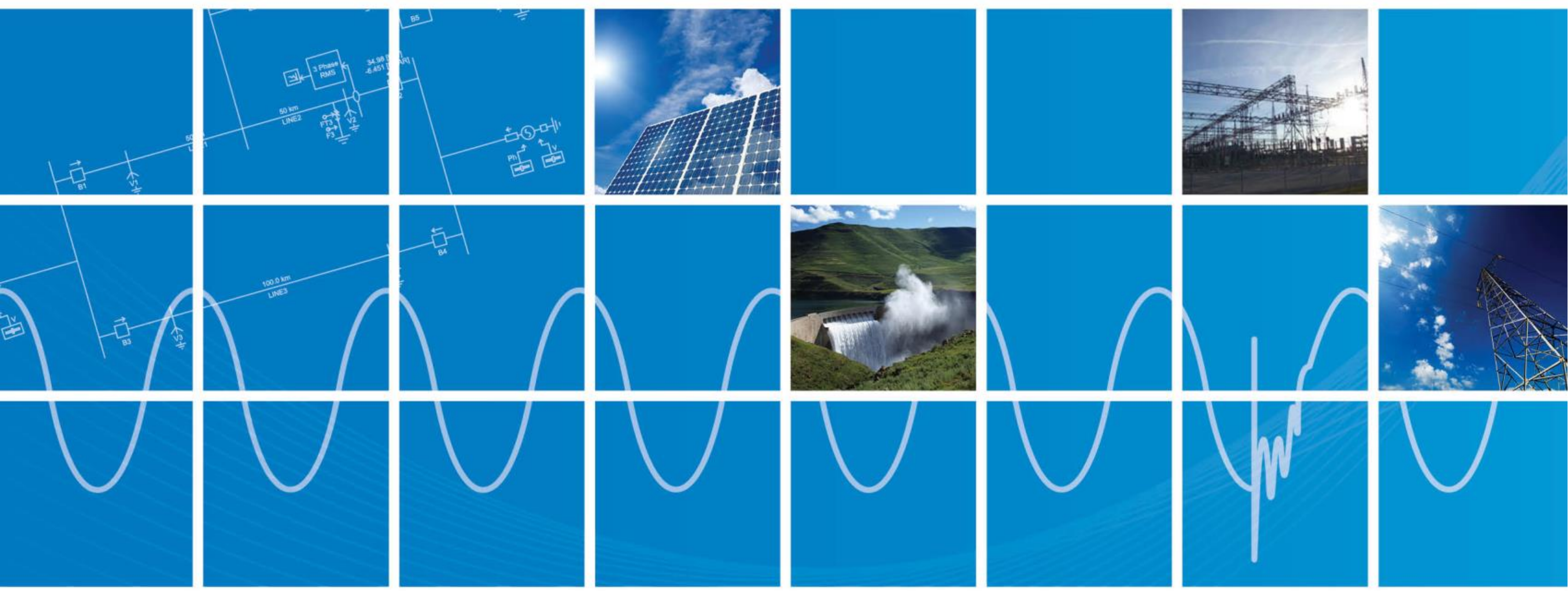
PSCAD™

Overhead Lines and Cable Modeling Guidelines for PSCAD

Written for PSCAD X4 and V5

May 29, 2023
Revision 1



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CONTENTS

1. Introduction

The purpose of this document is to address frequent support questions and to help in modeling of transmission lines.

2. Modeling transmission lines

The cable or overhead line model can be created in PSCAD as shown below. (For details, see PSCAD help (PSCAD>Transmission Line and Cables) and also transmission line page in the master library)

2.1. Three phase overhead line

Step1: To create an overhead line in PSCAD, click on canvas of PSCAD case, select “Component Wizard”, and follow instructions.

Step 2: Double-click on transmission line and go to the definition page. Click on canvas and select, “add tower cross-section”>”master library”>”Line constant three conductor flat tower”.

(see example overhead_example1.pscx)

2.2. Three Phase Underground Cable System

Step 1: To create an underground cable in PSCAD, click on canvas of PSCAD case, select “Component Wizard”, and follow instructions.

Step 2: Double-click on cable model and go to the definition page. Click on canvas and select “add cable cross-section”>”master library”>”Cable constants coaxial cable data”. Add two mode cables. Click on the cable and set the “cable number” of each cable as 1, 2 and 3 respectively. In addition, set the “horizontal translation from center” as 0, 1, 2 m respectively.

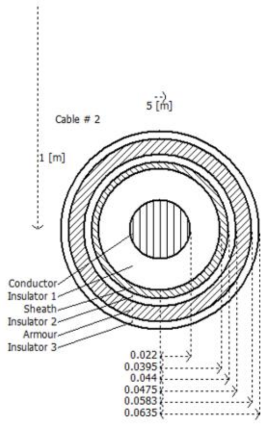
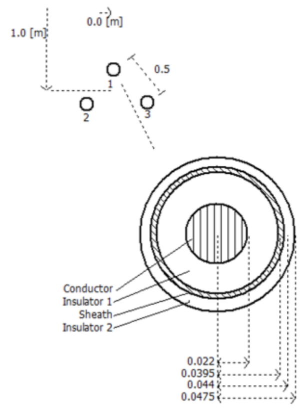
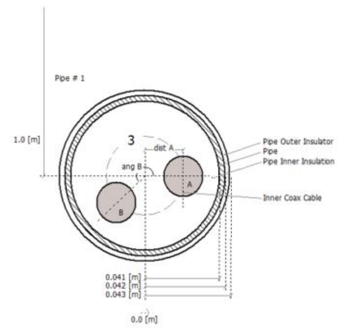
Step 3: Go back to the main canvas and click on canvas and select “Add component”>”cable interface”. Click on cable interface and set “Number of coaxial cables” to 3. Since each cable has main conductor and sheath as conducting layers, in the “External electrical connection”, the “Coaxial Cable 1” is set as conductor/sheath. Similarly set external connections for other two cables.

(see example cable_example1.pscx)

(see Appendix 1: Comparison of transmission line models in PSCAD and also Appendix 6)

2.3. Cable Models in PSCAD

There are mainly two types of cable models, one is coaxial cable model and other is pipe-type cable model.

<table>
<tr><th>Model</th><th>Coaxial cable</th><th>User Friendly Coaxial cable</th><th>Pipe-type cable</th></tr>
<tr><td></td><td>
</td><td>
</td><td>
</td></tr>
<tr><td>Typical Application</td><td>Land Cable</td><td>Land Cable</td><td>Submarine cable</td></tr>
</table>

2.4. Frequently Asked Questions

1. What is the difference between “Coaxial cable” and “User Friendly Coaxial cable” model?

They are both coaxial cables and theoretically, they are identical. However, the User-Friendly cable model is used to model an underground cable system from a datasheet more conveniently. The advantages are,

- Directly model three AC cables or two DC cables in flat or trefoil configurations
- Cable parameters from datasheets can be directly used without manual conversion
- Temperature corrections
- Typical cable parameters

2. When do I have to use pipe-type cable?

If there are coaxial cable models surrounded by a **common conducting layer** (wired armor etc. in submarine cable), pipe-type cable can be used. If there is no such common conducting layer (e.g. only common insulating layer exits), then model using individual coaxial cables neglecting common insulator layer.

2.5. What is the time step I can use for simulation?

The solution time step (default 50 us) for the simulation should be carefully selected and it depends on higest frequency of interest and also the smallest transmission line (travalling wave based) in the system. If you go to the OUTPUT page of any transmission line model (Bergeron or Phase model), you can see,

MINIMUM TIME DELAY AND RECOMMENDED TIME STEP

Minimum Time Delay for the Line [ms]: 0.581563256

Recommended Time Step for the Line [ms]: 0.058156326

In this example, the time step should be less than 0.581563256 ms. However, to get adequate accuracy of simulation, time step should be further decreased. So, a typical time step can be selected as 1/5 or 1/10 of the Time Delay of the line (or even ½).

3. Cable Modeling from Datasheet

The cable models require material properties and dimension data. These data can be obtained from manufacture datasheets.

First, clearly identify conducting layers, semi-conducting layers and insulation layers from different layers specified in the datasheet. For typical transient simulation, the correct modeling of conductor, main insulation and sheath is important. Usually manufactures accurately define conductor information (e.g. dc resistance and outer radius). The main insulation can be modelled accurately, if the capacitance is provided. In modelling cables, from datasheet

1. Prioritize data and neglect others
2. Combine adjacent layers of same

    e.g. Dual layer sheath

3. Make approximations

    e.g. Wired sheath, SC layers, stranded or segmented conductor

4. Perform temperature corrections
5. Neglect layers

Note: The sheath data (e.g. sheath dc resistance) is important, but sometimes it is difficult to find in the datasheet. The cable data may be average values not actual values (e.g. if the SC layer thickness is defined as 1 .5 mm, if measured accurately it can be 2.0mm or 1.0 mm). Sometimes, the manufactures define maximum and minimum values of data. Therefore, it is an engineering judgment on how much detail we should model/consider.

For detail information and example, see Appendix 2.

4. Sequence RXB Comparison

If the sequence RXB data is provided in the cable datasheet, we can compare it with PSCAD model sequence data. However, there can be differences between RXB defined in datasheet and PSCAD RXB output.

Note that,

1. Manufacturer uses simplified equations only valid at power frequency to calculate RXB data
2. PSCAD uses more accurate formulas valid for wider frequency range (e.g. from dc to few MHz)

4.1. Possible Reasons for Difference in Sequence RXB

1. Manufactures define seq. RXB based on series of assumptions/settings different from PSCAD settings

   e.g. trefoil, touching, ideally cross-bonded configuration

2. Poorly defined parameters or incorrect or missing information in datasheet

   e.g. unavailability of sheath resistance

3. Temperature corrections
4. Other assumptions including definition of return path

4.2. RXB Tool for Power Frequency Validation for Coaxial Cable System

This validation tool can help in analyzing the seq. RXB data. This tool uses the same formulas manufacturers used. PSCAD/EMTDC uses complicated formulas to compute parameters that are valid for wide frequency range. However, at power frequency, the RXB data from the tool should be in close agreement with RXB from PSCAD cable model output and with that of the manufacturer data. The following two steps help to identify the case of the mismatch between RXB values.

Step 1: Validate Input Data

With manufacture settings for RXB (e.g. trefoil, touching, ideally cross-bonded configuration), the RXB tool should give close agreement with RXB from datasheet.

i.e. RXB from the tool ~= RXB data defined in the datasheet

If there is no good match, this implies that fundamental input data and assumptions may be not correct. Try to change settings such as distance between cables, enable or disable temperature correction, poorly defined parameter values such as sheath resistance etc.

If there is a close agreement, now we are confident about our data.

Step 2: Validate PSCAD cable model

With actual settings of cable system (e.g. flat configuration without cross-bonding as in PSCAD cable model), match RXB data from the tool with RXB data in the PSCAD output file.

i.e. RXB from the tool ~= RXB data of PSCD cable model

Note: Usually a close match can be found, if step 1 is achieved. For further details of RXB validation tool, see Appendix 3.

4.3. Limitation

This validation tool is applicable to three coaxial cables only, not for pipe-type or submarine cables

(The validation tool is available in the Intermediate Library for PSCAD v5.0.0,

https://www.pscad.com/knowledge-base/article/808)

5. Mutual coupling

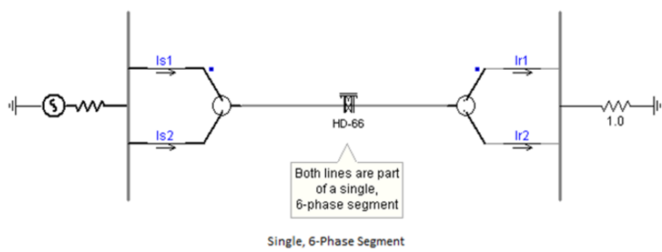
If there are parallel transmission lines, there can be induced voltages current on each other depending on many factors such as distance between them, conductor arrangements, transposition etc. In PSCAD, the mutual coupling among towers, cables, pipes is possible.

5.1. Mutual coupling between overhead lines

If the multiple overhead towers (or multiple cable segments) are in parallel and the mutual coupling between them can be done in two ways.

<u>Method 1: Model all towers in same line model</u> (**recommended method)**

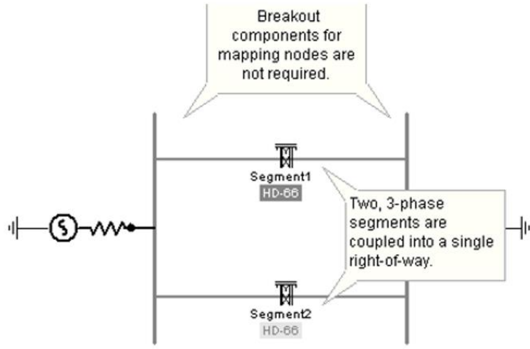
If the multiple towers (or cables) are modelled in a single transmission line model, the mutual coupling is automatically considered. It is important to properly set **phase/node connection** in towers.
(see example cases for details)



<u>Method 2: External mutual coupling</u>

If the transmission towers (or cable systems) are modeled separately as line or cable models, the mutual coupling between models can be enabled by enabling mutual coupling.

