Magnetic 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 magnetic field is computed. Specifically, the current is set to 1000 A in this model. In transmission lines with such a high voltage, the phase lines are usually using bundled conductors. For simplicity, a single conductor for each phase line is used in this model, but its radius is larger 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.

Model Definition

The geometry of one of the towers is shown in Figure 1. It is imported from an external file in the model 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. The air around the power lines is modeled using the default **Free Space** feature in the **magnetic fields** interface.

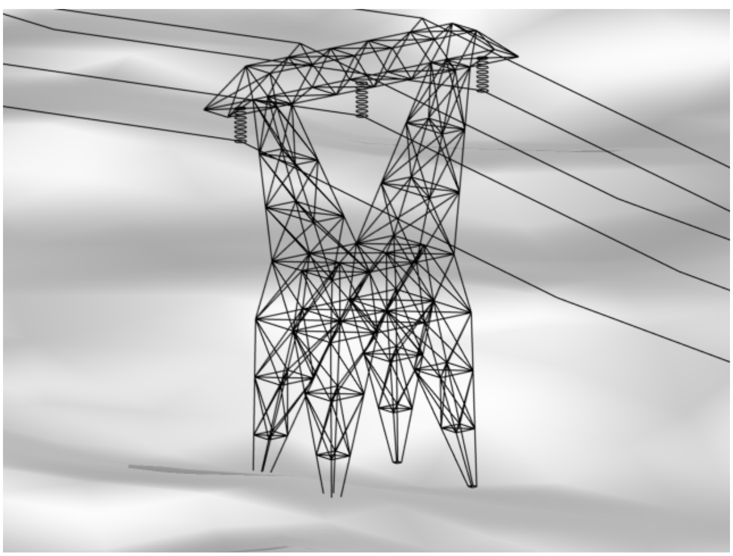

Figure 1: The geometry of the transmission tower. The two shielding lines can be seen on top, while the three phase lines are held by the insulators.

To solve the problem, use the 3D **Magnetic Fields** interface in the AC/DC Module. Since the model is solved in the frequency domain, the equation governing the problem is

$$(j\omega\sigma - \omega^2\varepsilon_0)\mathbf{A} + \nabla \times \left(\frac{1}{\mu}\nabla \times \mathbf{A}\right) = \mathbf{J}$$

where $\mathbf{A}$ is the magnetic vector potential, $\mathbf{J}$ is the current density, μ is the magnetic permeability, ε_0 is the permittivity of free space, and ω is the angular frequency. The magnetic field $\mathbf{H}$ and the magnetic flux density $\mathbf{B}$ are given by the potential as

$$\mathbf{B} = \nabla \times \mathbf{A}$$

$$\mathbf{H} = \mu^{-1}\mathbf{B}$$

On the phase lines in the model, the **Edge Current** feature sets the specified current, each one phase shifted with respect to the others. The default **Magnetic Insulation** boundary condition $\mathbf{n} \times \mathbf{A} = 0$ is imposed on all the boundaries in the model.

Results

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

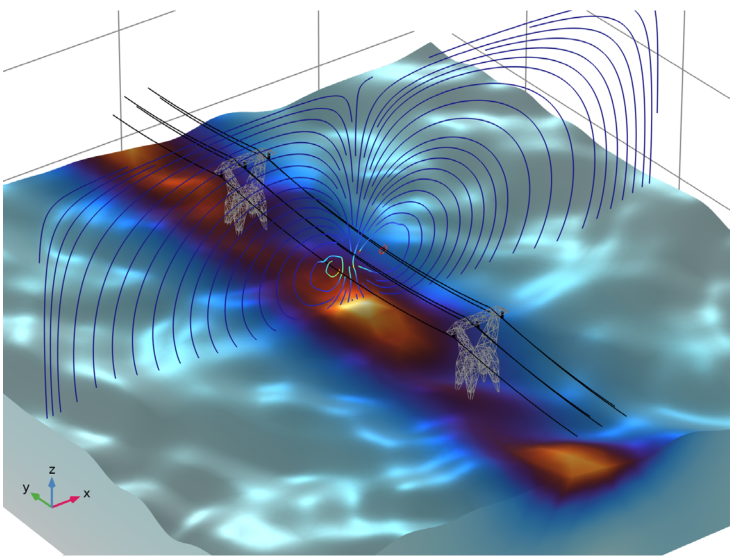

Figure 2: The magnetic field norm (surface) and the magnetic field (streamlines) from the transmission lines.

Application Library path: `ACDC_Module/Devices,_Inductive/power_line_magnetic_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>Electromagnetic Fields>Magnetic Fields (mf)**.

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
I0	1000[A]	1000 A	Power line current

For the sake of simplicity, the geometry of the model will be imported from an external file.

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_magnetic_field.mphbin`.

5 Click **Import**.

Block 1 (blk1)

1 In the **Geometry** toolbar, click **Block**.

2 In the **Settings** window for **Block**, locate the **Size and Shape** section.

3 In the **Width** text field, type `300`.

4 In the **Depth** text field, type `300`.

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

6 Locate the **Position** section. In the **x** text field, type `-150`.

7 In the **y** text field, type `-150`.

8 In the **z** text field, type `-50`.

MAGNETIC FIELDS (MF)

The air surrounding the power lines is represented by the **Free Space** feature. This adds a small value of stabilization conductivity to ensure the numerical solver converges well. In this case, a small value of 1e-3[S/m] is sufficient.

