



Model created in COMSOL Multiphysics 6.4

Partial Discharge Inside Solid Dielectrics

Introduction

The electrical insulation strength of gases is generally much lower than that of solid dielectrics. As a result, small voids, cracks, or imperfections within solid insulation can give rise to localized electrical discharges, commonly referred to as partial discharges (PDs). Although these discharges do not bridge the entire insulation system, they can gradually degrade the material, leading to long-term insulation failure. For this reason, partial discharge detection and analysis are widely used in high-voltage engineering as a diagnostic tool for assessing insulation condition.

This model simulates partial discharges in a spherical air void embedded within a solid dielectric subjected to a 50 Hz AC power frequency. The formulation includes detailed charge transport processes for electrons and ions, fully coupled with electrostatics. Surface charge accumulation at the gas–solid interface is also treated self-consistently, as it plays a key role in the development and quenching of the discharge.

The simulation outputs the Phase-Resolved Partial Discharge (PRPD) pattern, which provides insight into the timing, magnitude, and polarity of discharges relative to the applied voltage cycle. These results can be compared directly with experimental measurements, offering a valuable tool for studying the mechanisms of partial discharge initiation and progression in solid insulation systems.

Model Definition

The Electric Discharge interface is used to simulate the partial discharge. 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: V/m)
- z_i denotes the carrier charge (SI unit: 1)
- μ_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: m/s)
- D_i is the diffusion coefficient (SI unit: m^2/s)
- R_i is the reaction rate (SI unit: $1/(\text{m}^3\cdot\text{s})$)
- α is the ionization coefficient (SI unit: $1/\text{m}$)
- η is the attachment coefficient (SI unit: $1/\text{m}$)
- β_{ep} is the electron-ion recombination coefficient (SI unit: m^3/s)
- β_{pn} is the ion-ion recombination coefficient (SI unit: m^3/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 PRPD measured by discharge current as a function of phase angle. Figure 2 shows the surface charge density at the void-solid interface as a function of direction angle for several time instants.

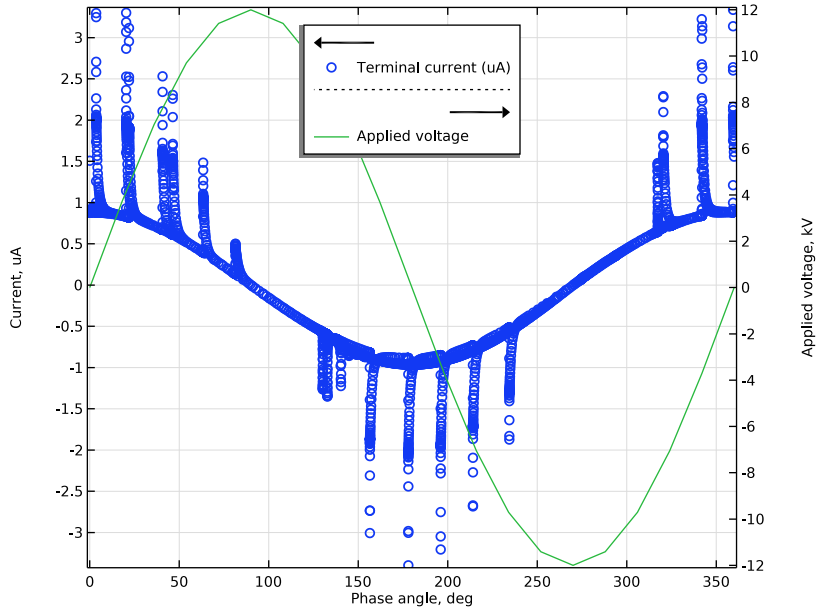


Figure 1: The partial discharge current as a function phase angle.