- Make sure to define “segment-end specification” as either sending or receiving (NOT automatic) with “remote-ends” connection. Otherwise results may not be accurate.
- May not be accurate with “direct” connection.



Two Mutually Coupled, 3-Phase Segments

5.2. Mutual coupling between cables

This can be done in the similar approach described in section 5.1.

<u>Limitation</u>

The above methods are NOT applicable to mutual coupling between overhead lines AND cables.

5.3. Mutual coupling between Overhead lines, cables, pipes [New in PSCAD V5]

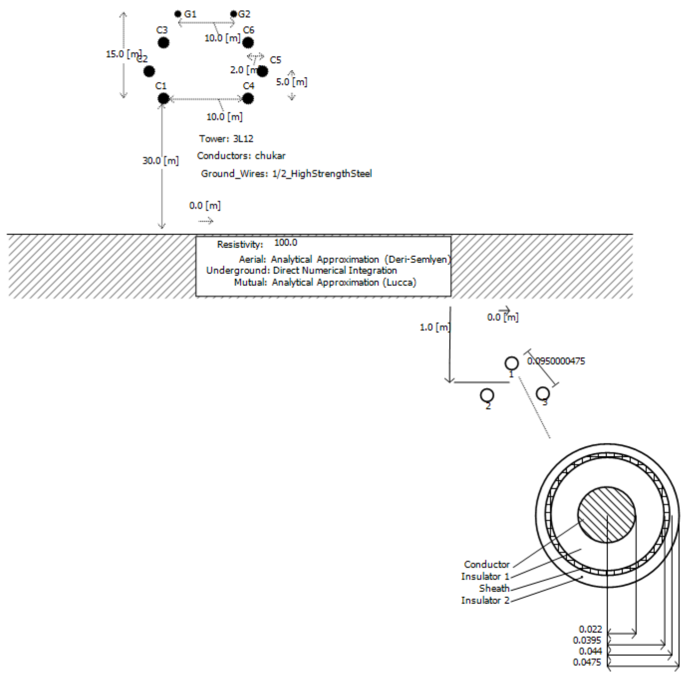
The mutual coupling between overhead lines, cables and pipes can be done in PSCAD V5 via a newly developed Super General Cable Algorithm (SGCA). The cable algorithm is generalized to model any combination of overhead lines towers, coaxial underground/aerial cables, pipes with all details.

To model parallel lines, aerial or underground cables or pipes, simply model everything in a single cable model. The mutual interactions are automatically considered in the algorithm.

In the cable model in PSCAD V5, example interactions studies that can be done are,

1. Mutual interaction between multiple towers
2. Mutual interaction between underground mutiple coaxial cables
3. Mutual interaction between towers and underground coaxial cables
4. Mutual interaction between towers and aerial coaxial cables (above ground)
5. Mutual interaction between towers and coaxial aerial pipes
6. Mutual interaction between towers and underground pipes
7. Mutual interaction between aerial mutiple cables

8. Mutual interation between aerial and underground coaxial cables



Limitation

The pipe-type cables are usually modeled separately as the pipe conductor shields the EM effect of inner cables and hence the induced voltages/currents on adjacent coaxial cables/pipe-type cables can be negligible. The interactions between multiple pipe-type cables or pipe-type cables and coaxial cables/towers can not be modelled.

Setting Cable interface

The cable interface defines connection between electrical network and cable configuration. The connections to the cables should be listed first. For example, if a three-phase tower and three cables are modelled, in the cable interface,

- *General*
    - Number of coaxial cables = 6 (three cables + three phase conductors in tower. Each conductor in towers is considered as a cable)

- *External electrical connections*
    - Coaxial cable 1 = conductor/sheath (this is cable #1 in cable definition page)

- Coaxial cable 2 = conductor/sheath (this is cable #2 in cable definition page)
- Coaxial cable 3 = conductor/sheath (this is cable #3 in cable definition page)
- Coaxial cable 4 = conductor (this is conductor #1 of tower in cable definition page)
- Coaxial cable 5 = conductor (this is conductor #2 of tower in cable definition page)
- Coaxial cable 6 = conductor (this is conductor #3 of tower in cable definition page)

Example cases

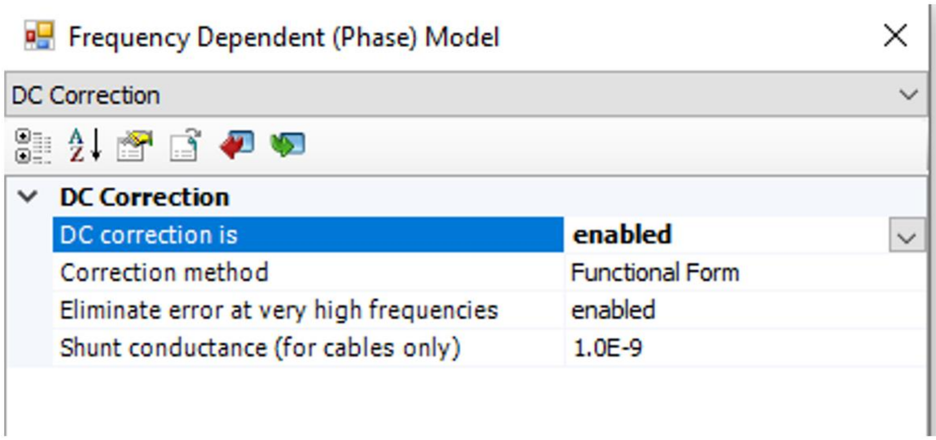
mutual_coupling_CAB_V5.pscx

mutual_coupling_OHL_CAB_V5.pscx

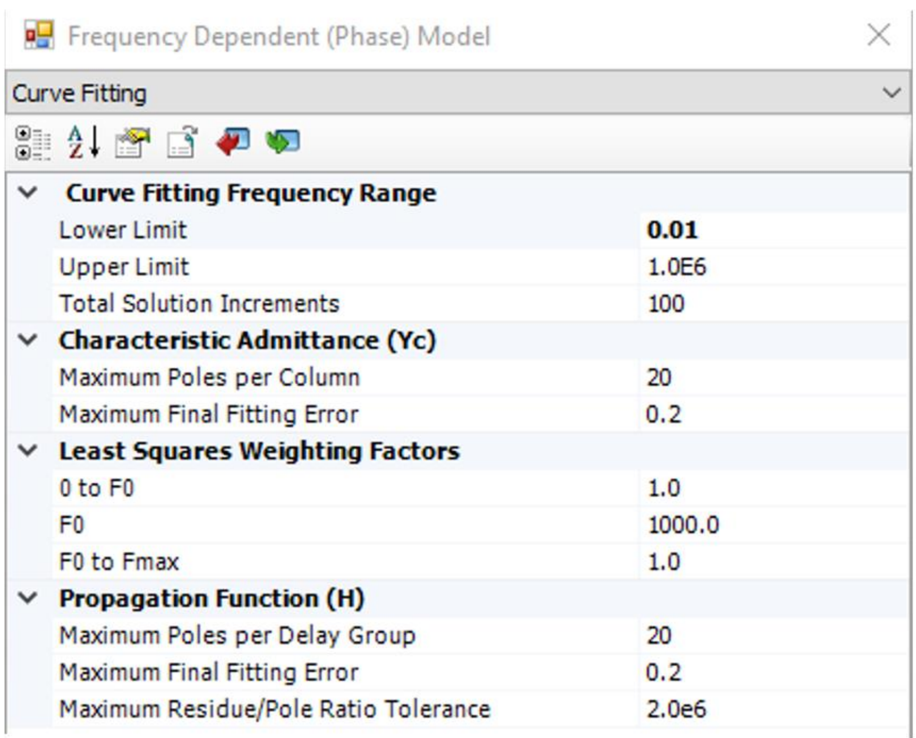
mutual_coupling_OHL_v5.pscx

6. DC correction

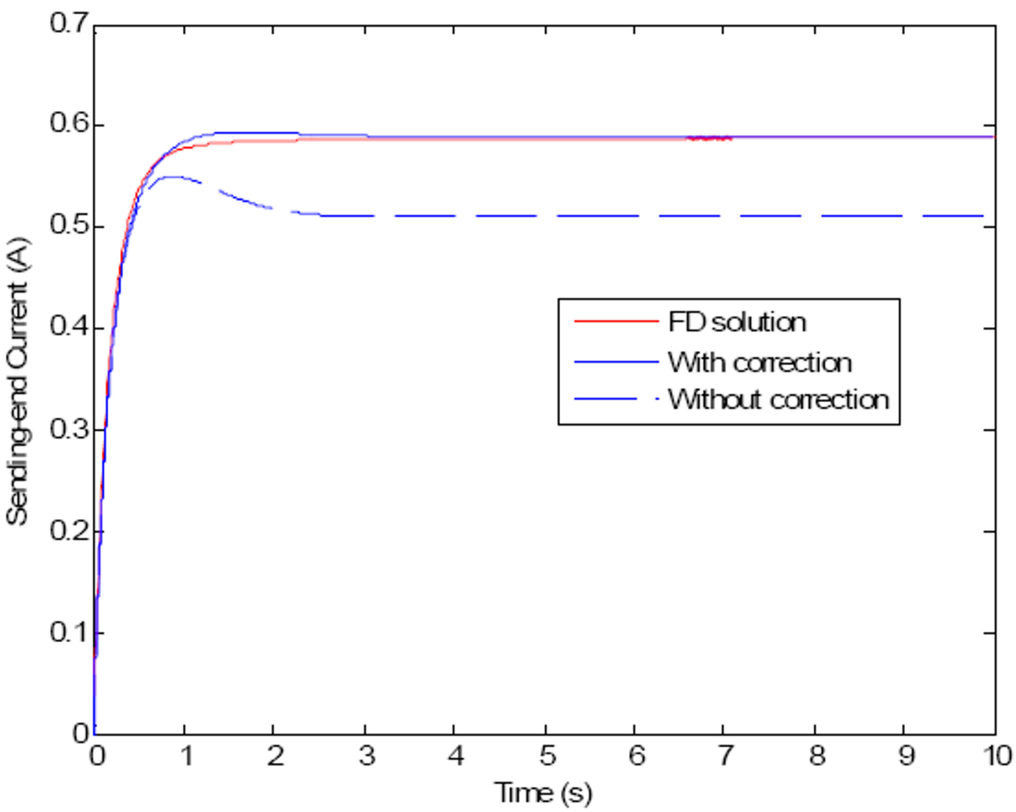
The DC correction can be used to ensure accurate dc response for HVDC cables and overhead lines. To enable dc correction, go to the Frequency Dependent (Phase) Model Options and set the parameters as shown below.



Functional form is the recommended method for dc correction. To get better response for frequencies approaching DC, reduce lower bound of fitting to small value (0.01 Hz vs default 0.5 Hz) in Curve-fitting section as shown below.



The figure below shows the short circuit current of a DC cable and with dc correction, the short circuit current is in a close agreement with the theoretical value.



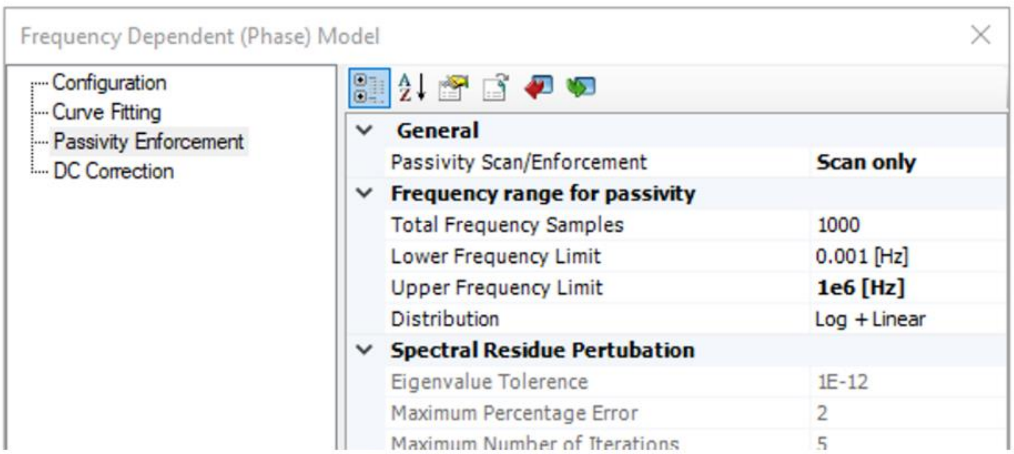
Simulation Results for a Short-Circuit Condition

For additional details, see Appendix 4.

7. Dealing with unstable simulation [New in PSCAD V5]

Sometimes you may experience unstable simulations when simulating cables or overhead lines. The unstable simulations associated with cables or overhead lines are due to passivity violations. The passivity violations can be seen as presence of negative eigenvalues for defined frequency range.

