Created in COMSOL Multiphysics 6.1

Electric Field from Power Lines

Introduction

Power lines are commonly used as a means of transmitting electrical power across large distances. In this tutorial, two towers transmitting high voltage three-phase AC power are modeled, and the resulting electric field is computed. Specifically, the voltage is set to 400 kV in this model. In transmission lines with such a high voltage, the phase lines are usually made up of several smaller conductors bundled together. For simplicity, a single conductor for each phase line is used in this model, but its radius is set to 10 cm in order to simulate the effective radius of a bundled conductor.

The towers also have two shielding lines above the phase lines, which protect the tower from lightning strikes. These shielding lines have a slightly smaller radius, which in this model is set to 1 cm.

Model Definition

The geometry of one of the towers is shown in Figure 1. It is imported from an external file due to its complexity. The ground level in this geometry is created using a geometry part from the Part Library, which creates a flat surface that is randomly perturbed. Note that the insulators purely are for aesthetic purposes in this model.

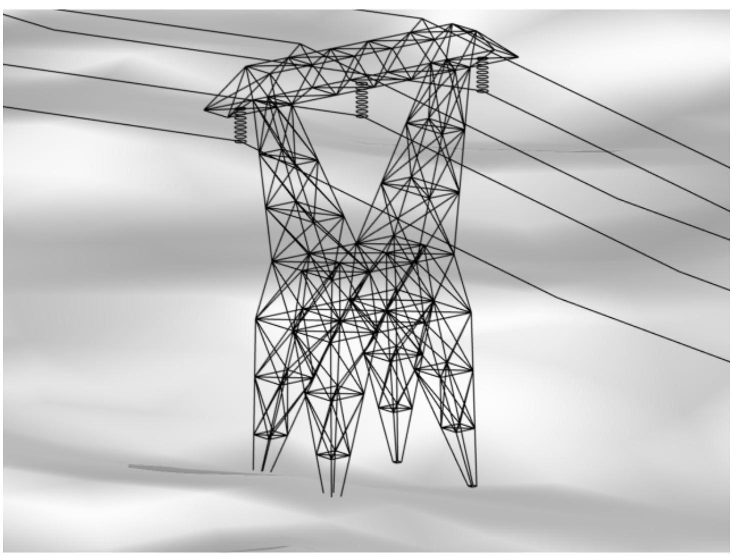

Figure 1: The geometry of the transmission tower. The two shielding lines can be seen on top, while the three phase lines are held by the insulators.

To solve the model, use the 3D **Electrostatics, Boundary Elements** interface in the AC/DC Module. In this physics interface, the electric scalar potential, V, satisfies the equation

$$-\nabla \cdot (\varepsilon_0 \varepsilon_r \nabla V) = \rho$$

where ε_0 is the permittivity of free space, ε_r is the relative permittivity, and ρ is the space charge density. The electric field and the displacement field are derived from the potential:

$$\mathbf{E} = -\nabla V$$
$$\mathbf{D} = \varepsilon_0 \varepsilon_r \mathbf{E}$$

In the model, the **Ground** feature sets the boundary condition $V = 0$ at the shielding lines, the tower, and the floor. On the phase lines, the **Electric Potential** feature is used to set the specified potentials, each of them phase shifted with respect to the others. Since the wires are edges in the geometry, it is also necessary to specify the corresponding edge radius for each such feature.

Since the model is using the boundary element method (BEM), and the potential is fixed at all the edges and surfaces, it only needs to solve the above equations in the *infinite void* surrounding the towers. This also illustrates the strength of using BEM in models where there are large empty spaces. If it instead had used the finite element method (FEM), like most other physics interfaces, it would have needed to create a volumetric mesh in the entire air domain. This would have significantly increased the number of degrees of freedom, which is likely to also increase the time required to solve the model.

Results

The electric field norm from the wires at ground level is shown Figure 2, along with streamlines showing the direction of the electric field,