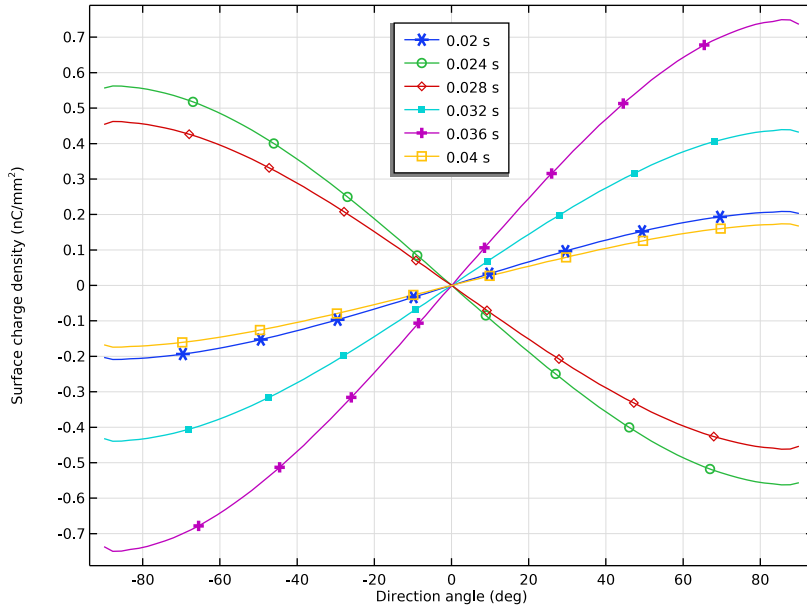


Figure 2: The distribution of surface charge density at the void-solid interface.

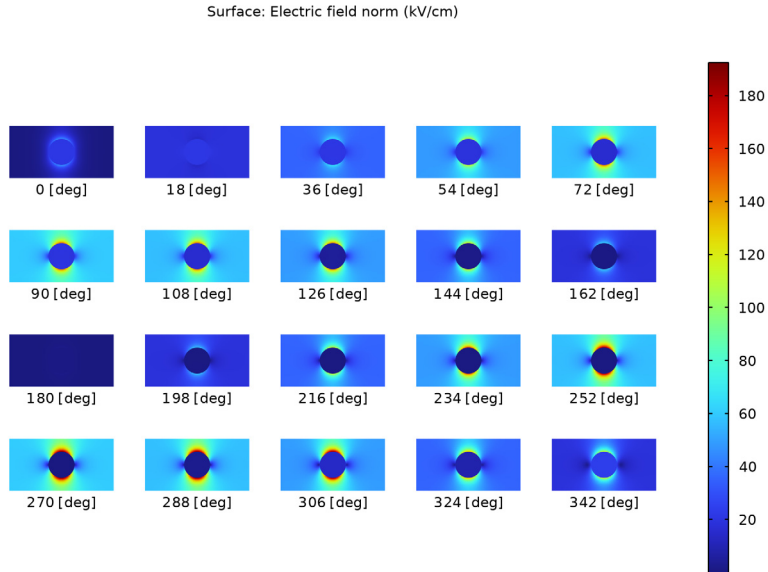



Figure 3: The distribution of electric field at different phase angles.

Application Library path: Electric_Discharge_Module/Partial_Discharges/
partial_discharge


Modeling Instructions



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

NEW

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

MODEL WIZARD


- 1** In the **Model Wizard** window, click  **2D 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 **mm**.

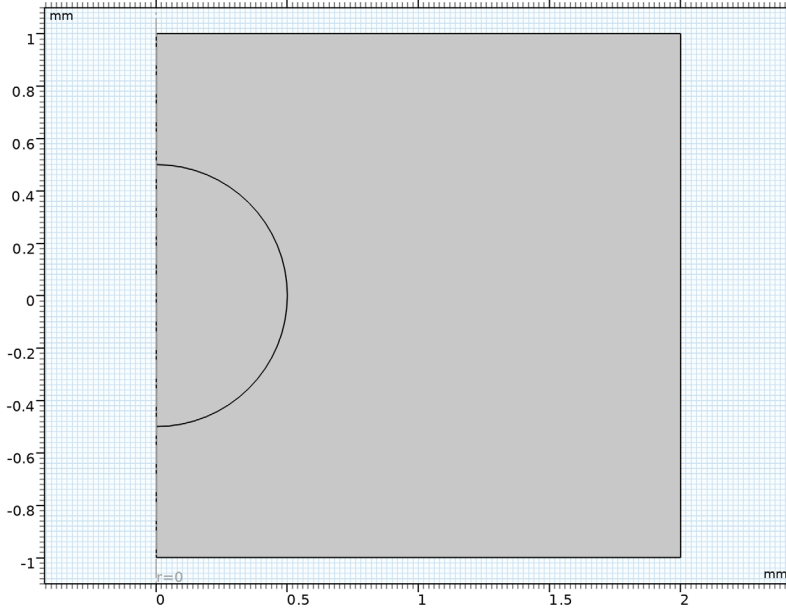
Rectangle 1 (r1)

- 1 In the **Geometry** toolbar, click  **Rectangle**.
- 2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.
- 3 In the **Width** text field, type 2.
- 4 In the **Height** text field, type 2.
- 5 Locate the **Position** section. In the **z** text field, type -1.

