

1 Coaxial Cable Model in HIFREQ

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1.1 Introduction

Coaxial power cables are used extensively in the electrical industry. Since the electromagnetic field is confined inside the cross-section of a cable, they can be easily installed in small spaces and buried underground.

Power cables can be easily studied in CDEGS using TRALIN and SPLITS, with TRALIN computing the line parameters of the cable and SPLITS computing the voltage and current distribution in the network based on circuit theory. However, prior to this version of the software, it was always difficult to model power cables and grounding systems simultaneously.

This has changed in this version of CDEGS, with the implementation of a cable model in HIFREQ. Cables in HIFREQ can be specified in much the same way as ordinary conductors. They can be energized and connected to other cables, or to ordinary conductors. Moreover, the electromagnetic fields computed by the program include the contribution of the cables.

This article describes the coaxial cable model in HIFREQ. It shows how to specify the cable data, and provides some examples to demonstrate the fundamental features of the cable model.

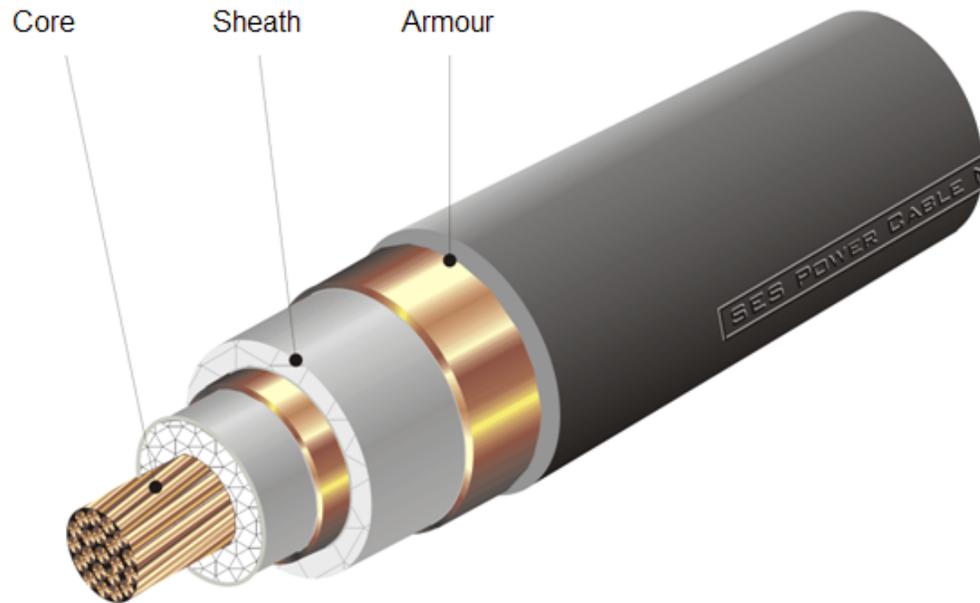


Figure 1-1: A coaxial cable

Note: The HIFREQ input files for all the cases described in this article are located in the folder "User's Group\Input Files\Coaxial Cable Model in HIFREQ" on your DVD.

1.2 Coaxial Cable Model in HIFREQ

1.2.1 Overview

A typical coaxial cable consists of a core, a sheath and armor, as shown in Figure 1-2. The cable data includes the outer and inner radii of the metallic layers, as well as the resistivity and permeability of the metal in each layer. The space between two neighboring metallic layers is filled with insulation material. The insulation material can be different for each individual insulation layer. There is also an optional coating on the outside of the cable.