To check the passivity in PSCAD V5, go to Frequency Domain (Phase) model and select Passivity Enforcement. Set the parameters as shown below. The frequency range for passivity violations is from 0.001 Hz to 1 MHz.



Passivity scan

Solve the transmission line and go to LOG page. The passivity violations can be seen.

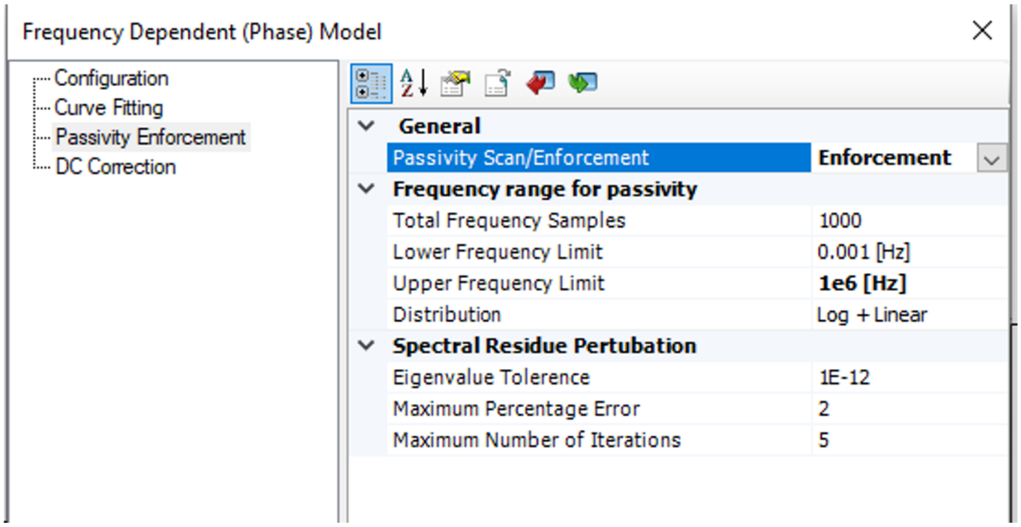
The solution to passivity violations involves two steps.

Step 1: Remove large violations

First large violations at low frequencies are eliminated. For that, enable dc correction (see Chapter 5: DC correction) and assume sufficient shunt conductance (or loss tangent).

Step 2: Remove rest of the violations

The rest of the passivity violations can be eliminated by selecting advanced Passivity Enforcement Algorithm based on quadratic optimization algorithm (experimental).



Passivity enforcement

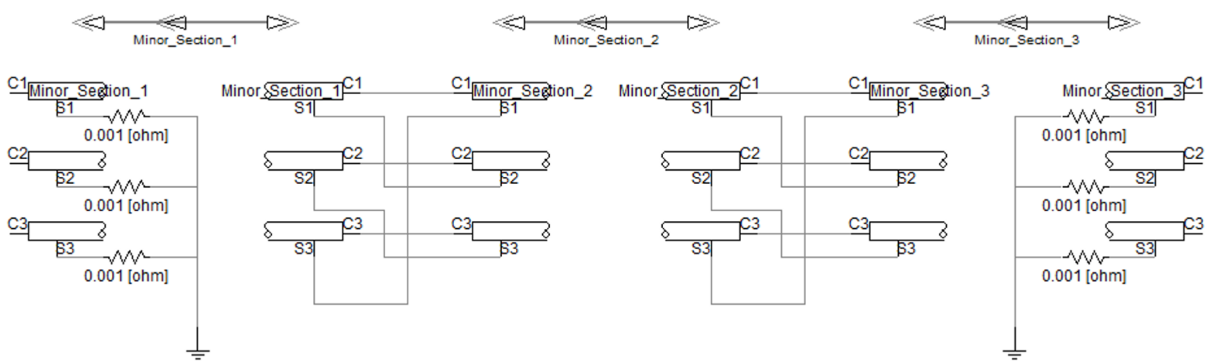
For details, see Appendix 5

8. Cross Bonding of Long AC Cables

The long AC cables are usually cross-bonded to reduce sheath losses. There are two ways to model a cross-bonded cable system.

Method 1: Detailed Modeling

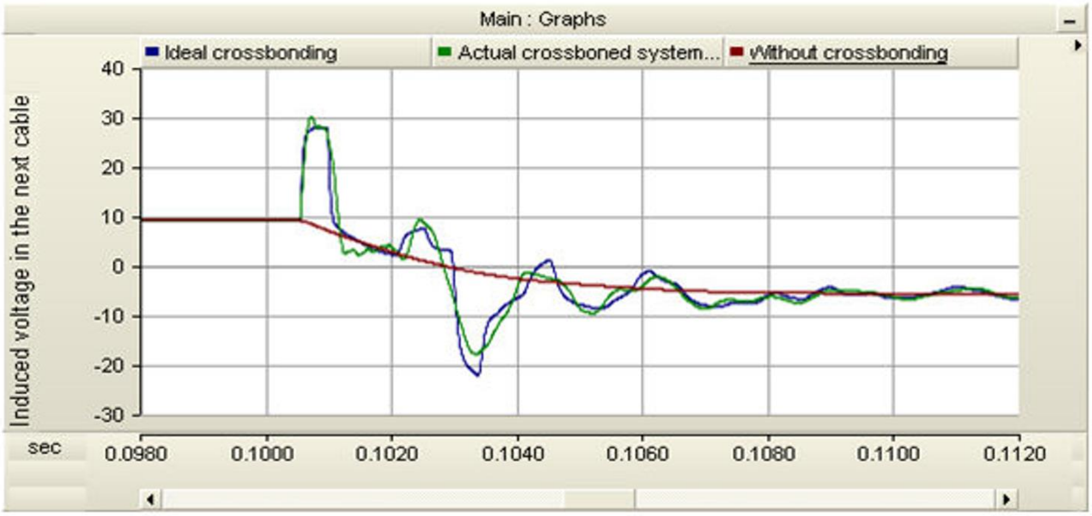
In detailed modeling, each minor, major sections, link boxes are modeled with all details. The long cable consists of series connected many small cable segments (e.g. minor segment). A drawback of this method is that a small time step is required to simulate small cable segments, however sheath currents can be observed.



Major Section of Cross-Bonded Sheaths for Three Single-Core Cables in PSCAD

Method 2: Ideal Cross-bonding for Entire Cable

Ideal Cross-bonding feature approximates the actual cross-bonded system. It is assumed that sheath is transposed and connected to the ground continuously assuming sheath voltage is small. To enable ideal cross-bonding, simply enable "ideal cross-bonding" in cable model. The long AC cable is modeled as a single cable hence a relatively large time step can be selected compared to method 1. However, sheath currents cannot be observed as sheath is automatically eliminated.



Comparing Induced Voltage in Ideal, Actual and Non-Cross-Bonded Systems

9. Conductor Approximation (i.e. Conductor Elimination)

An example of conductor approximation is the ground wires in overhead towers. If there are three conductors with two ground wires in a tower, then there are five conductors in total. However, since ground wires are usually grounded at regular intervals, we can assume that the voltage of ground wires is almost zero. Then five-conductor system can be reduced to three conductor system mathematically. This is called conductor approximation or elimination. This will reduce the complexity of the system.

This is also applicable to cables. The sheath or armour can be approximated if they are regularly grounded.

However, it is important to understand that conductor elimination does not mean the conductor is neglected. Instead, its effects (e.g. losses, currents) are approximately or indirectly considered.

It is important to set the line or cable interface accordingly as there is no external connection to the eliminated/approximated conductor. (see Appendix 6 as well)

9.1. Automatically Eliminated Conductors

- e.g. if last layer of underground cable is conductor, it is automatically eliminated
- e.g. ideally cross-bonded cable, sheath is eliminated
- e.g. Bare cable, conductor is eliminated

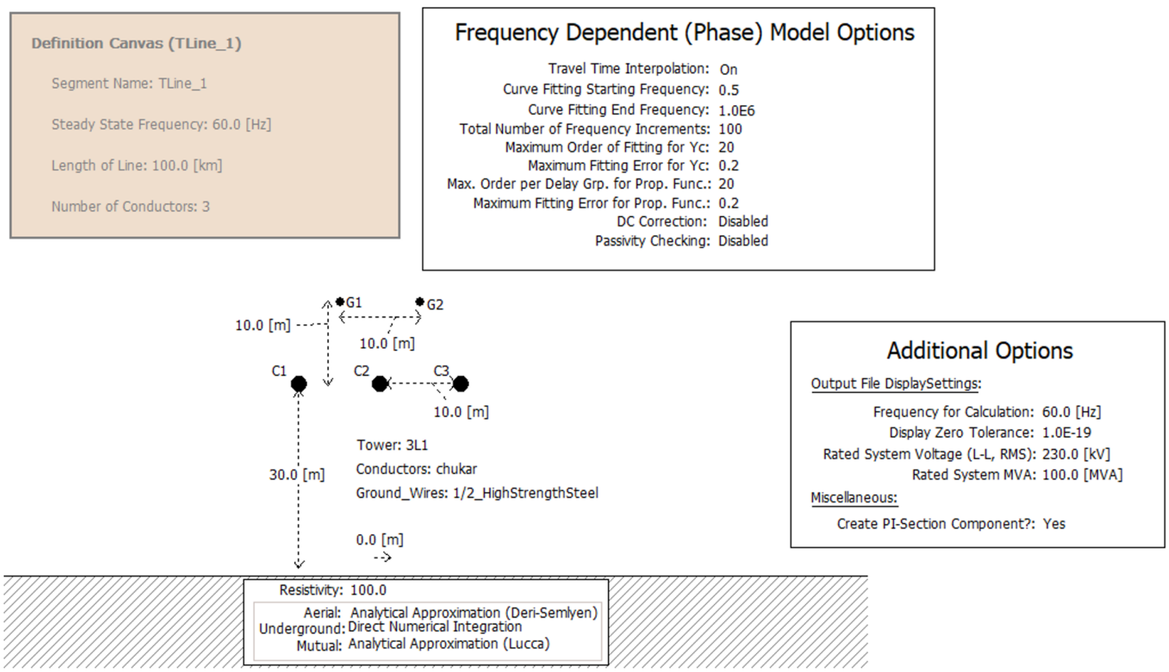
9.2. Manual Elimination

It is possible to manually set conductors to eliminate in the cable model.

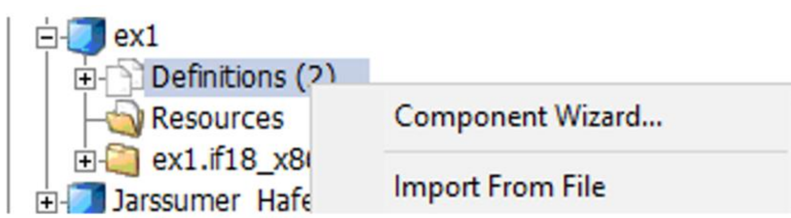
10. PI Circuits and Equivalent PI

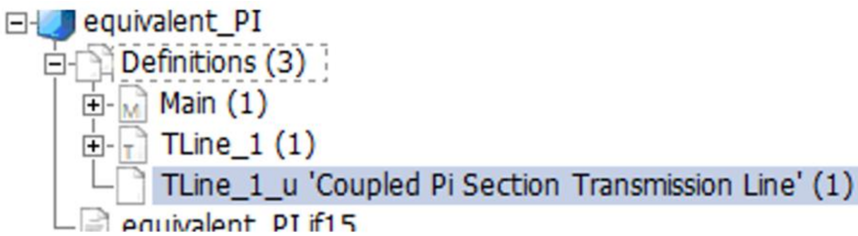
Sometimes it is required to create a pi circuit from a transmission line or cable model. To get an equivalent pi circuit,

1. Create a transmission line model and add any three phase tower.
2. Click on transmission line page and select “Additional Options” and enable “Create PI-section component ?” as shown below.

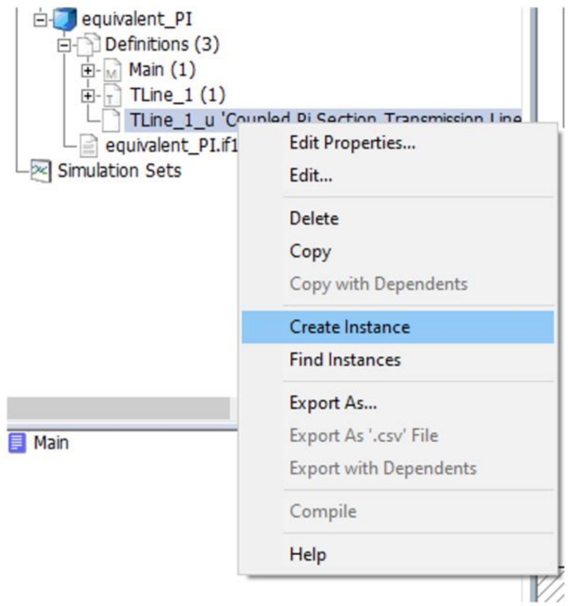


3. Click on transmission line page again and select “Solve Constants”. This will create a definition of pi component in the pscad case temporary directory (*.cmp file).
4. Go to workspace window and in the click on Definitions and select import from file and select *.cmp file





5. Click on the pi circuit definition (under definition) and select "Create instant" and paste on the PSCAD main page.



Note that this pi circuit is based on steady state frequency defined in the transmission line (but not the frequency for calculation in the Additional Options menu), see equivalent_PI.pscx example

Error Messages

Note: The interface should match the conductors in the cable or tower models. Otherwise, the following error message appears (DSLINT error). See Appendix 6.