Circle 1 (c1)

- 1 In the **Geometry** toolbar, click  **Circle**.
- 2 In the **Settings** window for **Circle**, locate the **Size and Shape** section.
- 3 In the **Radius** text field, type 0.5.
- 4 In the **Sector angle** text field, type 180.
- 5 Locate the **Rotation Angle** section. In the **Rotation** text field, type -90.

6 Click  **Build All Objects**.



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
V0	12[kV]	12000 V	
f	50[Hz]	50 Hz	
t	0[s]	0 s	
Va	$V0 \cdot \sin(2 \cdot \pi \cdot f \cdot t)$	0 V	

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 [Kang et al. 2003]**.
- 3 Right-click and choose **Add to Component 1 (comp1)**.

MATERIALS

Air [Kang et al. 2003] (mat1)

- 1 In the **Model Builder** window, under **Component 1 (comp1) > Materials** click **Air [Kang et al. 2003] (mat1)**.
- 2 Select Domain 2 only.

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.
Enable the isotropic diffusion stabilization.
- 4 Click the  **Show More Options** button in the **Model Builder** toolbar.
- 5 In the **Show More Options** dialog, select **Physics > Stabilization** in the tree.
- 6 In the tree, select the checkbox for the node **Physics > Stabilization**.
- 7 Click **OK**.
- 8 In the **Settings** window for **Electric Discharge**, click to expand the **Inconsistent Stabilization** section.
- 9 Select the **Isotropic diffusion** checkbox.


Gas 1

- 1 In the **Model Builder** window, under **Component 1 (comp1) > Electric Discharge (edis)** click **Gas 1**.
- 2 Select Domain 2 only.

Solid 1

- 1 In the **Model Builder** window, click **Solid 1**.
- 2 Select Domain 1 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 ϵ_r list, choose **User defined**. In the associated text field, type 4.3.

Electrode 1

- 1 In the **Physics** toolbar, click  **Attributes** and choose **Electrode**.
- 2 Select Boundary 6 only.
- 3 In the **Settings** window for **Electrode**, locate the **Terminal** section.
- 4 In the V_0 text field, type V_a .

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 2 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**.

Size 1

- 1 In the **Model Builder** window, right-click **Free Triangular 1** and choose **Size**.
- 2 In the **Settings** window for **Size**, locate the **Geometric Entity Selection** section.
- 3 From the **Geometric entity level** list, choose **Domain**.
- 4 Select Domain 2 only.
- 5 Locate the **Element Size** section. Click the **Custom** button.
- 6 Locate the **Element Size Parameters** section.
- 7 Select the **Maximum element size** checkbox. In the associated text field, type 20[um].