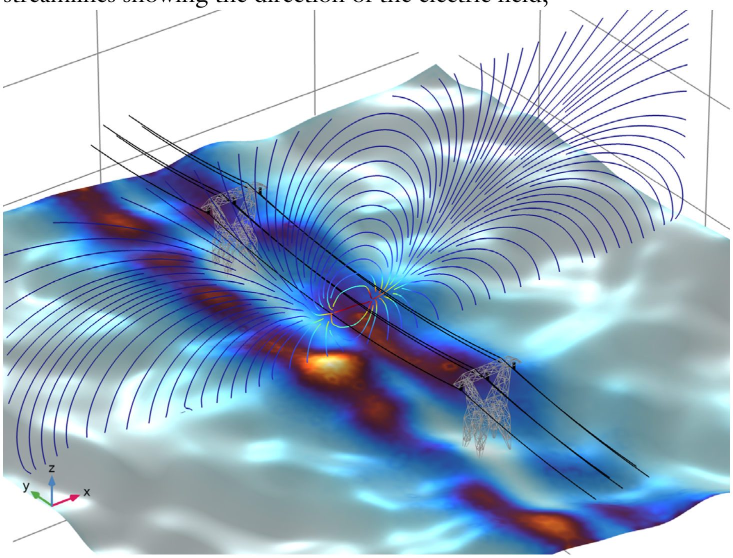

Figure 2: The electric field norm (surface) and the electric field (streamlines) from the transmission lines.

Application Library path: `ACDC_Module/Devices,_Capacitive/power_line_electric_field`

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 **3D**.

2 In the **Select Physics** tree, select **AC/DC>Electric Fields and Currents>Electrostatics, Boundary Elements (esbe)**.

3 Click **Add**.

4 Click **Study**.

5 In the **Select Study** tree, select **General Studies>Frequency Domain**.

6 Click **Done**.

First, define some parameters that will be used when building the model.

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	400[kV]	4E5 V	Power line voltage
r0	10[cm]	0.1 m	Phase line radius
rs	1[cm]	0.01 m	Shielding line radius

For the sake of simplicity, the geometry of the model will be imported from an external file. Note that since the boundary element method is used in this model, there is no need for an air domain in the geometry.

GEOMETRY 1

Import 1 (imp1)

1 In the **Home** toolbar, click **Import**.

2 In the **Settings** window for **Import**, locate the **Import** section.

3 Click **Browse**.

4 Browse to the model's Application Libraries folder and double-click the file `power_line_electric_field.mphbin`.

5 Click **Import**.

ADD MATERIAL

1 In the **Home** toolbar, click **Add Material** to open the **Add Material** window.

2 Go to the **Add Material** window.

3 In the tree, select **Built-in>Air**.

4 Click **Add to Component** in the window toolbar.

5 In the **Home** toolbar, click **Add Material** to close the **Add Material** window.

MATERIALS

Air (mat1)

1 In the **Settings** window for **Material**, locate the **Geometric Entity Selection** section.

2 From the **Geometric entity level** list, choose **Domain**.

3 From the **Selection** list, choose **All voids**.

In the physics interface, add phase shifted electric potentials on the three phase lines. Also, add ground at the towers, the shielding lines, and the floor.

ELECTROSTATICS, BOUNDARY ELEMENTS (ESBE)

Electric Potential 1

1 In the **Model Builder** window, under **Component 1 (comp1)** right-click **Electrostatics, Boundary Elements (esbe)** and choose **Edges>Electric Potential**.

2 In the **Settings** window for **Electric Potential**, locate the **Electric Potential** section.

3 In the V_0 text field, type `V0`.

4 Locate the **Edge Radius** section. In the **Edge radius** text field, type `r0`.

5 Locate the **Edge Selection** section. Click **Paste Selection**.

6 In the **Paste Selection** dialog box, type `66, 75, 94` in the **Selection** text field.

7 Click **OK**.

Electric Potential 2

1 In the **Physics** toolbar, click **Edges** and choose **Electric Potential**.

2 In the **Settings** window for **Electric Potential**, locate the **Electric Potential** section.

3 In the V_0 text field, type `V0*exp(i*2*pi/3)`.

4 Locate the **Edge Radius** section. In the **Edge radius** text field, type `r0`.

5 Locate the **Edge Selection** section. Click **Paste Selection**.

6 In the **Paste Selection** dialog box, type `802, 820, 856` in the **Selection** text field.

7 Click **OK**.

Electric Potential 3

1 In the **Physics** toolbar, click **Edges** and choose **Electric Potential**.

2 In the **Settings** window for **Electric Potential**, locate the **Electric Potential** section.

3 In the V_0 text field, type `V0*exp(i*4*pi/3)`.

4 Locate the **Edge Radius** section. In the **Edge radius** text field, type `r0`.

5 Locate the **Edge Selection** section. Click **Paste Selection**.

6 In the **Paste Selection** dialog box, type `1550, 1559, 1578` in the **Selection** text field.

7 Click **OK**.

Ground 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Ground**.