❶	ddds	Non-standard Messages: Abnormal program termination.
❶	ddds	EMTDC Runtime Error: abnormally terminated
❶	ddds	ERROR: DSLINT Transmission Line Data
❶	ddds	ERROR: Abnormal termination of EMTDC by OUTMSG
❶	ddds	Simulation stopped.

Appendix 1: Comparison of Transmission Line Models in PSCAD

There are four transmission line models in PSCAD.

PI Model

- Based on lumped constant parameters at defined frequency

Bergeron Model

- Travelling wave based model (i.e. voltage and current reflections at cable-ends can be studied with this model)
- Represents the constant R, L and C elements in a distributed manner
- It is accurate only at the specified frequency
- Studies where the specified frequency load-flow is most important (e.g. relay studies).
- Data input: Detailed tower/cable configuration or RXB data entry

Frequency-Dependent (Phase) Model

- Travelling wave based model
- Represents the frequency dependence and distributed nature of all parameters (Note that R(w),L(w) and C(w) are frequency dependent).
- Most advanced and accurate time domain line model in the world.
- Accurate for all transmission configurations, including unbalanced line geometry and underground cables, aerial cables etc.
- Data input : Detailed tower/cable configuration or RXB data entry (through multiple frequency option only).

Frequency-Dependent (Mode) Model

- This is similar to Phase model, but has many approximations and limitations (Obsolete).

Example case

line_models_comparison.pscx

Frequently Asked Questions

1. Which model I have to use and how much details required in the model for a particular study?

   Answer: refer Table 4-2 in the reference [1]

[1] CIGRE WG C4.502 “power system technical performance issues related to the application of long HVAC cables”

Appendix 2: Cable Modeling from Datasheet

Practical Considerations in Modelling Cables

Cables have different designs and complicated features. However, cable models in Electromagnetic Transient (EMT) program are developed based on several assumptions and simplifications. Sometimes, it is required to perform conversions to model practical cables for EMT studies.

For example, the core conductor in the cable model is modelled as a solid conductor. However, the core conductor in a practical cable may be a stranded conductor. The impedance of stranded conductor is different from solid conductor. So, a conversation is required to model core conductor in practical cable accurately [1]. In this section, we will discuss such useful conversions.

There can be many layers in the typical cable. The first step is to identify each layer as conducting layer, insulating layer or semi-conducting layer.

Core Conductor

In the coaxial or pipe-type cable model, the input data are the dc resistivity (ρ), inner and outer radius of the core conductor.

a. If dc resistance (R) is available in the datasheet,

	solid	stranded	hollow
Pipe-type or coaxial cable model	$\rho = R\frac{\pi {r_1}^2}{L}$ $r_0 = 0$	$\rho = R\frac{\pi {r_1}^2}{L}$ $r_0 = 0$	$\rho = R\frac{\pi({r_1}^2 - {r_0}^2)}{L}$

For simplified cable model, you can directly enter the dc resistance.

b. If dc resistance is not available, a dc resistivity (ρ_C) value can be assumed based on material (e.g. Cu or AL).

	solid	stranded	hollow
Pipe-type or coaxial cable model	$\rho = \rho_c$ $r_0 = 0$	$\rho = \rho_c \frac{\pi {r_1}^2}{A_c}$ $r_0 = 0$	$\rho = \rho_c$

For simplified cable model, you can enter the resistivity value or select typical values depending on the material. For stranded conductor, the effective resistivity can be computed as shown in above table.

Where, r_0, r_1 , L, A_C , ρ_C are the inner and outer radius of conductor, length, nominal cross-sectional area, resistivity of the material.

Insulation layers

For the insulation layer, the relative permittivity or capacitance, inner and outer radius of insulator are required.

(a) If the capacitance is known,

For Pipe-type or coaxial cable model, the following formula is used to calculate the relative permittivity value.

$$\varepsilon_r = C \frac{\ln\left(\frac{r_4}{r_3}\right)}{2\pi\varepsilon_0}$$

Where, ε_r , ε_0 , r_3, r_4 are the relative permittivity, permittivity of free space, inner and outer radius and capacitance.

For simplified cable model, the capacitance value can be directly entered.

(b) If the capacitance is not given,

Assume a relative permittivity value based on type of insulation (e.g. for XLPE, the relative permittivity can be assumed as 2.3 or 2.5).

(Note, the insulation properties can be changed due to presence of semi-conducting layers). So, an adjustment may be required for relative permittivity value to account for semi-conducting layers.

Semi-Conducting Layers

The semiconducting layers are usually present between core-conductor and main simulation and also between main insulation and sheath. Semi-conducting layers can be considered as a part of main insulation layer.

a. If the capacitance of main insulation layer is known,

Pipe-type or coaxial cable model	Set the outer radius of insulator (r_4) as insulator outer radius + outer semi-conducting layers. Then calculate the relative permittivity value as, $$\varepsilon_r = C\frac{\ln\left(\frac{r_4}{r_3}\right)}{2\pi\varepsilon_0}$$ (r_3 is the outer radis of core conductor without inner semi-conductor layer)

For simplified cable model, enter capacitance directly with inner and outer radii as calacuated above.

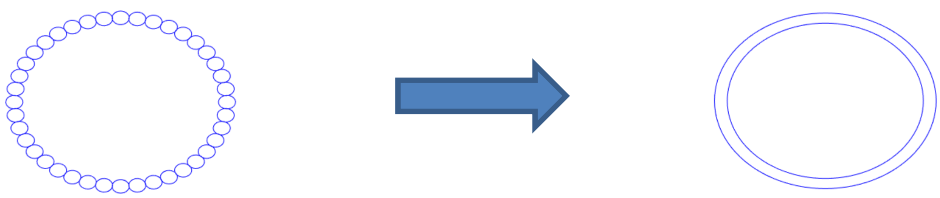
b. If the capacitance of main insulation layer is not known, there are two ways to modify insulating layer parameters as show below.

	Method 1 (recomended)	Method 2
Pipe-type or coaxial cable model	The follwing parameters are set (1) "Semi-conducting layers" = present (2) Enter "inner semi-conducting layer thickness" and "outer semi-conducting layer" thickness r_4 = insulator outer radius without outer semi-conducting layer r_3 = outer radius of core conductor without inner semi-conductor layer	In this method, the effective permittivity value is calculated considering semi-conductor layer data (see equation 10 in [1]). The follwing parameters are set (1) "Semi-conducting layers" = absent r_4 = insulator outer radius + outer semi-conducting layers r_3 = outer radius of core conductor without inner semi-conductor layer

If there are other semi-conducting layers in the cable, consider them as a part of adjasent insulator layers. If there are adjacent multiple semiconducting layers, combine them together and consider them as a single layer.

Wire screen

The sheath may consist of individual wires. This can be approximated with an equivalent solid sheath (annulus) as shown below.



The outer radius (r_3) of solid sheath is calculated as

$$r_3 = \sqrt{\frac{A_2}{\pi} + {r_2}^2}$$

Where, A_s is the total wire area (equals to area of each wire* $N_\emptyset$) and r_2 is the inner sheath radius of the sheath. The sheath resistivity can be calculated by

$$\rho = \frac{R_\emptyset}{N_\emptyset} \pi ({r_3}^2 - {r_2}^2)$$

where, R_φ , N_φ are the dc resistance of each wire and number of wires.

Dual Layer Sheath

In some cable models, there are two conducing layers separated by a thin semi-conducting layer. This can be approximated by an equivalent conducting layer (neglecting the semi-conducting layer). First, the effective dc resistance (Rs) of the equivalent sheath is calculated (assuming that two layers are in parallel and they are connected at either ends).

$$R_s = \frac{R_1 R_2}{R_1 + R_2}$$

Where, R_1 and R_2 are the dc resistances of each layer. Now the dc resistivity is calculated as

$$\rho = \frac{R_s}{A_1 + A_2}$$

Where, A_1 and A_2 are the cross-sectional areas of conducting layers. The outer radius of the equivalent sheath is,

$$r_3 = \sqrt{\frac{A_2 + A_2}{\pi} + r_2^{\,2}}$$

Temperature Corrections

If the manufacture datasheet gives resistance values at defined temperature (e.g. 20 C), the dc resistance/ resistivity may be changed to the operating temperature (typically 90C for core conductor) according to IEC 28 and IEC 889.

The dc resistance per unit length of the conductor at its operating temperature is given by:

$$R' = R_0.\left[1 + \alpha_{20}.(\theta - 20)\right]$$

where:

R_0 is the DC resistance of the conductor at 20 °C

α_{20} is the constant mass temperature coefficient at 20 °C per Kelvin

In the simplified cable model, the temperature correction can be done without manual calculation.

Example Case

In this example, three cables in flat configuration are modelled. The depth of each cable is 1.0 from ground surface and the distance between adjacent cables is 1.0 m; below shows the example cable datasheet (derived from a cable datasheet in [2]). See PSCAD case (coaxial_cable_example.pscx).

Component	Parameter	Description	Units	Value
Conductor	R_1	Inner radius of tubular core	Mm	0
	R_2	Outer radius of tubular core	Mm	28.3
	ρ_c	Resistivity of copper	Ω.m	1.724e-8
Conductor Screen	T_{cs}	Thickness of conductor screen	Mm	2

Component	Parameter	Description	Units	Value
Insulation	ε_{i1}	Relative permittivity of insulation material		2.4
	R_{so}	Outer radius of insulation	Mm	56.3
Insulation Screen	T_{is}	Thickness of insulation screen	Mm	2
Metallic Sheath	R_4	Average outer radius of sheath	Mm	60.3
	ρ_s	Resistivity of aluminium tape	Ω.m	2.840e-8
Outer Covering	ε_{i2}	Relative permittivity of cover		2.4
Complete Cable	R_5	Average outer radius of cable	Mm	65.3
	d	Burial depth	M	1.0
	h	Phase horizontal separation	M	1.0
Cable Charging	C'	Capacitance	µF/km	0.21551
	B'	Charging at 400 kV	MVar/km	10.832

The firs step is to identify the different layers of cable as conducting layer, insulation layer or semi-conducting layer.

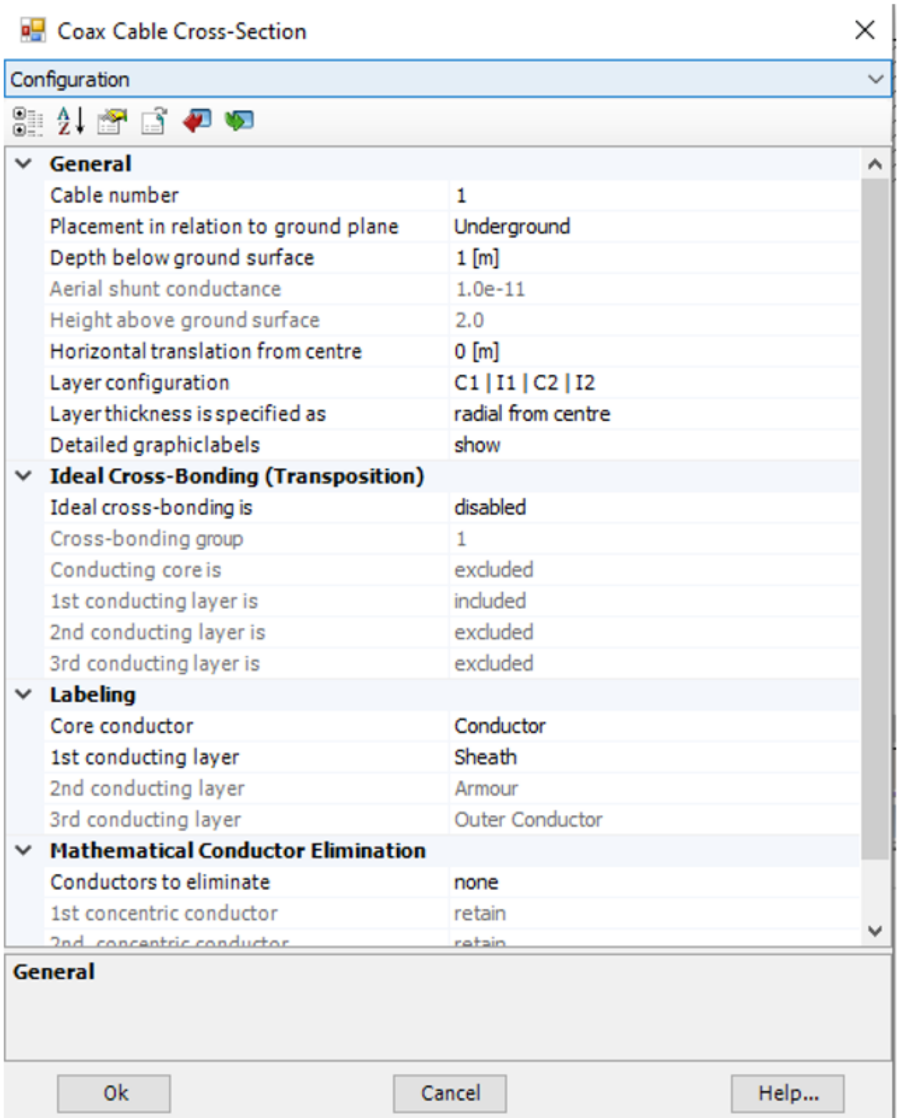
Layer from Datasheet	Layer Identification	PSCAD Model Layer
Conductor	Conducting layer	C1
Conductor Screen	Semi-conducting layer	N/A
Insulation	insulator	I1
Insulation Screen	Semi-conducting layer	N/A
Metallic Sheath	Conducting layer	C2
Outer Covering	Insulator	I2