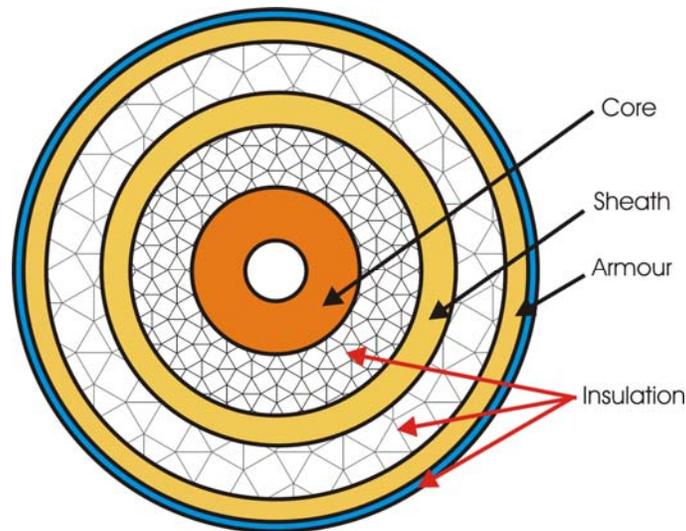


Figure 1-2: Configuration of a coaxial cable

In HIFREQ, the combination of a metallic layer and the insulation outside of it is known as a *cable component*. Presently, HIFREQ can model coaxial cables with up to three cable components. (Future versions of the program may introduce support for unlimited number of components as well as for Pipe-Type cables).

The specification of a cable in HIFREQ proceeds by first defining a *cable type*, i.e., by providing the above data for all components of the cable. Then, an ordinary conductor can be turned into a cable by setting its *cable-type code* to a non-zero value. This is similar, for example, to the way in which a coating is specified on a conductor.

When running a case that contains cables, HIFREQ internally generates one conductor segment for each component of a cable. These conductor segments all occupy the same physical location (the program was modified to avoid reporting overlaps between those conductor segments). Since these conductor segments all occupy the same location, this causes an ambiguity when conductors and cables intersect. The following rules apply by default:

- When an ordinary conductor intersects a cable, it is assumed to connect to the *core* of the cable.
- When two cables intersect, the connections are assumed to occur on a component by component basis, i.e. core to core, sheath to sheath, and armour to armour. (If a component is missing in one of the cables, the corresponding component in the other cable is left unconnected.)

For cases where the above connection scenarios are inappropriate, it is possible to specify an explicit connection between any two cable components (even on the same cable) using the new CONNECTION command. This command establishes a connection between the extremities of two conductors or cable components, allowing current to flow between them even if they are not at the same physical location.

1.2.2 Limitations of the HIFREQ Cable Model

Some limitations apply to the new cable model in HIFREQ:

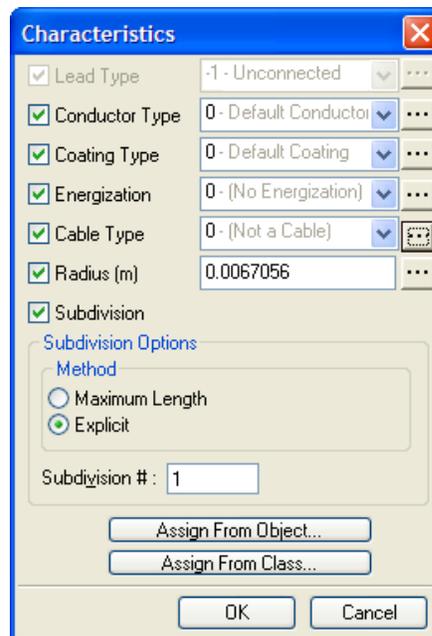
- Cables can only intersect with other conductors/cables at their *extremities*. Other types of intersections are forbidden, and are reported as errors.
- No energization can be assigned directly to the components of a cable. To energize a cable, an ordinary conductor must be specified and energized, then connected to the appropriate cable component.
- Pipe-type cables are not supported.

1.2.3 Specifying Coaxial Cable Data

In the present version of the software, cables can only be created and edited in SESCAD. The Input Toolbox (CDEGS – Specify Mode) can read and save the cable data, but cannot modify it. Note that the cable model is a feature of the HIFREQ program only: the tools related to the cable model are not active for MALT and MALZ.