2 In the **Settings** window for **Ground**, locate the **Boundary Selection** section.

3 Click **Paste Selection**.

4 In the **Paste Selection** dialog box, type `1` in the **Selection** text field.

5 Click **OK**.

Ground 2

1 In the **Physics** toolbar, click **Edges** and choose **Ground**.

2 In the **Settings** window for **Ground**, locate the **Edge Radius** section.

3 In the **Edge radius** text field, type `rs`.

4 Locate the **Edge Selection** section. Click **Paste Selection**.

5 In the **Paste Selection** dialog box, type `467, 484, 508, 1239, 1255, 1278` in the **Selection** text field.

6 Click **OK**.

Ground 3

1 In the **Physics** toolbar, click **Edges** and choose **Ground**.

2 In the **Settings** window for **Ground**, locate the **Edge Selection** section.

3 Click **Paste Selection**.

4 In the **Paste Selection** dialog box, type `4-21, 36, 37, 52-65, 74, 76, 77, 85, 93, 95, 96, 104-466, 468-483, 485-507, 509-769, 784, 785, 800, 801, 803-810, 818, 819, 821, 822, 830-846, 854, 855, 857, 858, 866-1238, 1240-1254, 1256-1277, 1279-1509, 1524, 1525, 1540-1549, 1558, 1560, 1561, 1569, 1577, 1579, 1580, 1588-1602` in the **Selection** text field.

5 Click **OK**.

Before solving, refine the mesh. This makes the resulting plots more detailed, and since there is no volumetric mesh in the model, it does not have as large of an impact on solving time as when using FEM.

MESH 1

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Mesh 1**.

2 In the **Settings** window for **Mesh**, locate the **Physics-Controlled Mesh** section.

3 From the **Element size** list, choose **Extra fine**.

4 Click **Build All**.

STUDY 1

Step 1: Frequency Domain

1 In the **Model Builder** window, under **Study 1** click **Step 1: Frequency Domain**.

2 In the **Settings** window for **Frequency Domain**, locate the **Study Settings** section.

3 In the **Frequencies** text field, type `50`.

4 In the **Model Builder** window, click **Study 1**.

5 In the **Settings** window for **Study**, locate the **Study Settings** section.

6 Clear the **Generate default plots** check box.

7 In the **Home** toolbar, click **Compute**.

RESULTS

In the **Model Builder** window, expand the **Results** node.

Grid 3D 1

1 In the **Model Builder** window, expand the **Results>Datasets** node.

2 Right-click **Results>Datasets** and choose **More 3D Datasets>Grid 3D**.

3 In the **Settings** window for **Grid 3D**, locate the **Parameter Bounds** section.

4 Find the **First parameter** subsection. In the **Minimum** text field, type `-150`.

5 In the **Maximum** text field, type `150`.

6 Find the **Second parameter** subsection. In the **Minimum** text field, type `-150`.

7 In the **Maximum** text field, type `150`.

8 Find the **Third parameter** subsection. In the **Maximum** text field, type `100`.

Electric Field Norm (surface)

1 In the **Results** toolbar, click **3D Plot Group**.

2 In the **Settings** window for **3D Plot Group**, type `Electric Field Norm (surface)` in the **Label** text field.

3 Locate the **Data** section. From the **Dataset** list, choose **Grid 3D 1**.

4 Click to expand the **Title** section. From the **Title type** list, choose **None**.

5 Locate the **Color Legend** section. Clear the **Show legends** check box.

6 Locate the **Plot Settings** section. Clear the **Plot dataset edges** check box.

Line 1

1 Right-click **Electric Field Norm (surface)** and choose **Line**.

2 In the **Settings** window for **Line**, locate the **Data** section.

3 From the **Dataset** list, choose **Study 1/Solution 1 (sol1)**.

4 Locate the **Expression** section. In the **Expression** text field, type `1`.

5 Locate the **Coloring and Style** section. From the **Line type** list, choose **Tube**.

6 In the **Tube radius expression** text field, type `0.1`.

7 Select the **Radius scale factor** check box.

8 From the **Coloring** list, choose **Uniform**.

9 From the **Color** list, choose **Black**.

Selection 1

1 Right-click **Line 1** and choose **Selection**.

2 In the **Settings** window for **Selection**, locate the **Selection** section.

3 Click **Paste Selection**.

4 In the **Paste Selection** dialog box, type `4-21, 55, 56, 59, 60, 62-65, 76, 77, 95, 96, 106, 108, 110, 112-466, 468-483, 485-507, 509-769, 803-810, 818, 821, 822, 830, 832-846, 854, 857, 858, 866, 868-1238, 1240-1254, 1256-1277, 1279-1509, 1543, 1544, 1547, 1548, 1560, 1561, 1579, 1580, 1589-1592, 1594, 1596, 1598, 1600-1602` in the **Selection** text field.

