Created in COMSOL Multiphysics 5.2

Effective Nonlinear Magnetic Curves Calculator

Using the Effective Nonlinear Magnetic Curves Calculator

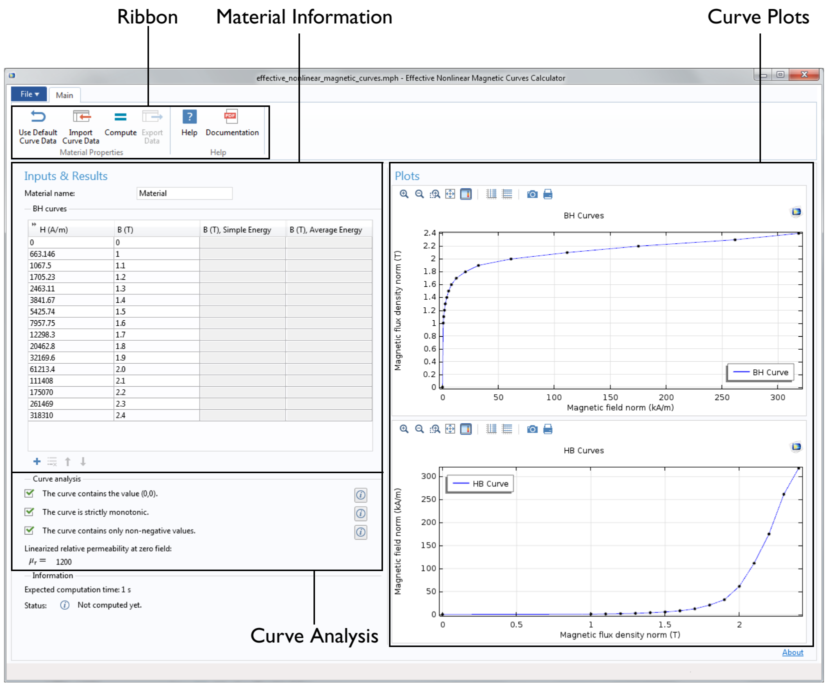
Magnetic interfaces in the AC/DC Module support the **Effective HB/BH Curve** material model, which can be used to approximate the behavior of a nonlinear magnetic material in a frequency domain simulations. This approach allows computing the approximate response of the material to a time harmonic excitation, avoiding the additional computational cost of a full transient simulation.

The **Effective HB/BH Curve** material model requires the effective $H_{eff}(B)$ or $B_{eff}(H)$ relations, which are usually defined as interpolation functions in a **Material** feature or directly in an **Interpolation** feature in COMSOL Multiphysics. This application can be used to compute such interpolation data starting from a material's H(B) or B(H) relations, which are often derived from experimental data or from literature sources.

The data for the H(B) or B(H) relations can be imported from a text file or entered in a table. The app will then compute the curves for the $H_{eff}(B)$ or $B_{eff}(H)$ relations using two different energy methods. Finally, the results can be exported either as a text file, which can be imported in an **Interpolation** feature, or as a **Material** feature in a Material Library file, which can be loaded in COMSOL Multiphysics. These features can then be used when modeling applications containing the nonlinear magnetic material.

!	For more information, see Effective Nonlinear Magnetic Constitutive Relations in the *AC/DC Module Manual*.

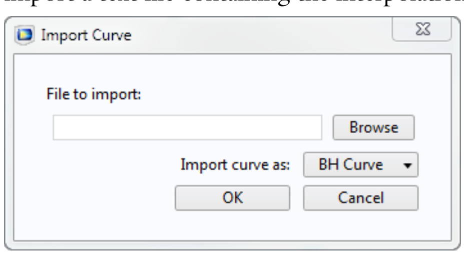
USER INTERFACE



Material Information

The **BH curves** table presents the loaded or entered interpolation data that defines the BH curve (first two columns) and, if a solution is available, the computed interpolation data describing the effective curves (other columns). The values in the first two columns, that describe the BH curve, can be modified directly in the table. Rows can be added and removed using the buttons below the table.

Click the **Import Curve Data** button in the Ribbon to open the **Import Curve** dialog and import a text file containing the interpolation data for the BH or HB curve.