Specifications of Cables

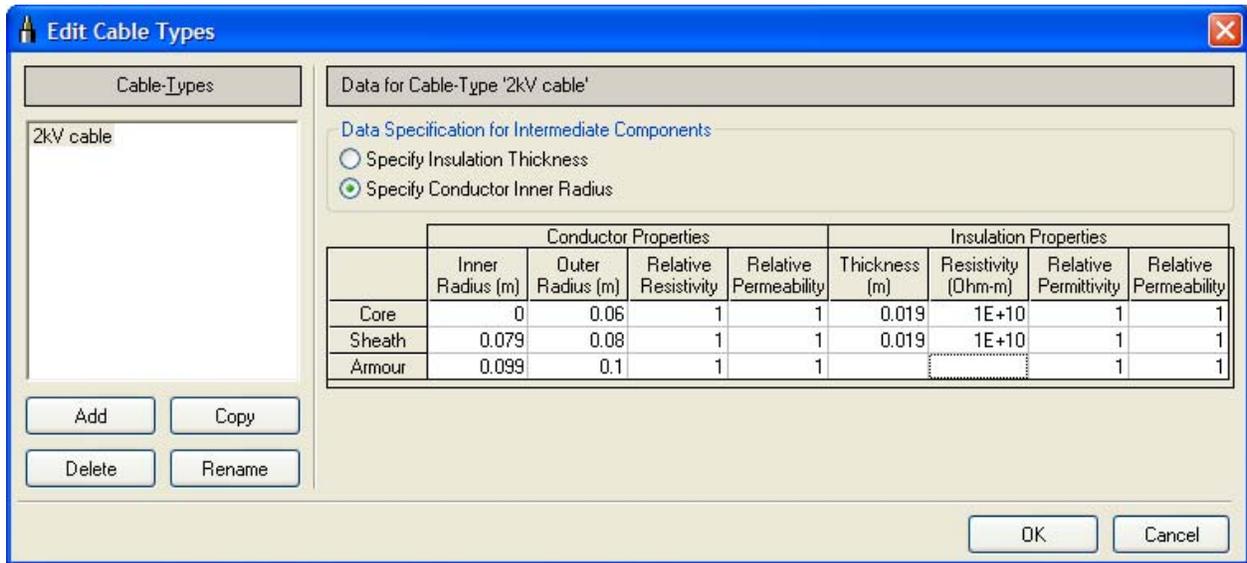
Specification of a cable in SESCAD is quite easy: you can define the **Cable Type** of selected conductors from the 'Characteristics' window (**Edit | Characteristics**).



Specifying 0 for the **Cable Type** indicates that the selected conductors are not cables; specifying a non-zero value indicates that the selected conductors are cables of the specified type.

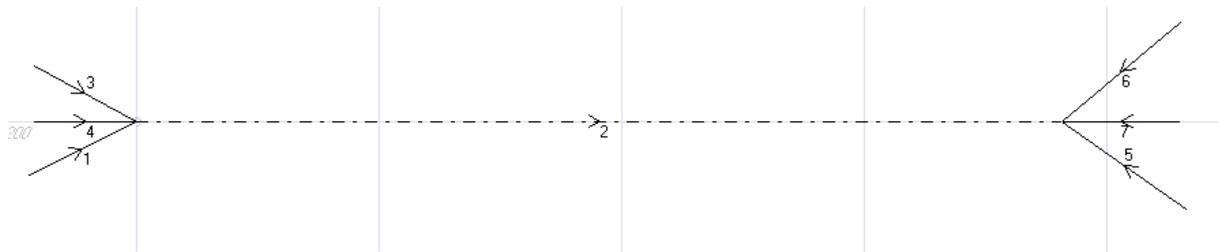
To specify the properties of a cable-type, click the  button located to the right of the **Cable Type** item in the 'Characteristics' window: this brings up the 'Edit Cable Types' window. (You can also use **Advanced | View/Edit Cable Types** to get this window.) This

window can be used to add or delete cable types, or to edit the properties of the cable types that are defined in the file.