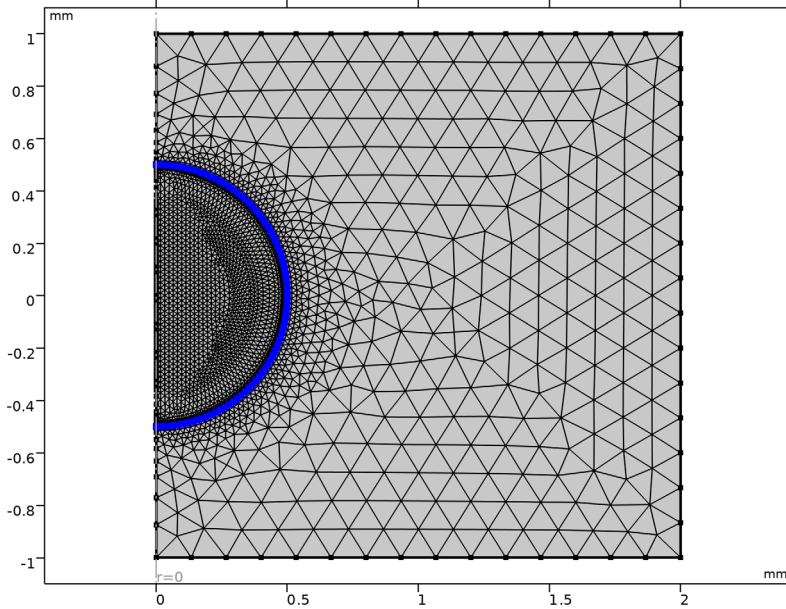
Boundary Layers 1

- 1 In the **Mesh** toolbar, click  **Boundary Layers**.
- 2 In the **Settings** window for **Boundary Layers**, locate the **Domain Selection** section.
- 3 From the **Geometric entity level** list, choose **Domain**.
- 4 Select Domain 2 only.

Boundary Layer Properties

- 1 In the **Model Builder** window, click **Boundary Layer Properties**.
- 2 Select Boundaries 8 and 9 only.

- 3 In the **Settings** window for **Boundary Layer Properties**, click  **Build All**.




STUDY 1

Step 2: Time Dependent

- 1 In the **Model Builder** window, expand the **Component 1 (comp1) > Definitions** node, then click **Study 1 > 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(0, 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**, type I0 in the **Variable name** text field.
- 3 Locate the **Expression** section. In the **Expression** text field, type edis.I0_0.
- 4 In the **Table and plot unit** field, type uA.

Global Variable Probe 2 (var2)

- 1 In the **Definitions** toolbar, click  **Probes** and choose **Global Variable Probe**.

- 2 In the **Settings** window for **Global Variable Probe**, type phase in the **Variable name** text field.
- 3 Locate the **Expression** section. In the **Expression** text field, type $\text{mod}(2*\pi*f*t, 2*\pi)$.
- 4 In the **Table and plot unit** field, type deg.
- 5 Select the **Description** checkbox. In the associated text field, type Phase angle.

STUDY 1

- 1 In the **Model Builder** window, click **Study 1**.
- 2 In the **Settings** window for **Study**, locate the **Study Settings** section.
- 3 Clear the **Generate default plots** checkbox.
- 4 In the **Study** toolbar, click  **Compute**.

RESULTS

Probe Table Graph 1

- 1 In the **Model Builder** window, expand the **Probe Plot Group 1** node, then click **Probe Table Graph 1**.
- 2 In the **Settings** window for **Table Graph**, locate the **Data** section.
- 3 In the **Columns** list box, select **Terminal current (uA)**.
- 4 From the **x-axis data** list, choose **Phase angle (deg)**.
- 5 Locate the **Coloring and Style** section. Find the **Line style** subsection. From the **Line** list, choose **None**.
- 6 Find the **Line markers** subsection. From the **Marker** list, choose **Circle**.
- 7 From the **Positioning** list, choose **In data points**.

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

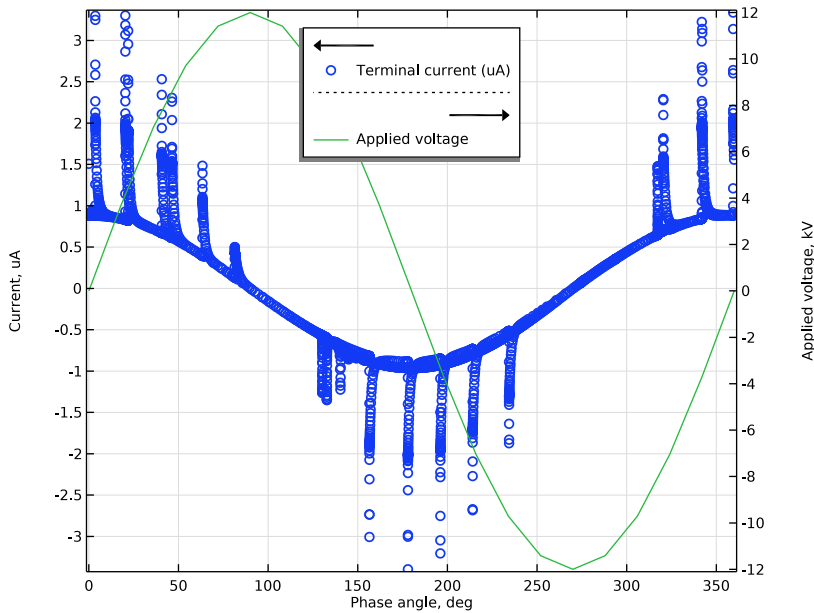
Expression	Unit	Description
Va	kV	Applied voltage