In the **Import Curve** dialog, specify the file to import. The text file must contain pairs of values separated by whitespace characters or commas, with one pair for each line. From the **Import curve as** combo box, choose **BH Curve** or **HB Curve** to specify how to interpret the interpolation data. Choose **BH Curve** to import the first column as H values and the second column as B values. Choose **HB Curve** to import the first column as B values and the second column as H values.

Importing a text file will replace the existing data with the imported data, which can then be edited in the table.'

The curve data in the table can be reset to the default values by clicking the **Use Default Curve Data** button in the Ribbon.

Curve Analysis

An automatic analysis of the curve data is performed each time the curve is modified or loaded from a file. The analysis verifies that the specified BH curve satisfies three conditions:

- The curve must contain the value (0,0); that is, $B = 0$ for $H = 0$. HB and BH curves can only be used to model saturation effects, not remanent magnetization (nonzero magnetization for zero applied field). To ensure that there is no remanent magnetization, the point (0,0) must be included explicitly in the curve.
- The curve must be strictly monotonic; that is, for any two curve points (H_1, B_1) and (H_2, B_2), it must be so that $H_1 \neq H_2$; $B_1 \neq B_2$; and if $H_1 < H_2$, then $B_1 < B_2$. Since the HB curve and BH curve are inverse functions of each other, they must be strictly monotonic for the inverse function to exist. Note that the values in the table need not be sorted.
- The curve values must be nonnegative, since the curves are functions of the norms of the magnetic field and the magnetic flux density, which are nonnegative quantities.

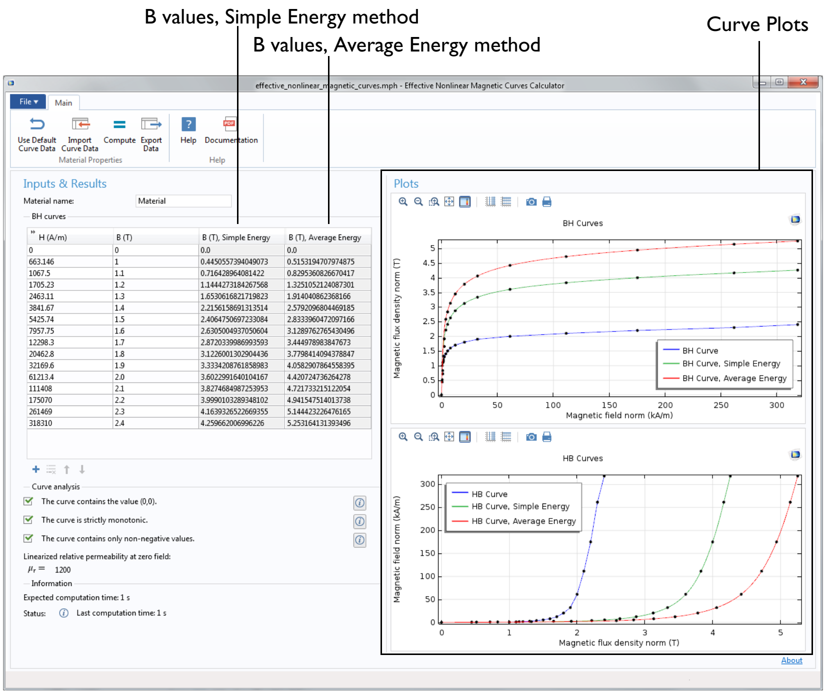
The results of the analysis are presented in the **Curve Analysis** section. The curves will be plotted only if they satisfy the three conditions.

A BH curve that does not satisfy these condition may be unphysical or cause convergence problems when used in magnetic simulations in COMSOL Multiphysics. If the imported or entered interpolation data does not fulfill the conditions, modify the values in the table to correct the problems.

The linearized permeability at zero field (the slope of the curve at $H = 0$) is also computed and displayed in the **Curve Analysis** section.

Computing the Effective Curves

Once the data for the BH curve has been entered or imported, click the **Compute** button in the Ribbon to compute the effective curves using the Simple energy and Average energy methods. The computation takes a couple of seconds on a typical desktop computer. Once the computation is complete, the table is populated with the values of effective B corresponding to the values of H. The plots are updated to show the computed effective curves.