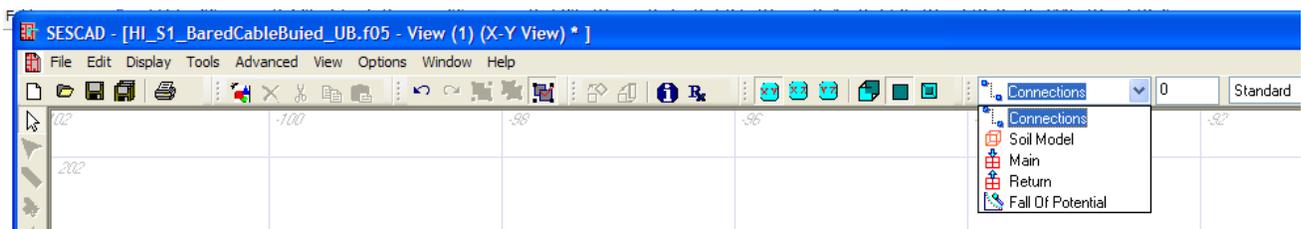


Specifications of Connections

In SESCAD, a cable is displayed as a single dashed line although the cable generally consists of more than one individual conductor. As mentioned before, this introduces difficulties when trying to connect conductors to cables, since it isn't clear which component of the cable should connect to the conductor, and this has led to the introduction of the notion of *connection*.



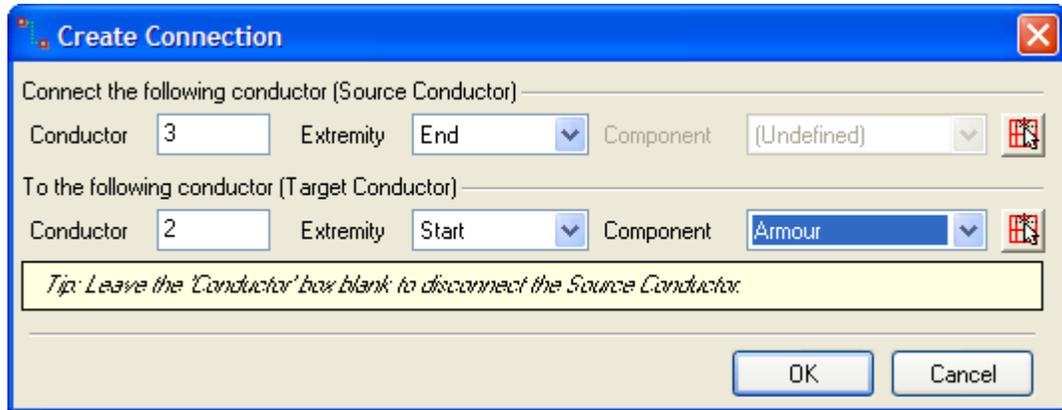
Connections in SESCAD are special objects that link the extremities of two conductors. Connections are located in a special "Connections" layer, which can be activated from the drop-down list located at the top of SESCAD's main window. Connections can only be edited when this layer is activated.



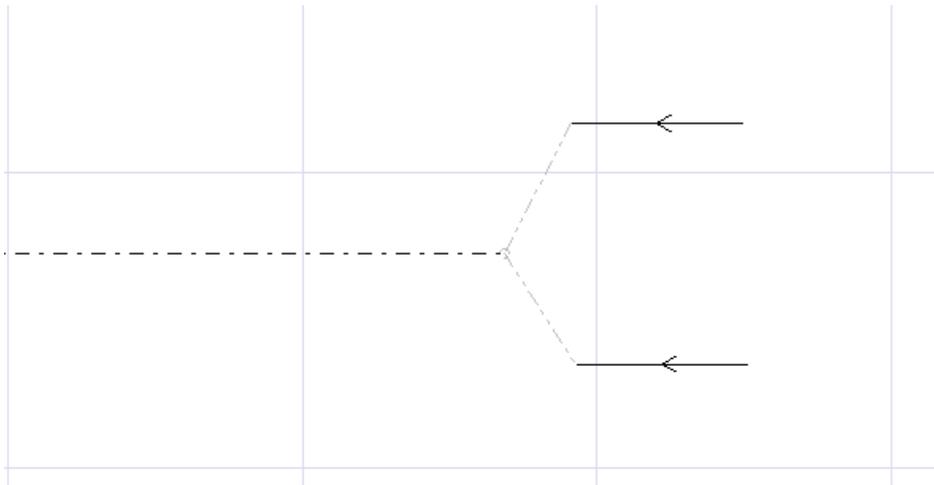
When the "Connections" layer is active, connections can be created by clicking **Edit | Create Object**. In the **Create Connection** window, you can specify the conductor numbers of the **Source Conductor** and of the **Target Conductor**, and select which extremity of each

conductor is to be connected. These operations can be done graphically by clicking on the “Pick” button  at the right of the screen, and clicking on a conductor in the drawing.