- 4 Locate the **x-Axis Data** section. From the **Parameter** list, choose **Expression**.
- 5 In the **Expression** text field, type $2*\pi*f*t$.
- 6 In the **Unit** field, type deg.


- 7 Locate the **Data** section. From the **Dataset** list, choose **Study 1/Solution 1 (sol1)**.
- 8 From the **Time selection** list, choose **From list**.
- 9 In the **Times (s)** list, choose **0, 0.001, 0.002, 0.003, 0.004, 0.005, 0.006, 0.007, 0.008, 0.009, 0.01, 0.011, 0.012, 0.013, 0.014, 0.015, 0.016, 0.017, 0.018, 0.019, and 0.02**.

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 **x-axis label** checkbox. In the associated text field, type **Phase angle, deg**.
- 5 Select the **y-axis label** checkbox. In the associated text field, type **Current, uA**.
- 6 Select the **Secondary y-axis label** checkbox. In the associated text field, type **Applied voltage, kV**.
- 7 In the table, select the **Plot on secondary y-axis** checkbox for **Global 1**.
- 8 Locate the **Legend** section. From the **Position** list, choose **Upper middle**.
- 9 Click to expand the **Title** section. From the **Title type** list, choose **None**.
- 10 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.

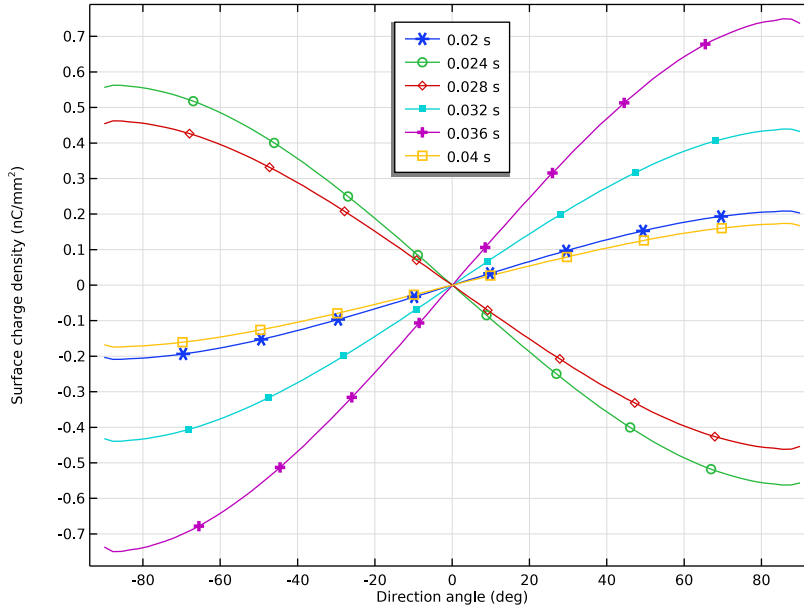
Line Graph 1

- 1 Right-click **Surface Charge Density** and choose **Line Graph**.
- 2 Select Boundaries 8 and 9 only.
- 3 In the **Settings** window for **Line 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`.
- 6 Locate the **x-Axis Data** section. From the **Parameter** list, choose **Expression**.
- 7 In the **Expression** text field, type `atan(z/r)`.
- 8 In the **Unit** field, type `deg`.
- 9 Select the **Description** checkbox. In the associated text field, type `Direction angle`.
- 10 Click to expand the **Coloring and Style** section. Find the **Line markers** subsection. From the **Marker** list, choose **Cycle**.
- 11 From the **Positioning** list, choose **Interpolated**.
- 12 Click to expand the **Legends** section. Select the **Show legends** checkbox.