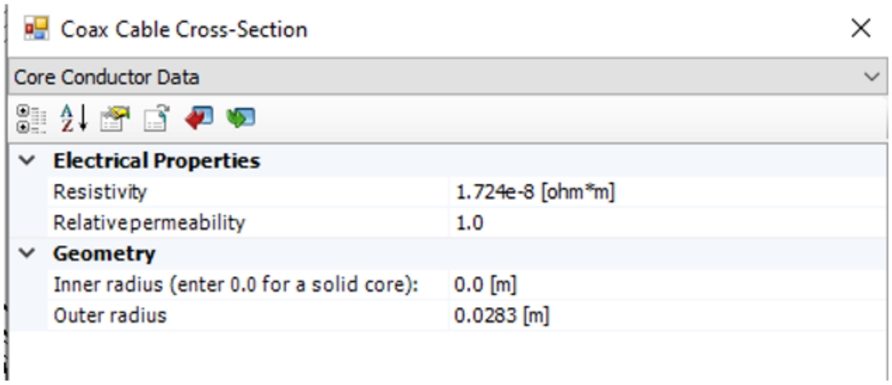
This can be modelled using a cable model with configuration C1-I1-C2-I2. Note that in PSCAD cable model, the layers are configured as main conductor (C1), first insulation layer (I1), conducting layer (C2) and second insulation layer (I2) etc.

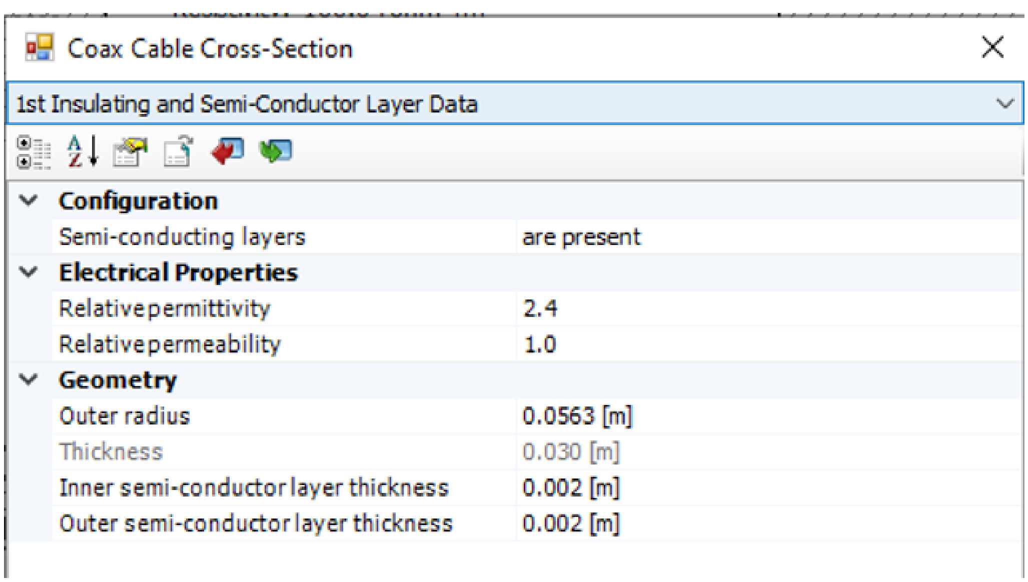
If there are adjacent multiple layers of same type, then they should be combined together. For example, if there are multiple semi-conducing layers, connect them together.

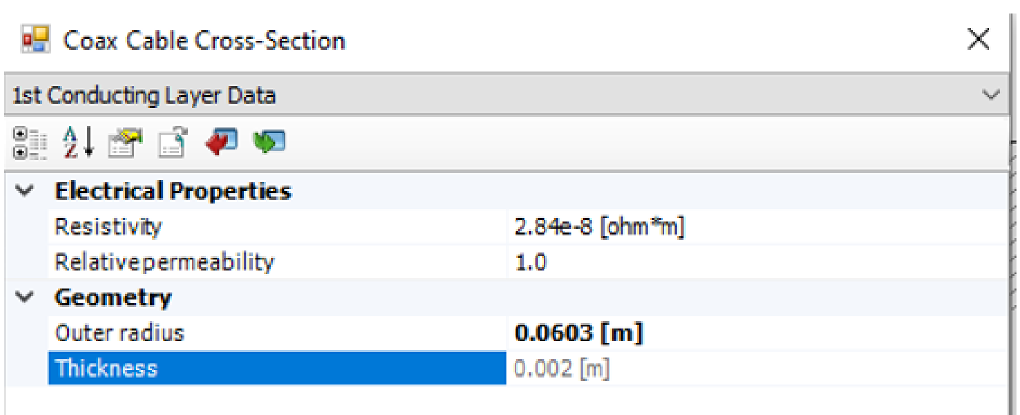
Modelling Using Coaxial Cable

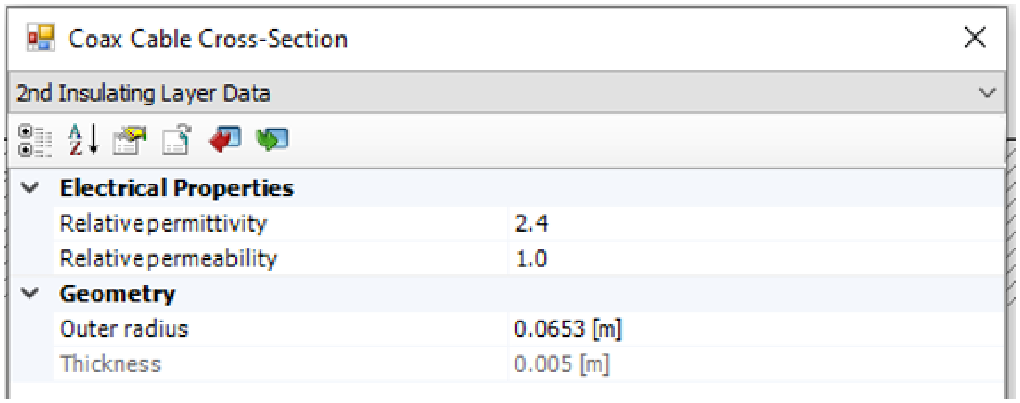
The coaxial cable is modelled as shown in below images.




Coax Cable Cross-Section
Core Conductor Data
Electrical Properties
Resistivity
1.724e-8 [ohm*m]
Relative permeability
1.0
Geometry
Inner radius (enter 0.0 for a solid core):
0.0 [m]
Outer radius
0.0283 [m]


Coax Cable Cross-Section
1st Insulating and Semi-Conductor Layer Data
Configuration
Semi-conducting layers
are present
Electrical Properties
Relative permittivity
2.4
Relative permeability
1.0
Geometry
Outer radius
0.0563 [m]
Thickness
0.030 [m]
Inner semi-conductor layer thickness
0.002 [m]
Outer semi-conductor layer thickness
0.002 [m]

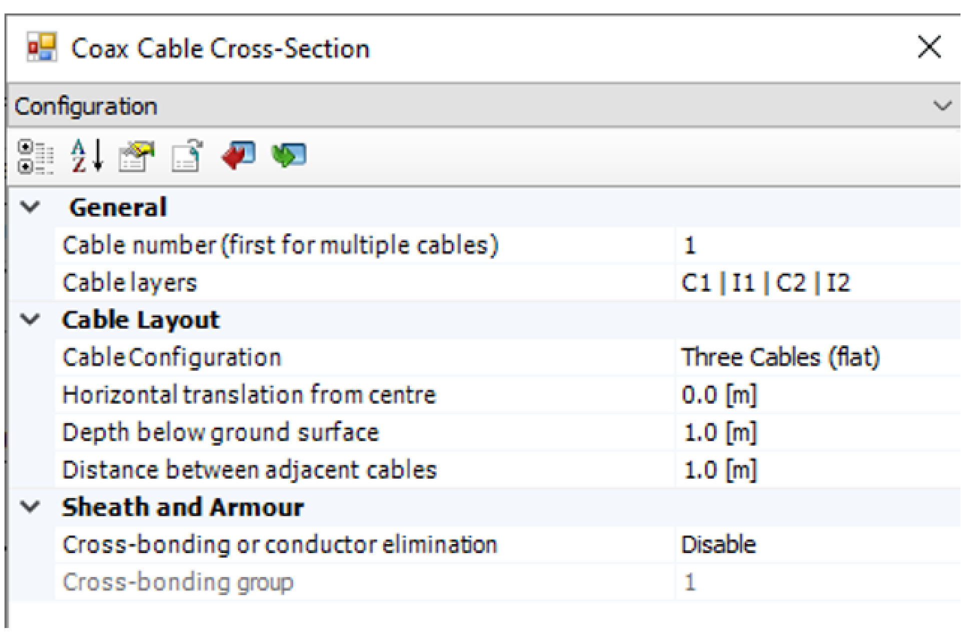

Coax Cable Cross-Section
1st Conducting Layer Data
Electrical Properties
Resistivity
2.84e-8 [ohm*m]
Relative permeability
1.0
Geometry
Outer radius
0.0603 [m]
Thickness
0.002 [m]



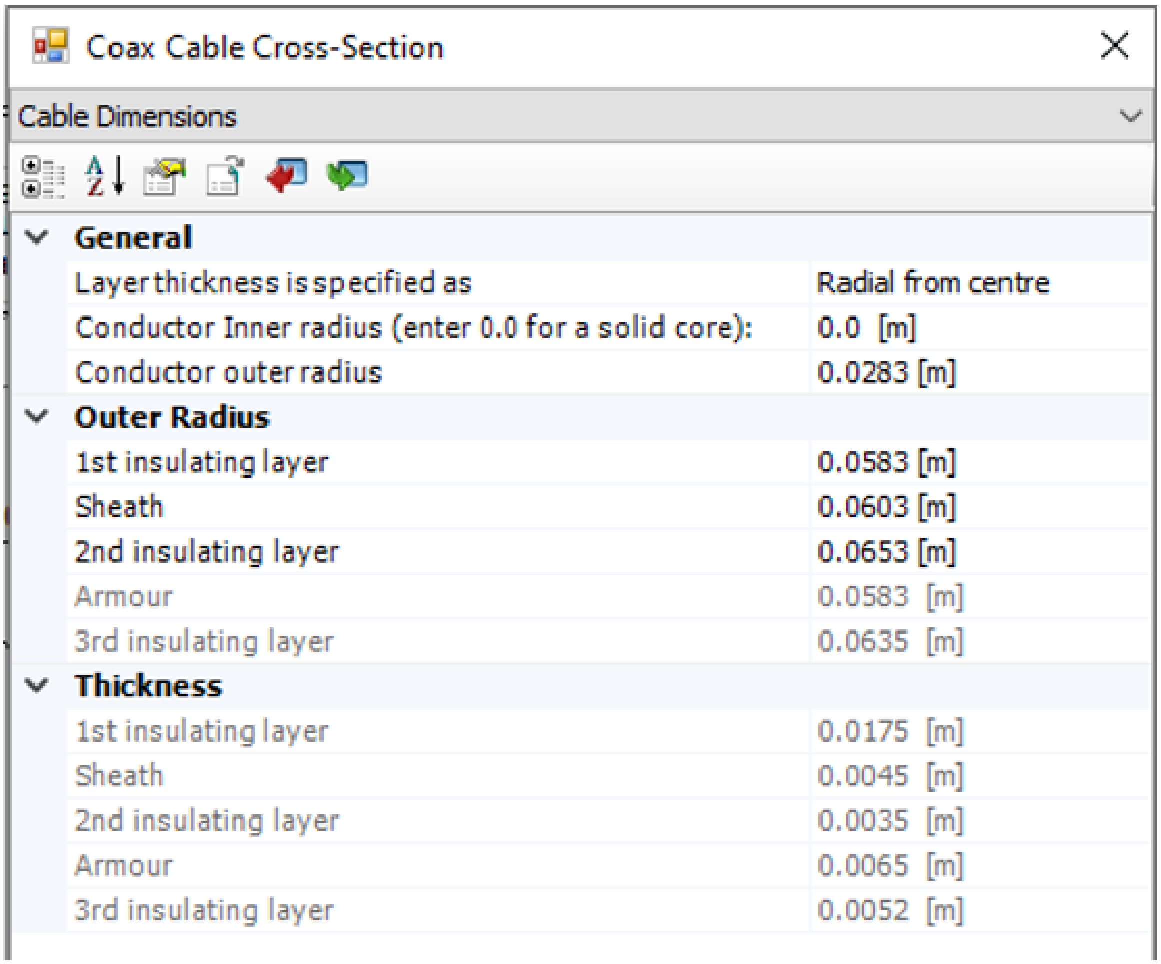
We need to model three cables with same data as above and the horizontal distance and cable number parameters are modified. The cable numbers are 1, 2 and 3 and the horizontal spacing is 0.0 m, 1.0 m and 2.0 m respectively for three cables.