If one of the conductors is a cable, the corresponding **Component** drop-down list is active and allows you to select the cable component to be connected.



Connections are displayed (by default) as “dash-dot-dot” lines. Connections can be deleted in the same way as for any other objects. They are also deleted automatically if one of the conductors that are part of the connection is deleted. Connections move automatically when the conductors that are being connected are moved. However, they cannot be moved directly since, by definition, they are tied to the conductors that are being connected.



New and Updated Commands for Cables

A few new SICL commands have been added in HIFREQ to record the data of cables and the connection information in HIFREQ input files (F05). Also, the CONDUCTOR command has been modified through the addition of one variable (CABLE-TYPE). These changes are described below:

New Commands:

CABLE-TYPE, *Name*

COMPONENT, *CORE/SHEATH/ARMOUR*, *ConductorRadius*

METAL, *Rel_Resist*, *Rel_Permea*, *Inner_Radius*, *Capacit1*, *Res*, *Working_Poten*

INSULATION, *Resistivity, Thick, Rel_Permit, Rel_Permea*

CONNECTION, *SourceConductorID, SourceComponentID, SourceExtremityID, TargetConductorID, TargetComponentID, TargetExtremityID*

Modified command:

CONDUCTOR , *Lead_Type , Cond_Type , Coat_Type , Energ_Type , Xorig , Yorig , Zorig , Xend , Yend , Zend , Radius , Nb_Segments , GroupIndex , ObjectType, Cable_Type*

1.2.4 Presentation of the Computation Results

The fact that all components of a cable occupy the same physical location in the system introduces some difficulties when presenting the computation results in Configuration plots. HIFREQ presents the cable results in a special way: the data for the core stays at the initial position of the cable, the data for the sheath is shifted to the right of the system, and the data for the armour is shifted even more to the right of the sheath data. See Figure 1-3 for an example of this type of display.



(a) Cables modeled in SESCAD



(b) Computation results conductor data are displayed separately for core, sheath and armour

Figure 1-3 : Display of computation results of cables

1.3 Examples

In this section, several examples are presented to demonstrate the basic behavior of cables in HIFREQ.

1.3.1 Capacitive Coupling: Coaxial Cable with a Grounded Sheath

Figure 1-4 shows a setup used to demonstrate the capacitive coupling and shielding of a conductor. A long horizontal conductor with a length of 200 m is located 10 meters above the ground. The right half of the conductor (100 m) is placed inside a metallic tube to form a coaxial cable. A 200 m long observation profile is placed at 0.5 m under the conductor. The conductor (core) is energized with 1000 Volts; the sheath is grounded at one end. The radius of the core is 60 mm, the outer radius of the sheath is 80 mm, and the thickness of the sheath is 1 mm.

[Input File: HI_Core-GroundedSheath_FieldShield_capacitive.F05

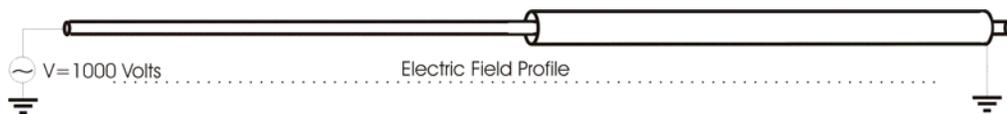


Figure 1-4 : A coaxial cable setup to demonstrate the capacitive behavior of a cable

Figure 1-5 shows the potential along the profile. It shows that the induced potential under the unshielded conductor (left half) is about 450 Volts. The potential is almost zero along the profile under the shielded portion (right half). This is the expected behavior.

