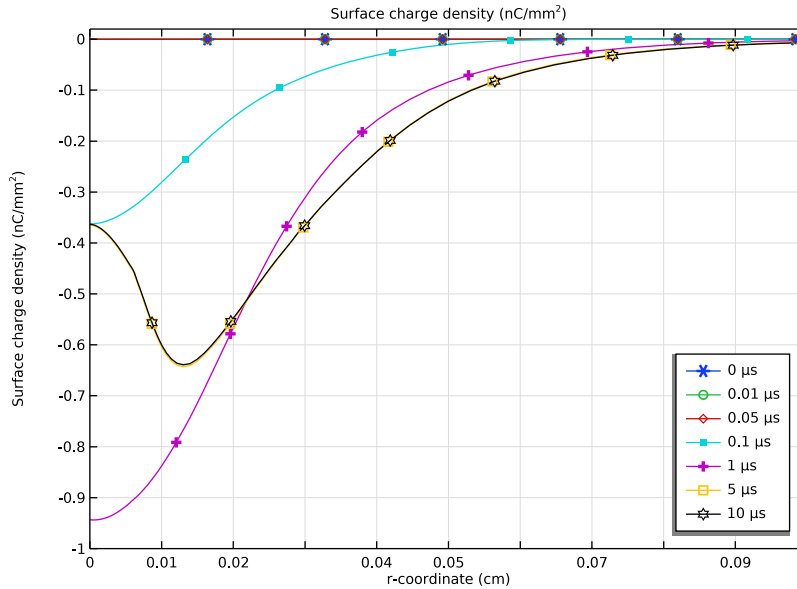


Figure 2: The radial distributions surface charge density at several time instants of the first study.

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**Application Library path:** Electric\_Discharge\_Module/  
Dielectric\_Barrier\_Discharges/dbd


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### Modeling Instructions


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From the **File** menu, choose **New**.

#### NEW

In the **New** window, click  **Model Wizard**.

#### MODEL WIZARD

- 1 In the **Model Wizard** window, click  **ID Axisymmetric**.
- 2 In the **Select Physics** tree, select **Electric Discharge > Electric Discharge (edis)**.
- 3 Click **Add**.

- 4 Click  **Study**.
- 5 In the **Select Study** tree, select **Preset Studies for Selected Physics Interfaces > Time Dependent with Initialization**.
- 6 Click  **Done**.

### GEOMETRY I

- 1 In the **Model Builder** window, under **Component 1 (comp1)** click **Geometry 1**.
- 2 In the **Settings** window for **Geometry**, locate the **Units** section.
- 3 From the **Length unit** list, choose **cm**.

### GLOBAL DEFINITIONS

#### *Parameters 1*

- 1 In the **Model Builder** window, under **Global Definitions** click **Parameters 1**.
- 2 In the **Settings** window for **Parameters**, locate the **Parameters** section.
- 3 In the table, enter the following settings:

Name	Expression	Value	Description
Vp	1 [kV]	1000 V	
f	50 [Hz]	50 Hz	
t	1/f/100	2E-4 s	
Va	$Vp \cdot \sin(2 \cdot \pi \cdot f \cdot t)$	62.791 V	

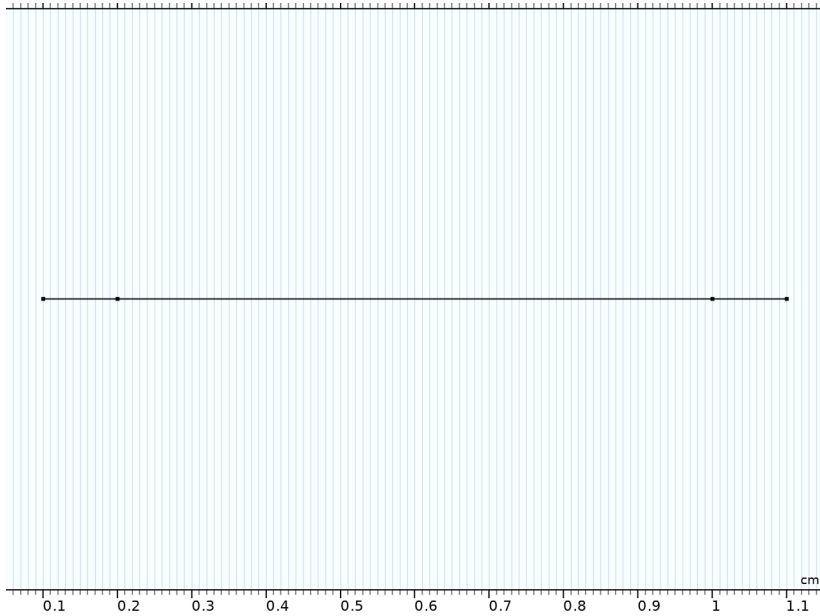
### GEOMETRY I

#### *Interval 1 (i1)*

- 1 In the **Model Builder** window, under **Component 1 (comp1)** right-click **Geometry 1** and choose **Interval**.
- 2 In the **Settings** window for **Interval**, locate the **Interval** section.
- 3 In the table, enter the following settings:

Coordinates (cm)
0.1
0.2
1
1.1

4 Click  **Build All Objects**.



#### **ELECTRIC DISCHARGE (EDIS)**

- 1 In the **Model Builder** window, under **Component 1 (comp1)** click **Electric Discharge (edis)**.
- 2 In the **Settings** window for **Electric Discharge**, locate the **Physical Model** section.
- 3 Select the **Solid** checkbox.