Free Space 1

1 In the **Model Builder** window, under **Component 1 (comp1)>Magnetic Fields (mf)** click **Free Space 1**.

2 In the **Settings** window for **Free Space**, locate the **Stabilization** section.

3 From the σ_{stab} list, choose **User defined**. In the associated text field, type `1e-3`.

Add **Ampère's Law** in solids to the soil.

Ampère's Law in Solids 1

1 In the **Physics** toolbar, click **Domains** and choose **Ampère's Law in Solids**.

2 Select Domain 1 only.

In the physics interface, add currents to the three phase lines.

Edge Current 1

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

2 Select Edges 76, 85, and 104 only.

3 In the **Settings** window for **Edge Current**, locate the **Edge Current** section.

4 In the I_0 text field, type `I0`.

Edge Current 2

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

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

3 Click **Paste Selection**.

4 In the **Paste Selection** dialog box, type `812,830,866` in the **Selection** text field.

5 Click **OK**.

6 In the **Settings** window for **Edge Current**, locate the **Edge Current** section.

7 In the I_0 text field, type `I0*exp(i*2*pi/3)`.

Edge Current 3

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

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

3 Click **Paste Selection**.

4 In the **Paste Selection** dialog box, type `1560,1569,1588` in the **Selection** text field.

5 Click **OK**.

6 In the **Settings** window for **Edge Current**, locate the **Edge Current** section.

7 In the I_0 text field, type `I0*exp(i*4*pi/3)`.

Add the material properties for the soil.

MATERIALS

Soil

1 In the **Model Builder** window, under **Component 1 (comp1)** right-click **Materials** and choose **Blank Material**.

2 Right-click **Material 1 (mat1)** and choose **Rename**.

3 In the **Rename Material** dialog box, type `Soil` in the **New label** text field.

4 Click **OK**.

5 Select Domain 1 only.

6 In the **Settings** window for **Material**, locate the **Material Contents** section.

7 In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Relative permeability	mur_iso ; murii = mur_iso, murij = 0	1	1	Basic
Electrical conductivity	sigma_iso ; sigmaii = sigma_iso, sigmaij = 0	0.5	S/m	Basic
Relative permittivity	epsilonr_iso ; epsilonrii = epsilonr_iso, epsilonrij = 0	10	1	Basic

Before solving, refine the mesh in order to properly resolve the geometry. This also makes the resulting plots more detailed.

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

2 In the **Settings** window for **Size**, locate the **Element Size** section.

3 From the **Predefined** list, choose **Finer**.

4 Click the **Custom** button.

5 Locate the **Element Size Parameters** section. In the **Minimum element size** text field, type 0.1.

6 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.

Magnetic Field Norm

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

2 Right-click **Results** and choose **3D Plot Group**.

3 In the **Settings** window for **3D Plot Group**, type `Magnetic Field Norm` in the **Label** text field.

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 **Magnetic Field Norm** 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 `14-31, 65, 66, 69, 70, 72-75, 86, 87, 105, 106, 116, 118, 120, 122-466, 468-476, 478-483, 485-493, 495-507, 509-517, 519-779, 813-820, 828, 831, 832, 840, 842-848, 851, 852, 854,`

856, 864, 867, 868, 876, 878-1248, 1250-1264, 1266-1287, 1289-1519, 1553, 1554, 1557, 1558, 1570, 1571, 1589, 1590, 1599-1602, 1604, 1606, 1608, 1610-1612 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 **Magnetic Field Norm** 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 32-64, 67, 68, 71, 77-84, 88-103, 107-115, 117, 119, 121, 780-811, 821-827, 829, 833-839, 841, 857-863, 865, 869-875, 877, 1520-1552, 1555, 1556, 1559, 1561-1568, 1572-1587, 1591-1598, 1603, 1605, 1607, 1609 in the **Selection** text field.

5 Click **OK**.

Line 3

1 In the **Model Builder** window, right-click **Magnetic Field Norm** 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 `76, 85, 104, 477, 494, 518, 812, 830, 866, 1249, 1265, 1288, 1560, 1569, 1588` in the **Selection** text field.
5. Click **OK**.

Volume 1

1. In the **Model Builder** window, right-click **Magnetic Field Norm** and choose **Volume**.
2. In the **Settings** window for **Volume**, locate the **Coloring and Style** section.
3. Click **Change Color Table**.
4. In the **Color Table** dialog box, select **Thermal>ThermalWave** in the tree.
5. Click **OK**.

Selection 1

1. Right-click **Volume 1** and choose **Selection**.
2. Select Domain 1 only.

Magnetic Field Norm

In the **Model Builder** window, under **Results** click **Magnetic Field Norm**.

Streamline Multislice 1

1. In the **Magnetic Field Norm** 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

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

Magnetic Field Norm

In the **Magnetic Field Norm** toolbar, click **Plot**.