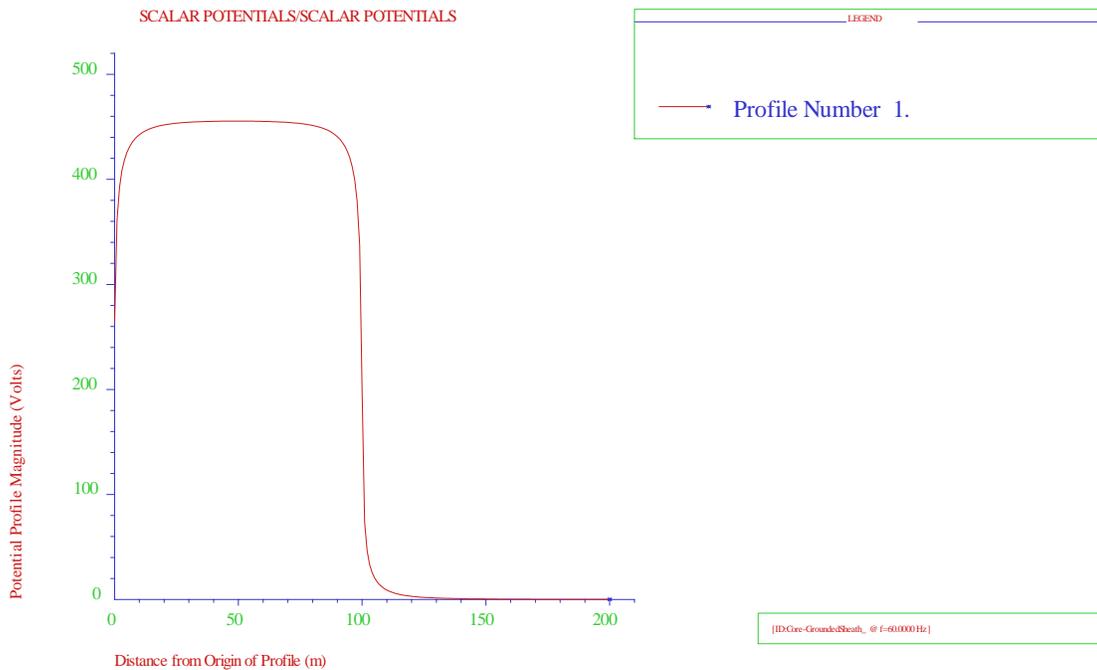


Figure 1-5: Potential close to unshielded and shielded conductors

1.3.2 Inductive Coupling: Coaxial Cable with a Grounded Sheath

The configuration used to study inductive coupling (Figure 1-6) is similar to that shown in Figure 1-4, with the exception that the energization is modified: the core of the cable is energized with a current of 1000 Amperes, and the sheath is grounded at both end to form a loop. The magnetic field along the profile under the conductor is examined.

[Input File: HI_Core-GroundedSheath_FieldShield_inductive.F05

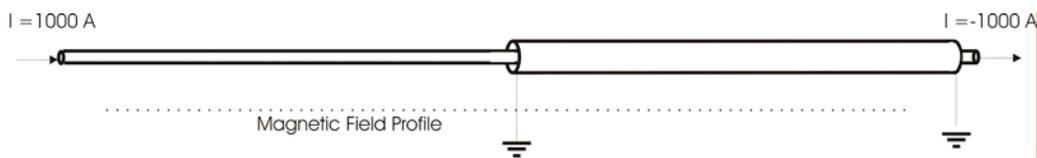


Figure 1-6 : A coaxial cable setup to demonstrate the inductive behavior of a cable

Figure 1-7 shows the magnetic field along the profile. The induced magnetic field under the unshielded conductor (left half) is about 320 A/m. The magnetic field is almost zero along the profile under the shielded portion (right half). Again, this is the expected behavior.