Modelling using Simplified Cable Model

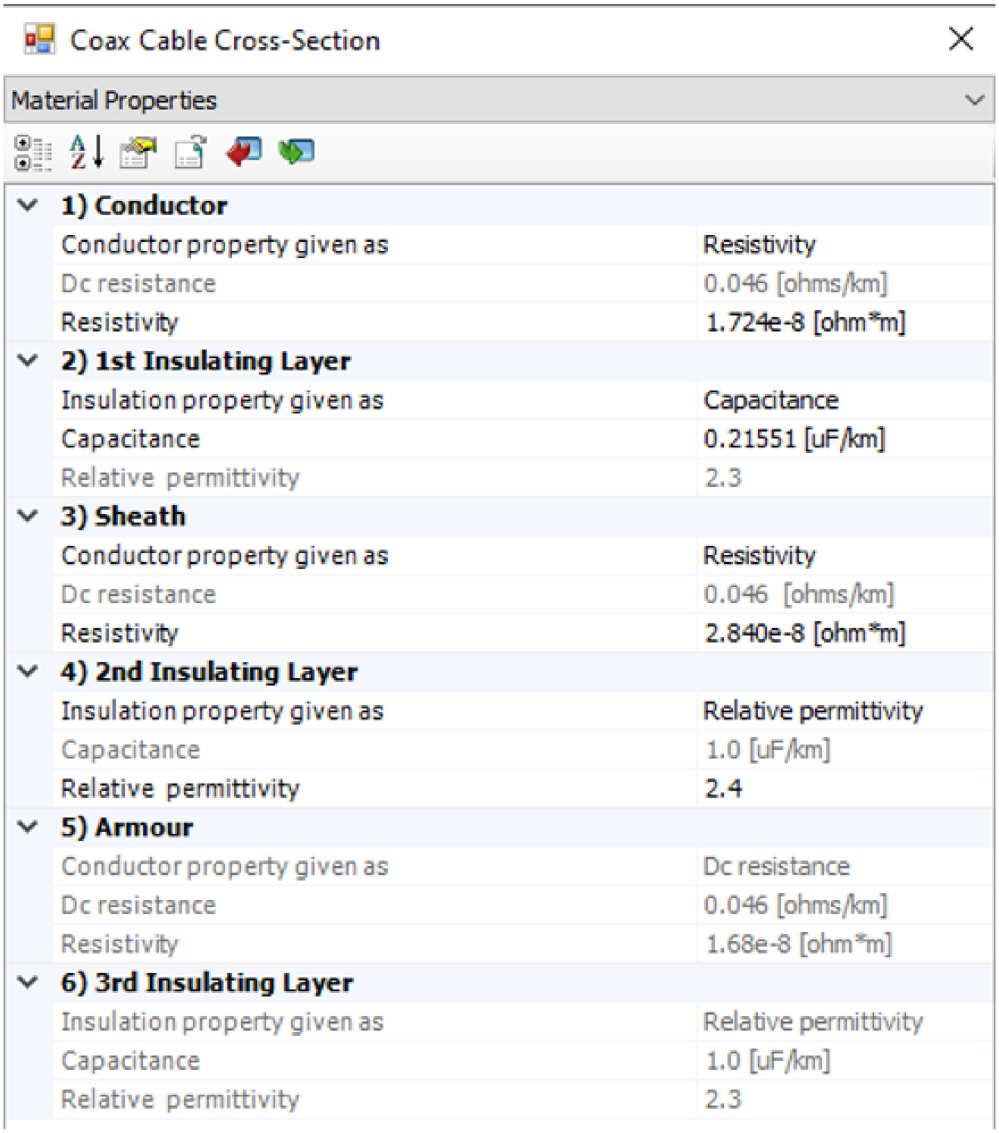
User-friendly cable or simplified cable is technically more or less same as the coaxial cable model. However, the interface is modified so that it is much easier to model directly from the datasheet with minimum conversions. The three cables can be directly modelled by defining space between them as shown below.



The insulation and semi-conducting layers are modelled in a different way compared to the previous coaxial model example as the capacitance is directly provided in the datasheet. The semi-conducting layers are now considered as a part of insulation, so that combined insulation outer radius is 0.583 m (= 0.0563 m + 0.002 m, note that 0.0563 m is the outer radius of main insulator and 2 mm is the thickness of the semi-conducting layer). All cable dimensions are shown in a single page.



Next, material properties are entered. The insulation property is directly entered as a capacitance.



Coax Cable Cross-Section

Material Properties

1) Conductor	
Conductor property given as	Resistivity
Dc resistance	0.046 [ohms/km]
Resistivity	1.724e-8 [ohm*m]
2) 1st Insulating Layer	
Insulation property given as	Capacitance
Capacitance	0.21551 [uF/km]
Relative permittivity	2.3
3) Sheath	
Conductor property given as	Resistivity
Dc resistance	0.046 [ohms/km]
Resistivity	2.840e-8 [ohm*m]
4) 2nd Insulating Layer	
Insulation property given as	Relative permittivity
Capacitance	1.0 [uF/km]
Relative permittivity	2.4
5) Armour	
Conductor property given as	Dc resistance
Dc resistance	0.046 [ohms/km]
Resistivity	1.68e-8 [ohm*m]
6) 3rd Insulating Layer	
Insulation property given as	Relative permittivity
Capacitance	1.0 [uF/km]
Relative permittivity	2.3

Note: In cable modelling, the accurate modeling of core-conductor, main insulation and sheath is important for transient simulations. It is observed that in many instances, the datasheets do not provide adequate information required for an accurate model.

E.g. the dimensions of cable layers can be average values, but not from accurate measurements. For example, the given average thickness of the semiconducting layers can be significantly different from the actual thickness. The cable capacitance may be missing in the datasheet, so insulation property is defined based on semi-conducting layer data and assumption of the material of the insulation (for XLPE insulation, publications suggest different values of relative permittivity ,i.e. 2.3, 2.5 etc.). Similarly the dc resistance of core-conductor or sheath is not given. Therefore, we have to assume dc resistivity based on material properties and other factors, which can be different from the actual values.

References

1. B. Gustavsen, "Panel session on data for modeling system transients insulated cables," 2001 IEEE Power Engineering Society Winter Meeting. Conference Proceedings (Cat. No.01CH37194), 2001, pp. 718-723 vol.2, doi: 10.1109/PESW.2001.916943.
2. CIGRE WG C4.502 "Power system technical performance issues related to the application of long HVAC cables"

Appendix 3: Documentation for Power Frequency Cable Validation Tool (PCVT)

What Is PCVT

This tool is used to validate the sequence RXB values generated by PSCAD coaxial cables.

Why We Need It

The sequence RXB values provided by the manufactures can be different from that of PSCAD cable models. Note that the RXB values depend on many factors such as distance between cables, temperature corrections, cable layout, cross-bonding etc. Due to different factors/assumptions used for RXB calculation, the RXB values can be different.

How We Use It

Step 1: Understand the assumptions in manufacturer defined sequence RXB

Enter the cable data in to the validation tool and run PSCAD case (make sure that the object files are set properly). You should get the close RXB values as defined by manufacture datasheet. If not, change the cross-bonding, temperature corrections, bonding type, some poorly defined cable parameters (sheath resistivity) etc.

Step 2: Enter data for PSCAD cable model with same settings as Step 1

With same data/configuration as in step 1, PSCAD cable model should provide close RXB values. This ensure that the cable input data is correct.

Step 3: Change values in RXB tool for the actual cable configuration/layout

Observe the RXB values

Step 4: Enter data for PSCAD cable model for the actual cable configuration/layout

Observe the RXB values and should be close to step 3.

(e.g. For steps 1 and 2, the details for manufacturer defined RXB can be ideally cross-bonded, trefoil-touched, temperature correction applied. For steps 3 and 4, the details of actual cable model (used for simulation studies) can be flat configuration with distance between cables 0.5m without cross-bonding, without temperature correction etc. Therefore, RXB values can be different between Step 1/2 and Step 3/4)

Other Details

The manufactures use power frequency simplified formulas to calculate sequence RXB values (usually present in datasheets) [1]. The RXB tool uses the same formulas. If the assumptions/data in sequence calculation is same, then the RXB values should be very close.

However, in PSCDA cable model, the assumptions/data can be different, hence different RXB values can be expected. These values can also be verified with the tool (see steps 3 and 4 in previous section).

The PSCAD cable model uses complicated formulas to calculate parameters, however at power frequency, sequence RXB values in PSCAD are in a close match with that calculated from simplified formula.

Limitations

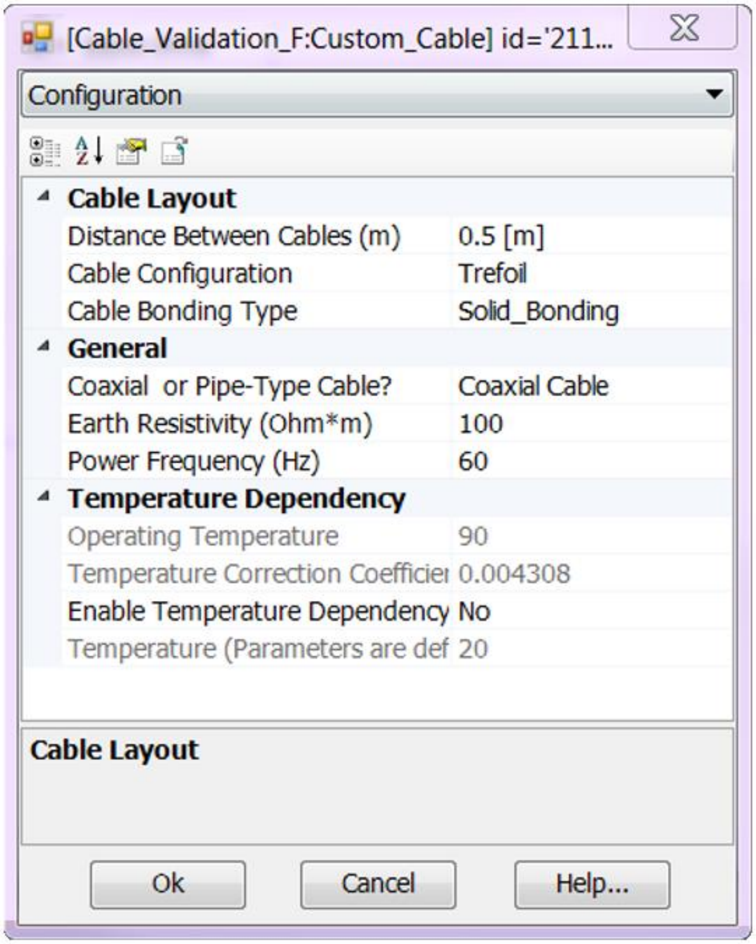
This tool is applicable to three coaxial cables only, but not to pipe-type cables. It is advised not to compare pipe-type cable sequence data as the formulas used by manufactures may not be accurate. This is currently under investigation by several CIGRE working groups.

Example case

(see Cable_Validation_V5.pscx)

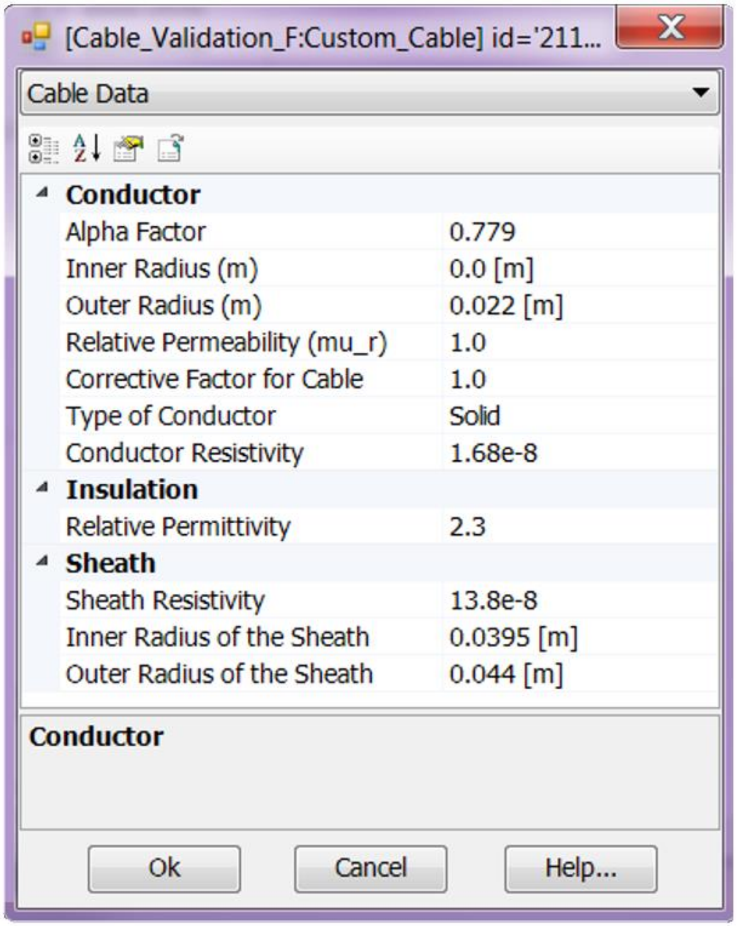
Description

The input to this model is basic data for cable model.