#### *Solid 1*

- 1 In the **Model Builder** window, under **Component 1 (comp1) > Electric Discharge (edis)** click **Solid 1**.
- 2 Select Domains 1 and 3 only.
- 3 In the **Settings** window for **Solid**, locate the **Model Formulation** section.
- 4 From the **Material model** list, choose **Insulator**.
- 5 Locate the **Constitutive Relation D-E** section. From the  $\epsilon_r$  list, choose **User defined**. In the associated text field, type 3.5.

#### **ADD MATERIAL FROM LIBRARY**


In the **Home** toolbar, click  **Windows** and choose **Add Material from Library**.

## ADD MATERIAL

- 1 Go to the **Add Material** window.
- 2 In the tree, select **Electric Discharge > Gases > Air > Air [Morrow and Lowke, 1997]**.
- 3 Right-click and choose **Add to Component 1 (comp1)**.

## MATERIALS

*Air [Morrow and Lowke, 1997] (mat1)*


- 1 In the **Model Builder** window, under **Component 1 (comp1) > Materials** click **Air [Morrow and Lowke, 1997] (mat1)**.
- 2 In the **Settings** window for **Material**, locate the **Geometric Entity Selection** section.
- 3 In the list, choose **1** and **3**.
- 4 Click  **Remove from Selection**.
- 5 Select Domain 2 only.

## ELECTRIC DISCHARGE (EDIS)

*Solid 1*

In the **Model Builder** window, under **Component 1 (comp1) > Electric Discharge (edis)** click **Solid 1**.

*Electrode 1*

- 1 In the **Physics** toolbar, click  **Attributes** and choose **Electrode**.
- 2 Select Boundary 1 only.
- 3 In the **Settings** window for **Electrode**, locate the **Terminal** section.
- 4 In the  $V_0$  text field, type Va.

*Solid 1*

In the **Model Builder** window, click **Solid 1**.

*Electrode 2*

- 1 In the **Physics** toolbar, click  **Attributes** and choose **Electrode**.
- 2 Select Boundary 4 only.


## MESH 1

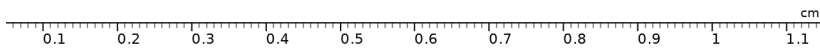
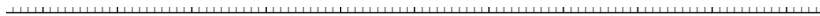
- 1 In the **Model Builder** window, under **Component 1 (comp1)** click **Mesh 1**.
- 2 In the **Settings** window for **Mesh**, locate the **Sequence Type** section.
- 3 From the list, choose **User-controlled mesh**.

*Distribution 1*

- 1 In the **Model Builder** window, right-click **Edge 1** and choose **Distribution**.
- 2 Select Domain 2 only.
- 3 In the **Settings** window for **Distribution**, locate the **Distribution** section.
- 4 From the **Distribution type** list, choose **Predefined**.
- 5 In the **Number of elements** text field, type 200.
- 6 In the **Element ratio** text field, type 5.
- 7 Select the **Symmetric distribution** checkbox.

*Distribution 2*

- 1 Right-click **Edge 1** and choose **Distribution**.
- 2 Select Domains 1 and 3 only.
- 3 In the **Settings** window for **Distribution**, locate the **Distribution** section.
- 4 In the **Number of elements** text field, type 10.
- 5 Click  **Build All**.




## STUDY 1

### Step 2: Time Dependent

- 1 In the **Model Builder** window, under **Study 1** click **Step 2: Time Dependent**.
- 2 In the **Settings** window for **Time Dependent**, locate the **Study Settings** section.
- 3 In the **Output times** text field, type range  $(1/f/100, 1/f/20, 2/f)$ .


## DEFINITIONS

### Global Variable Probe 1 (var1)


- 1 In the **Definitions** toolbar, click  **Probes** and choose **Global Variable Probe**.
- 2 In the **Settings** window for **Global Variable Probe**, locate the **Expression** section.
- 3 In the **Expression** text field, type `edis.I0_0`.

## STUDY 1

### Parametric Sweep

- 1 In the **Study** toolbar, click  **Parametric Sweep**.
- 2 In the **Settings** window for **Parametric Sweep**, locate the **Study Settings** section.
- 3 Click **+ Add**.
- 4 In the table, enter the following settings:

Parameter name	Parameter value list	Parameter unit
Vp	1 10 20	kV

- 5 In the **Model Builder** window, click **Study 1**.
- 6 In the **Settings** window for **Study**, locate the **Study Settings** section.
- 7 Clear the **Generate default plots** checkbox.
- 8 In the **Study** toolbar, click  **Compute**.