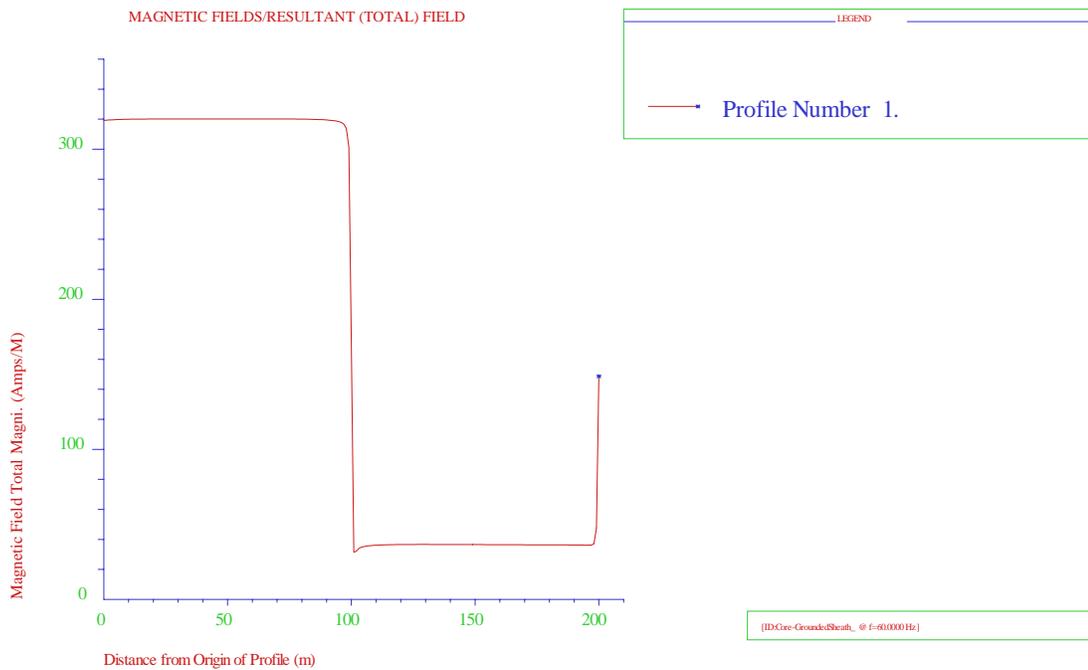


Figure 1-7 : Magnetic field close to shielded and unshielded conductors

1.3.3 Current Flow in Cable

Figure 1-8 shows a three-component coaxial cable in the air. The energization of the cable is very special. At the left extremity, a current of 1000A is injected in the core and the sheath and the armour are interconnected. At the right extremity, the core and the sheath are interconnected, and the armour is energized with a current of $1000 \angle 180^\circ$ Amperes, thereby collecting the current that was injected at the other end of the cable. This particular setup verifies the behaviour of user-defined connections.

Input Files: HI_Core-GroundedSheath_CurrentFlow.F05

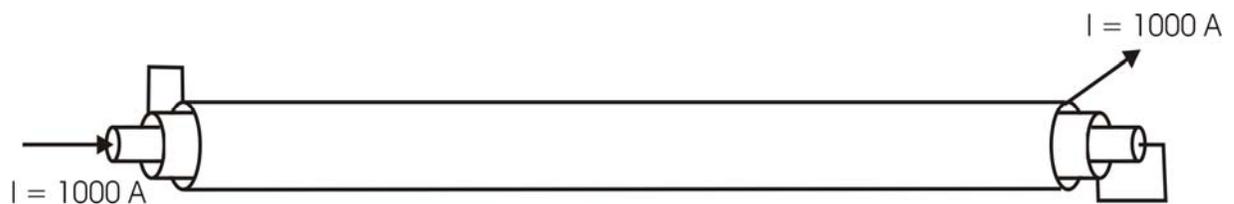


Figure 1-8: Connections of three-component coaxial cable

In

Figure 1-9, the current flowing in the cable is displayed, with the cable represented as three separate conductors, the core to the left of the figure, the sheath in the middle, and the armor to the right. The figure shows that the current flows from the left to the right side in the core, from the right to the left side in the sheath and from the left to right side in the armor. This is the expected behavior.