Note

Cable bonding type	Model does not work for Single Point Bonding
Coaxial or Pipe-type Cable?	Model works only for Coaxial Cable


[Cable_Validation_F:Custom_Cable] id='211...
Cable Data
Conductor
Alpha Factor
0.779
Inner Radius (m)
0.0 [m]
Outer Radius (m)
0.022 [m]
Relative Permeability (mu_r)
1.0
Corrective Factor for Cable
1.0
Type of Conductor
Solid
Conductor Resistivity
1.68e-8
Insulation
Relative Permittivity
2.3
Sheath
Sheath Resistivity
13.8e-8
Inner Radius of the Sheath
0.0395 [m]
Outer Radius of the Sheath
0.044 [m]
Conductor
Ok
Cancel
Help...

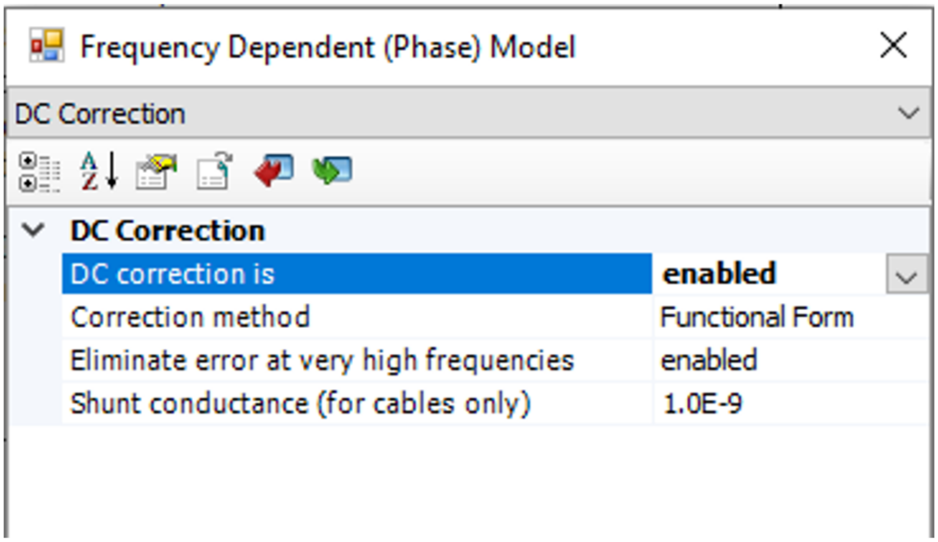
<table>
<tr><td>Type of Conductor</td><td>Model works only for Round_Solid type</td></tr>
<tr><td>Alpha Factor</td><td>
<table>
<tr><td>Type of</td><td>conductor</td><td>Value of α</td></tr>
<tr><td>Solid or Stranded</td><td>compacted</td><td>$e^{-0.25}=0.779$</td></tr>
<tr><td rowspan="7">Stranded non-compacted</td><td>3 wires</td><td>0.678</td></tr>
<tr><td>7 wires</td><td>0.726</td></tr>
<tr><td>19 wires</td><td>0.758</td></tr>
<tr><td>37 wires</td><td>0.768</td></tr>
<tr><td>61 wires</td><td>0.772</td></tr>
<tr><td>91 wires</td><td>0.774</td></tr>
<tr><td>127 wires</td><td>0.776</td></tr>
<tr><td>Hollow</td><td>outer radius r_1
inner radius r_0</td><td>$\alpha = e^{-\left[\frac{0.25-a^2+a^4(0.75-\ln a)}{(1-a^2)^2}\right]}$ $a = \frac{r_0}{r_1}$</td></tr>
</table>

Table 6 : α coefficient
</td></tr>
<tr><td>Corrective Factor for Cable</td><td>This value is used to calculate the cross-section of the Cable.
The corrective factor K_c depends on manufacturing process.
Typical values for conductors manufactured to fit IEC 60 228 requirements range between 0.85 and 0.93 with extreme values of 0,76 to 1.02 .</td></tr>
</table>

References

1. CIGRE WG C4.502 "Power system technical performance issues related to the application of long HVAC cables"
2. CIGRE WG B1.30, "Cable Systems Electrical Characteristics"

Appendix 4: DC correction



DC correction in V46

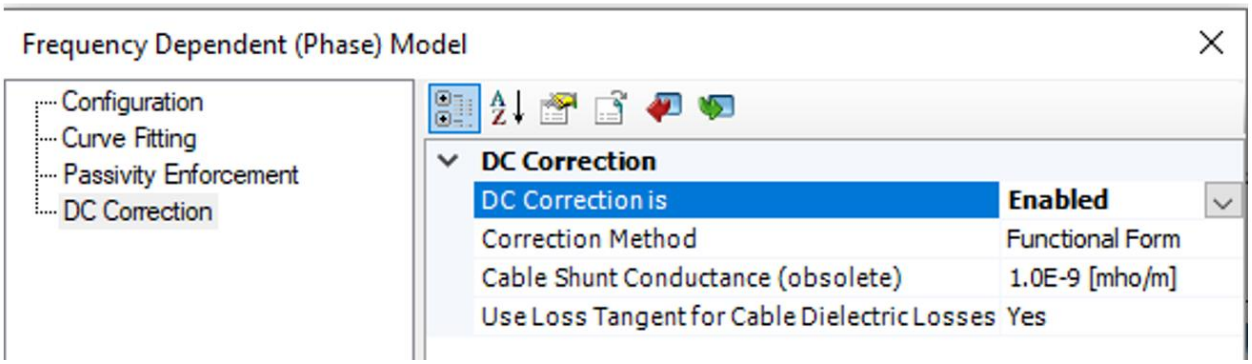
Frequently Asked Questions

1. What value of shunt conductance do I have to use for cables?

For overhead lines, shunt conductance is defined in tower models. For cables, the shunt conductance value is related to the insulation properties of cable. The shunt conductance can be calculated based on loss tangent of the insulation. LC program assume constant shunt conductance. The sufficient shunt conductance value is important to enhance stability of the simulation.

In PSCAD V5, a more accurate representation of shunt conductance is introduced. The loss tangent is used in each insulation layer of cables to calculate shunt conductance. Hence, the shunt conductance defined under DC correction is not used. In case, if you want to use shunt conductance defined in DC correction instead of loss tangent information, set “Use loss tangent for cable dielectric losses” to “No”.

(When importing PSCAD V463 case with dc correction, you can set the parameters to “No”, if you want to keep original shunt conductance value.). However, it is recommended to use loss tangent for better accurate representation.



DC correction in PSCAD V5

2. What is “Eliminate error at high frequencies”?

This is not used in the algorithm in PSCAD V46 or PSCAD V5. Simply ignore that parameter.

3. What is the difference between functional form method and Add pole method?

The functional form method is the most accurate one. For details see reference [1].

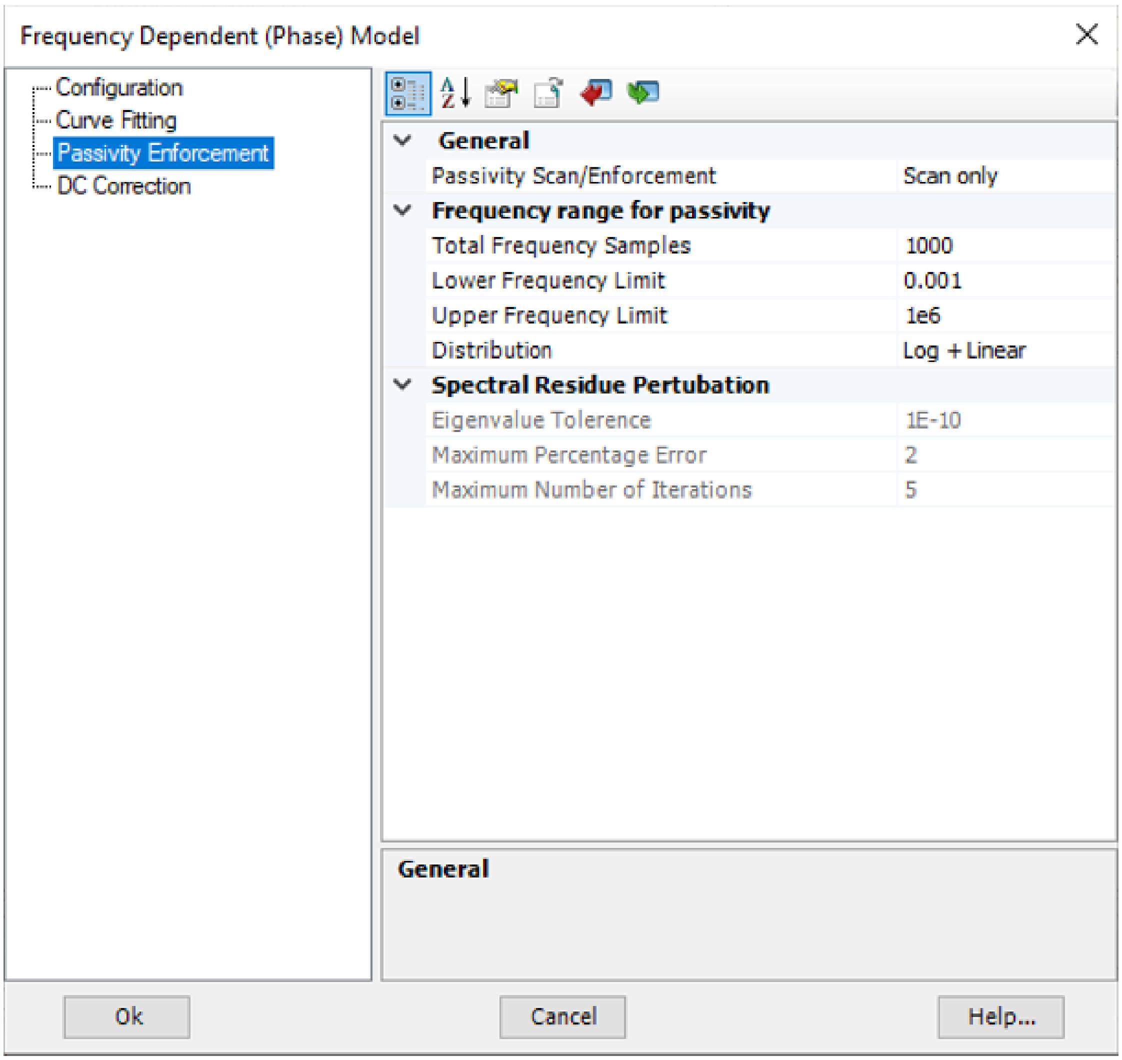
References

1. H.M.J. De Silva, A.M. Gole and L.M. Wedepohl, “Accurate Electromagnetic Transient Simulations of HVDC Cables and Overhead Transmission Lines.” (2007), International Conference on Power Systems Transients (IPST’07) in Lyon, France on June 4-7, 2007

Appendix 5: Dealing with Unstable Simulation

Verify Passivity of the Model

A non-passive model results in stable or unstable simulations. A passive model is always stable assuming that the network connected is also passive. To check passivity violations, simply set the parameters in Phase model options as shown below.



The passivity violations are checked between 0.001 Hz to 1 MHz with 1000 samples. The log + Linear distribution is better in representing frequency samples in a wide frequency range. You can see the violations at the bottom of the Log file as shown below (if the case is built.

```
                -------    -------------    --------    -----
                   1          0.01415 %       11          0.594658 ms
                   2          0.01430 %       12          4.828047 ms

Hphase:       Maximum            Maximum        Maximum
             Fitting Error      RMS Error      Residue/Pole Ratio
              --------------     ----------     ------------------
                 0.0483 %         0.0147 %               1.49

--------------------------------------------------------------------
====================================================================


Checking for Passivity Violations Between  0.100E-02 Hz and  0.100E+07 Hz


====================================================================
The presence of negative eigenvalues indicates passivity violations
and hence possibility of unstable simulations
-----------------------------------------------------------------
Frequency range                              smallest eigenvalue
-----------------------------------------------------------------

From  0.830E-01 Hz to  0.270E+00 Hz         -0.246E-05
From  0.392E+00 Hz to  0.692E+00 Hz         -0.864E-07
From  0.903E+00 Hz to  0.173E+01 Hz         -0.315E-06
From  0.262E+01 Hz to  0.586E+01 Hz         -0.107E-05

Passivity violations detected. See help for further details


LCP solve constants complete.
0
```

Schematic | Input | Constants | Log | Output |

The presence of negative eigenvalues indicates passivity violations.