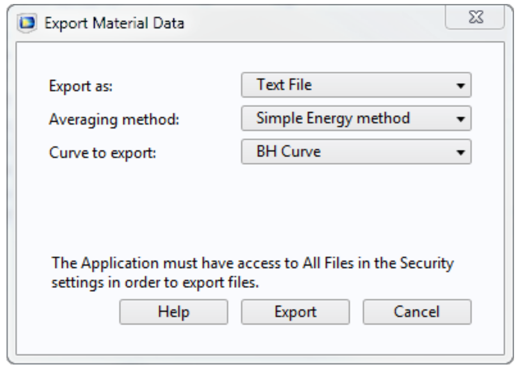


Exporting the Data

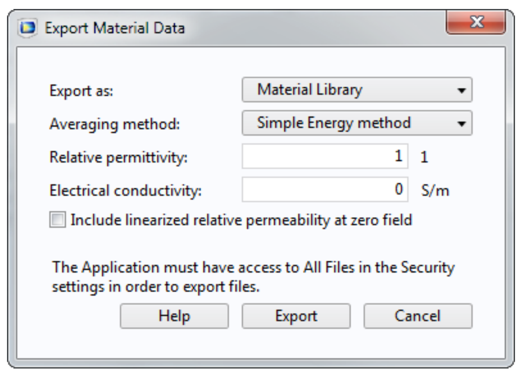
The computed interpolation data can be exported in order to be used in other COMSOL Multiphysics applications. Click on the **Export Data** button in the Ribbon to open the

Export Material Data dialog. From the **Export as** combo box, select the desired export format.

- Choose **Text file** to export a single curve as interpolation data in a text file. Select the curve to export using the **Averaging method** and the **Curve to export** combo boxes. Then click the **Export** button and specify where to save the exported file. In the exported text file, each line will contain a pair of values giving the position of an interpolation point. A file in this format can be imported, for example, in an **Interpolation** function node in a COMSOL Multiphysics application.



- Choose **Material Library** to create a COMSOL Multiphysics Material Library file (in `.mph` format) containing a single material with the material data computed by this app. The exported file can be added to COMSOL Multiphysics from the **Material Browser** by clicking the **Import Material Library** button. The exported material will contain these material models: **HB Curve**, **BH Curve**, **Effective HB Curve**, and **Effective BH Curve**. Select the curve to use for the Effective material models by means of the **Averaging method** combo box. The material will also contain definitions for relative permittivity and electrical conductivity with the values specified in the corresponding input fields, which means it can be used directly when performing simulations using a magnetic physics interface in COMSOL Multiphysics.



  If the **Include linearized relative permeability at zero field** check box is selected, the material will also contain a definition for the relative permeability with the value obtained from linearizing the HB/BH curves, so it can be also used as a linear material.

The Embedded Model

The embedded model uses two methods to compute the effective nonlinear magnetic curves for the material: the Simple energy method and the Average energy method. The effective magnetic flux density strengths are computed as:

$$B_{\mathrm{SE}} = \frac{2}{H}\int_0^H B(H)dH$$

$$B_{\mathrm{AE}} = \frac{16}{TH}\int_0^{T/4}\left(\int_{H(0)}^{H(t)} B(H)dH\right)dt \tag{1}$$

where H is the amplitude of the (time-harmonic) magnetic field, B(H) is the material's nonlinear BH relation, H(t) is the time-dependent oscillating magnetic field and T is the (arbitrary) period of the oscillation.

The app performs the integrations in a fictitious geometry consisting of two 1-dimensional entities, which represent the values of the magnetic field and the magnetic flux density. The size of the geometrical entities depends on the maximum strength of the fields and is adjusted dynamically according to the application inputs.

The embedded model does not contain any physics interfaces, because all of the calculations are performed during the **Compile Equations** phase of the study, or directly as postprocessing operations. Once the computation is performed, the numerical interpolation data for the effective curves is evaluated using **Point Evaluation** features.

Application Library path: `ACDC_Module/Applications/effective_nonlinear_magnetic_curves`