## RESULTS

### Global 1


- 1 In the **Model Builder** window, right-click **Probe Plot Group 1** and choose **Global**.
- 2 In the **Settings** window for **Global**, locate the **Data** section.
- 3 From the **Dataset** list, choose **Study 1/Parametric Solutions 1 (sol3)**.
- 4 From the **Parameter selection (Vp)** list, choose **Last**.

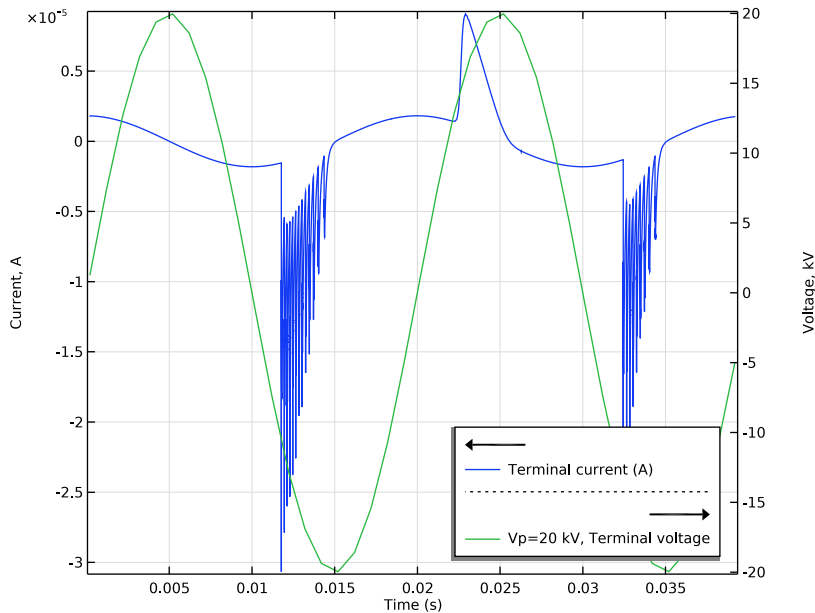
5 Locate the **y-Axis Data** section. In the table, enter the following settings:

Expression	Unit	Description
edis.V0_0	kV	Terminal voltage


6 Locate the **x-Axis Data** section. From the **Axis source data** list, choose **Time**.

*Probe Plot Group 1*

- 1 In the **Model Builder** window, click **Probe Plot Group 1**.
- 2 In the **Settings** window for **ID Plot Group**, locate the **Plot Settings** section.
- 3 Select the **Two y-axes** checkbox.
- 4 Select the **y-axis label** checkbox. In the associated text field, type **Current**, **A**.
- 5 Select the **Secondary y-axis label** checkbox. In the associated text field, type **Voltage**, **kV**.
- 6 In the table, select the **Plot on secondary y-axis** checkbox for **Global 1**.
- 7 Locate the **Legend** section. From the **Position** list, choose **Lower right**.
- 8 Click to expand the **Title** section. From the **Title type** list, choose **None**.
- 9 In the **Probe Plot Group 1** toolbar, click  **Plot**.



### Surface Charge Density

- 1 In the **Results** toolbar, click  **ID Plot Group**.
- 2 In the **Settings** window for **ID Plot Group**, type Surface Charge Density in the **Label** text field.

### Point Graph 1

- 1 Right-click **Surface Charge Density** and choose **Point Graph**.
- 2 Select Boundaries 2 and 3 only.
- 3 In the **Settings** window for **Point Graph**, locate the **y-Axis Data** section.
- 4 In the **Expression** text field, type `edis.rhos`.
- 5 In the **Unit** field, type `nC/mm^2`.

### Global 1

In the **Model Builder** window, under **Results > Probe Plot Group 1** right-click **Global 1** and choose **Copy**.

### Global 1

In the **Model Builder** window, right-click **Surface Charge Density** and choose **Paste Global**.

### Surface Charge Density

- 1 In the **Settings** window for **ID Plot Group**, locate the **Title** section.
- 2 From the **Title type** list, choose **None**.
- 3 Locate the **Plot Settings** section. Select the **Two y-axes** checkbox.
- 4 Select the **y-axis label** checkbox. In the associated text field, type Surface charge density,  $\text{nC/mm}^2$ .
- 5 Select the **Secondary y-axis label** checkbox.


### Point Graph 1

- 1 In the **Model Builder** window, click **Point Graph 1**.
- 2 In the **Settings** window for **Point Graph**, click to expand the **Legends** section.
- 3 Select the **Show legends** checkbox.
- 4 From the **Legends** list, choose **Manual**.
- 5 In the table, enter the following settings:

Legends
Inner surface
Outer surface

- Click to expand the **Coloring and Style** section. Find the **Line markers** subsection. From the **Marker** list, choose **Cycle**.

### Surface Charge Density

- In the **Model Builder** window, click **Surface Charge Density**.
- In the **Settings** window for **ID Plot Group**, locate the **Legend** section.
- From the **Position** list, choose **Upper left**.
- In the **Surface Charge Density** toolbar, click  **Plot**.