Surface Charge Density

- 1 In the **Model Builder** window, click **Surface Charge Density**.
- 2 In the **Settings** window for **ID Plot Group**, locate the **Data** section.
- 3 From the **Time selection** list, choose **Interpolated**.
- 4 In the **Times (s)** text field, type `range(1/f, 1/f/5, 2/f)`.
- 5 Locate the **Title** section. From the **Title type** list, choose **None**.
- 6 Locate the **Legend** section. From the **Position** list, choose **Upper middle**.


7 In the **Surface Charge Density** toolbar, click  **Plot**.



Mirror 2D 1

- 1 In the **Model Builder** window, expand the **Results > Datasets** node.
- 2 Right-click **Results > Datasets** and choose **More 2D Datasets > Mirror 2D**.

2D Plot Group 3

In the **Results** toolbar, click  **2D Plot Group**.

Surface 1


- 1 In the **Model Builder** window, right-click **2D Plot Group 3** and choose **Surface**.
- 2 In the **Settings** window for **Surface**, locate the **Expression** section.
- 3 In the **Expression** text field, type `edis.normE`.
- 4 In the **Unit** field, type `kV/cm`.

Solution Array 1

Right-click **Surface 1** and choose **Solution Array**.

2D Plot Group 3

- 1 In the **Settings** window for **2D Plot Group**, locate the **Data** section.
- 2 From the **Dataset** list, choose **Mirror 2D 1**.

- 3 Locate the **Plot Settings** section. Clear the **Plot dataset edges** checkbox.
- 4 In the **2D Plot Group 3** toolbar, click  **Plot**.

Solution Array 1

- 1 In the **Model Builder** window, under **Results > 2D Plot Group 3 > Surface 1** click **Solution Array 1**.
- 2 In the **Settings** window for **Solution Array**, locate the **Data** section.
- 3 From the **Time selection** list, choose **From list**.
- 4 In the **Times (s)** list, choose **0.02, 0.021, 0.022, 0.023, 0.024, 0.025, 0.026, 0.027, 0.028, 0.029, 0.03, 0.031, 0.032, 0.033, 0.034, 0.035, 0.036, 0.037, 0.038, and 0.039**.

2D Plot Group 3

- 1 In the **Model Builder** window, under **Results** click **2D Plot Group 3**.
- 2 In the **Settings** window for **2D Plot Group**, click to expand the **Plot Array** section.
- 3 From the **Array type** list, choose **Square**.
- 4 In the **Relative row padding** text field, type **-1.5**.

Solution Array 1

- 1 In the **Model Builder** window, under **Results > 2D Plot Group 3 > Surface 1** click **Solution Array 1**.
- 2 In the **Settings** window for **Solution Array**, locate the **Plot Array** section.
- 3 From the **Array shape** list, choose **Square**.

Annotation 1

In the **Model Builder** window, right-click **2D Plot Group 3** and choose **Annotation**.

Solution Array 1

In the **Model Builder** window, under **Results > 2D Plot Group 3 > Surface 1** right-click **Solution Array 1** and choose **Copy**.

Solution Array 1




In the **Model Builder** window, right-click **Annotation 1** and choose **Paste Solution Array**.

Annotation 1

- 1 In the **Settings** window for **Annotation**, click to expand the **Plot Array** section.
- 2 Select the **Manual indexing** checkbox.
- 3 Locate the **Position** section. In the **y** text field, type **-1.2**.
- 4 Locate the **Coloring and Style** section. From the **Anchor point** list, choose **Upper middle**.
- 5 Clear the **Show point** checkbox.

- 6 Locate the **Annotation** section. In the **Text** text field, type `eval(phase,deg,3) [deg]`.
- 7 Locate the **Position** section. In the **y** text field, type `-1`.

Electric Fields

- 1 In the **Model Builder** window, under **Results** click **2D Plot Group 3**.
- 2 In the **Settings** window for **2D Plot Group**, type **Electric Fields** in the **Label** text field.
- 3 Click to expand the **Title** section. From the **Title type** list, choose **Custom**.
- 4 Find the **Solution** subsection. Clear the **Solution** checkbox.
- 5 Click the  **Show Grid** button in the **Graphics** toolbar.
- 6 Click the  **Zoom Extents** button in the **Graphics** toolbar.
- 7 In the **Electric Fields** toolbar, click  **Plot**.

Surface: Electric field norm (kV/cm)