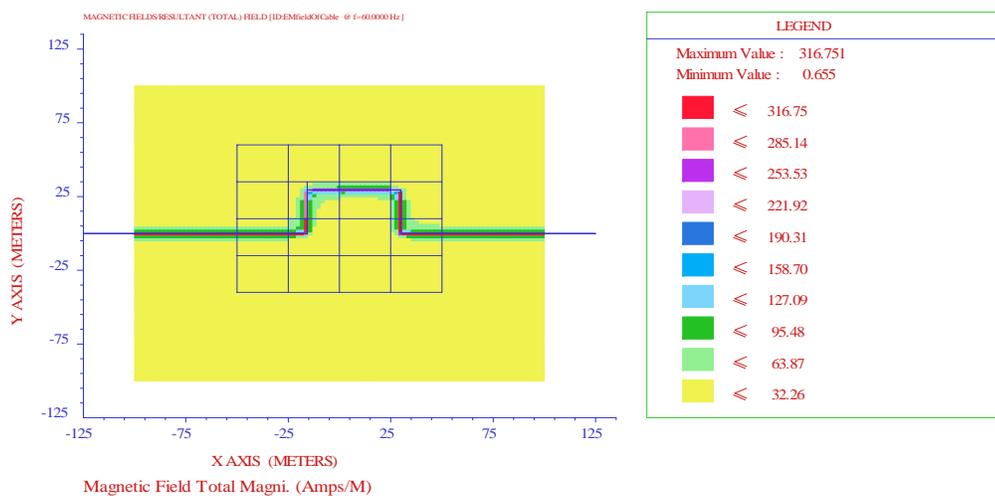
Figure 1-9: Current flow in the metallic layers of a cable

1.3.4 The Electromagnetic Fields near an Energized Cable

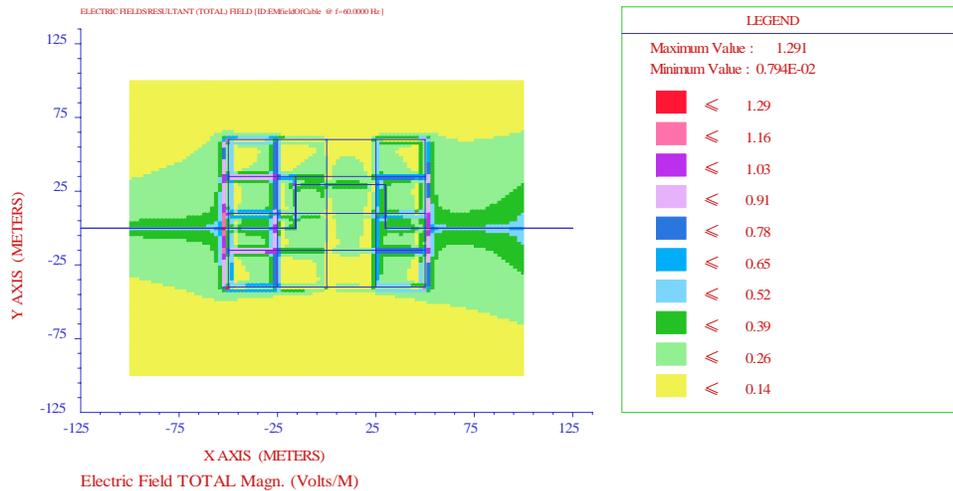
Before the cable model was implemented in HIFREQ, it was possible to use the TRALIN and SPLITS modules to determine the current flowing in the metallic layers of a cable; however, computing the electromagnetic fields in the vicinity of a grid when cables were involved was more complex. With the new implementation of the cable model in HIFREQ, the electromagnetic fields of this complex system can be computed accurately in a single run.

In this example, a 50 kV power cable is buried at a depth of 0.5 m in a two-layer soil (1000/100 Ω -m with a top layer thickness of 2 meters). The current in the cable is 1000 Amperes. The cable consists of a core and a sheath. The radius of the sheath is 0.016 meter, and its thickness is 1 mm. The radius of the core is 0.015 m. The sheath is connected at one location to a grounding grid underneath the cable. An observation surface is placed at the earth surface, above the cable.

Input Files: HI_EMfieldOfCable.f05



(a) The magnetic field distribution



(b) The electric field distribution

Figure 1-10: The field distribution on the earth surface above a cable

Figure 1-10 shows the magnetic field and the electric field on the earth surface above the area. It can be seen in Figure (a) that the maximum magnetic field generated by a buried cable is 316 A/m. From Figure (b), it can be seen that the electric field generated by a buried cable is very small. Therefore, a buried cable can generate very strong magnetic fields if the sheath is not well grounded at both ends of the cable, but the electric field is negligible. This result is expected.

1.4 Conclusion

A coaxial cable model is now available in the HIFREQ module. It can be used to model coaxial cables together with ordinary conductors. The cable can have a core, a sheath and an armour. With this enhancement, complex grounding systems including cables can be analyzed in a single model.