5 Click **OK**.

Material Appearance 1

1 In the **Model Builder** window, right-click **Line 1** and choose **Material Appearance**.

2 In the **Settings** window for **Material Appearance**, locate the **Appearance** section.

3 From the **Appearance** list, choose **Custom**.

4 From the **Material type** list, choose **Steel**.

Line 2

1 In the **Model Builder** window, right-click **Electric Field Norm (surface)** and choose **Line**.

2 In the **Settings** window for **Line**, locate the **Data** section.

3 From the **Dataset** list, choose **Study 1/Solution 1 (sol1)**.

4 Locate the **Expression** section. In the **Expression** text field, type `1`.

5 Locate the **Coloring and Style** section. From the **Line type** list, choose **Tube**.

6 In the **Tube radius expression** text field, type `0.1`.

7 Select the **Radius scale factor** check box.

8 From the **Coloring** list, choose **Uniform**.

9 From the **Color** list, choose **Black**.

Selection 1

1 Right-click **Line 2** and choose **Selection**.

2 In the **Settings** window for **Selection**, locate the **Selection** section.

3 Click **Paste Selection**.

4 In the **Paste Selection** dialog box, type `22-54, 57, 58, 61, 67-74, 78-93, 97-105, 107, 109, 111, 770-801, 811-817, 819, 823-829, 831, 847-853, 855, 859-865, 867, 1510-1542, 1545, 1546, 1549, 1551-1558, 1562-1577, 1581-1588, 1593, 1595, 1597, 1599` in the **Selection** text field.

5 Click **OK**.

Line 3

1 In the **Model Builder** window, right-click **Electric Field Norm (surface)** and choose **Line**.

2 In the **Settings** window for **Line**, locate the **Data** section.

3 From the **Dataset** list, choose **Study 1/Solution 1 (sol1)**.

4 Locate the **Expression** section. In the **Expression** text field, type `1`.

5 Locate the **Coloring and Style** section. From the **Coloring** list, choose **Uniform**.

6 From the **Color** list, choose **Black**.

Selection 1

1 Right-click **Line 3** and choose **Selection**.

2 In the **Settings** window for **Selection**, locate the **Selection** section.

3 Click **Paste Selection**.

4 In the **Paste Selection** dialog box, type `66, 75, 94, 802, 820, 856, 1550, 1559, 1578, 467, 484, 508, 1239, 1255, 1278` in the **Selection** text field.

5 Click **OK**.

Surface 1

1 In the **Model Builder** window, right-click **Electric Field Norm (surface)** and choose **Surface**.

2 In the **Settings** window for **Surface**, locate the **Data** section.

3 From the **Dataset** list, choose **Study 1/Solution 1 (sol1)**.

4 Locate the **Expression** section. In the **Expression** text field, type `esbe.normE`.

5 Locate the **Coloring and Style** section. Click **Change Color Table**.

6 In the **Color Table** dialog box, select **Thermal>ThermalWave** in the tree.

7 Click **OK**.

Selection 1

1 Right-click **Surface 1** and choose **Selection**.

2 In the **Settings** window for **Selection**, locate the **Selection** section.

3 Click **Paste Selection**.

4 In the **Paste Selection** dialog box, type `1` in the **Selection** text field.

5 Click **OK**.

Electric Field Norm (surface)

In the **Model Builder** window, under **Results** click **Electric Field Norm (surface)**.

Streamline Multislice 1

1 In the **Electric Field Norm (surface)** toolbar, click **More Plots** and choose **Streamline Multislice**.

2 In the **Settings** window for **Streamline Multislice**, locate the **Multiplane Data** section.

3 Find the **x-planes** subsection. In the **Planes** text field, type `0`.

4 Find the **z-planes** subsection. In the **Planes** text field, type `0`.

5 Locate the **Streamline Positioning** section. From the **Positioning** list, choose **Uniform density**.

6 In the **Separating distance** text field, type `0.02`.

Color Expression 1

1 Right-click **Streamline Multislice 1** and choose **Color Expression**.

2 In the **Settings** window for **Color Expression**, locate the **Expression** section.

3 In the **Expression** text field, type `esbe.normE`.

Electric Field Norm (surface)

1 In the **Model Builder** window, under **Results** click **Electric Field Norm (surface)**.

2 In the **Electric Field Norm (surface)** toolbar, click **Plot**.