Frequently Asked Questions

1. What is the frequency range used?

It depends on the range of frequencies present in the time domain simulation. Usually a very low frequency (say 0.001 Hz) to up to one or few MHz is sufficient for many studies.

2. How many samples I have to use?

There can be passivity violations between frequency samples. Therefore, to minimize that, you can select many samples as possible (e.g. 1000 or 5000 samples).

3. I see passivity violations; does that mean my simulation is inaccurate?

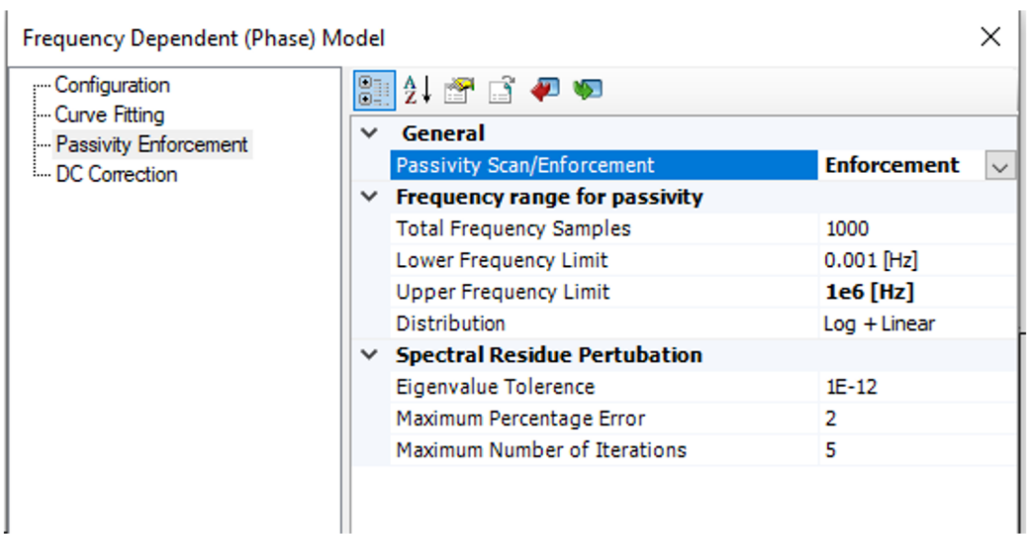
No. As long as the simulation is stable, the passivity violations do not change the accuracy of simulation.

4. I see passivity violations; does that mean my simulation is unstable?

If you are simulation is stable, then you do not need to worry about passivity violations. A non-passive model results in stable or unstable simulations.

Enforce Passivity

To enforce passivity (small violations only), simply set the parameters in Phase model options as shown below.



<u>Eigenvalue tolerance</u> = The algorithm makes sure that the all eigenvalues are set above a tolerance (a very small positive value). If it is set to zero or extremely small value, negative eigenvalues may occur due to machine precision etc. A large value may result in poor accuracy of the transmission line. Always a small positive value is recommended.

<u>Maximum percentage error</u> = the algorithm ensures that the accuracy of the transmission line (curve-fitting error) is above that value.

<u>Maximum number of iterations</u> = This is the maximum number of iterations (outer) for passivity enforcement.

You can see the output of the passivity enforcement at the boom of the Log file as shown below (if the case is built).

```
====================================================================

                    Passivity Enforcement
 ====================================================================
  Optimization via Spectral Residue Pertubation
  of propagation matrix
  Number of ports                                 2
  Order of the transfer function                 26

   --------------------------------------------------------------------
   Main Iteration  #   1
   --------------------------------------------------------------------
  Initial passivity violations
    Frequency [Hz]         Negative eigenvalue minimas
    ..............          ............
        2.2972973E-01       -2.4333230E-08
        9.7567568E-01       -4.8143528E-07
        3.0270270E+00       -2.5198389E-06
        6.5135135E+00       -1.1677858E-06
    ...........
  Model Order reduction
  Original    24, Reduced    24

    Inner Iteration  #  1
    Frequency [Hz]         Negative eigenvalue minimas
    ..............          ............
        9.2702703E-01       -2.0924702E-08
        2.9459459E+00       -1.9739013E-07
        6.5135135E+00       -3.3916070E-09

    Inner Iteration  #  2
    Frequency [Hz]         Negative eigenvalue minimas
    ..............          ............
        9.2702703E-01       -2.0924702E-08
        2.9459459E+00       -1.9739013E-07
        6.5135135E+00       -3.3916070E-09

    Inner Iteration  #  3
    Frequency [Hz]         Negative eigenvalue minimas
    ..............          ............
        9.2702703E-01       -2.0924702E-08
        2.9459459E+00       -1.9739013E-07
        6.5135135E+00       -3.3916070E-09
   --------------------------------------------------------------------
   Main Iteration  #   2
   --------------------------------------------------------------------
    ...........
  Model Order reduction
  Original    24, Reduced    24

    Inner Iteration  #  1
    Frequency [Hz]         Negative eigenvalue minimas
    ..............          ............
        2.2162162E-01       -3.3445209E-09
        2.9459459E+00       -2.8526611E-09
```

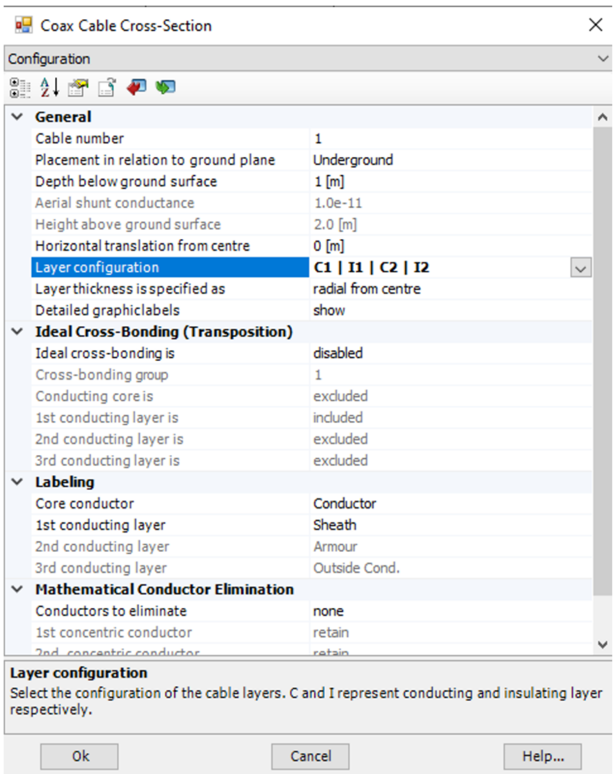
```
   Inner Iteration  #  2
   Frequency [Hz]         Negative eigenvalue minimas
   ..............           ............
       2.9459459E+00       -2.7918521E-09

   Inner Iteration  #  3
   Frequency [Hz]         Negative eigenvalue minimas
   ..............           ............
       2.9459459E+00       -2.7918521E-09
  --------------------------------------------------------------------
  Main Iteration  #   3
  --------------------------------------------------------------------

 Model Order reduction
 Original    24, Reduced    24

   Inner Iteration  #  1

 There are no passivity violations. Passivity is successfully enforced
  --------------------------------------------------------------------
Maximum abs. error    1.714613636528976E-002 %
Time elapsed    0.328125000000000        [sec]
====================================================================

LCP solve constants complete.
```

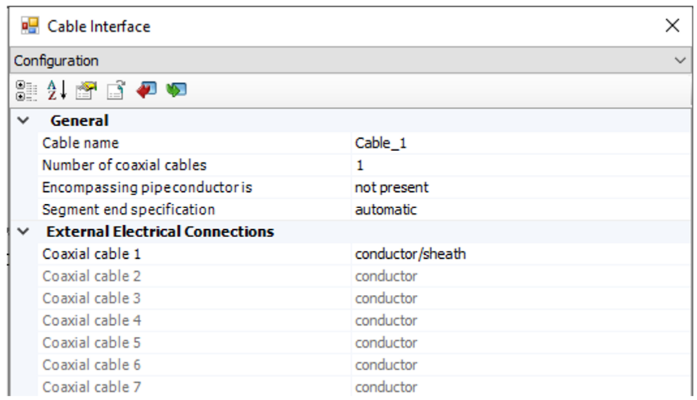
References

1. H. M. J. De Silva, A. M. Gole, J. E. Nordstrom and L. M. Wedepohl, "Robust Passivity Enforcement Scheme for Time-Domain Simulation of Multi-Conductor Transmission Lines and Cables," in IEEE Transactions on Power Delivery, vol. 25, no. 2, pp. 930-938, April 2010, doi: 10.1109/TPWRD.2009.2035916

Appendix 6: Transmission Line Interface and Conductor Elimination

For cables, the cable configuration should match the cable interface. Otherwise, there can be a DSLINT error. For example, if the layer configuration of a cable is C1,I1,C2,I2, then the conducting parts are C1 (conductor) and C2 (insulator). In the cable interface, the external electrical connection for coaxial cable 1 should be conductor/sheath as shown below.





Exceptions (Very Important)

Under following circumstance, the corresponding conductor/conducting layer does not appear in the interface

(A) The outermost layer of <u>underground</u> cable is a conducting layer (no insulation layer between conducting layer to earth)

(B) The “Ideal cross-bonding” is enabled and the sheath or any conducting layer defined as “included”

(C) If the conductor/conducting layer under “Mathematical conductor elimination” is eliminated.

Examples for scenario (A)

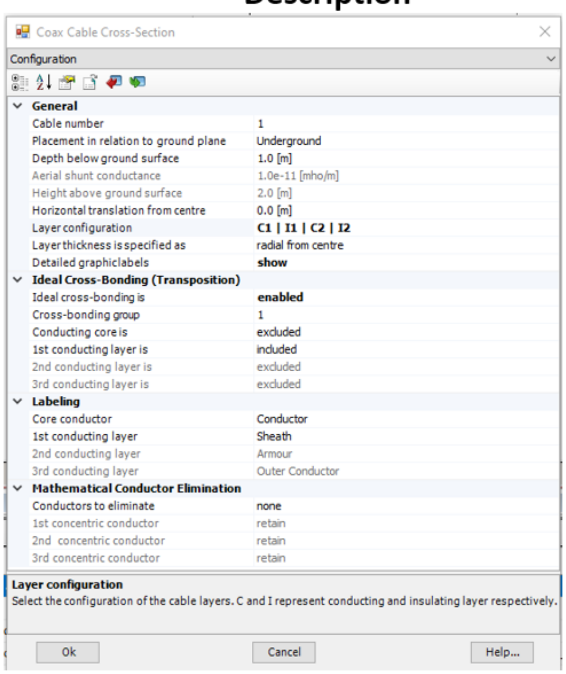
The following table shows the external electrical connection for underground cables.

Layer configuration	External electrical connection
C1	*
C1-I1	Conductor
C1-I1-C2	Conductor *
C1-I1-C2-I2	Conductor/sheath
C1-I1-C2-I2-C3	Conductor/sheath *
C1-I1-C2-I2-C3-I3	Conductor/sheath/armour
C1-I1-C2-I2-C3-I3-C4	Conductor/sheath/armour *
C1-I1-C2-I2-C3-I3-C4-I4	Conductor/sheath/armour/outer conductor

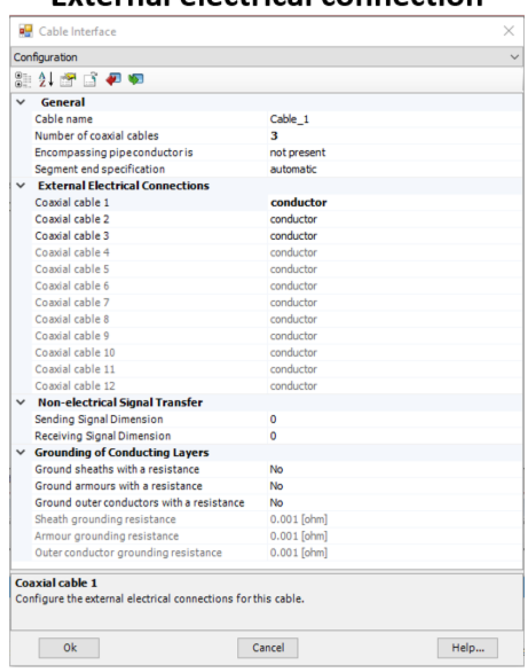
Note, for C1 or bare cable, there is no external connection. Also * shows where the rule (A) is applied.

Example for scenario (B)

Description



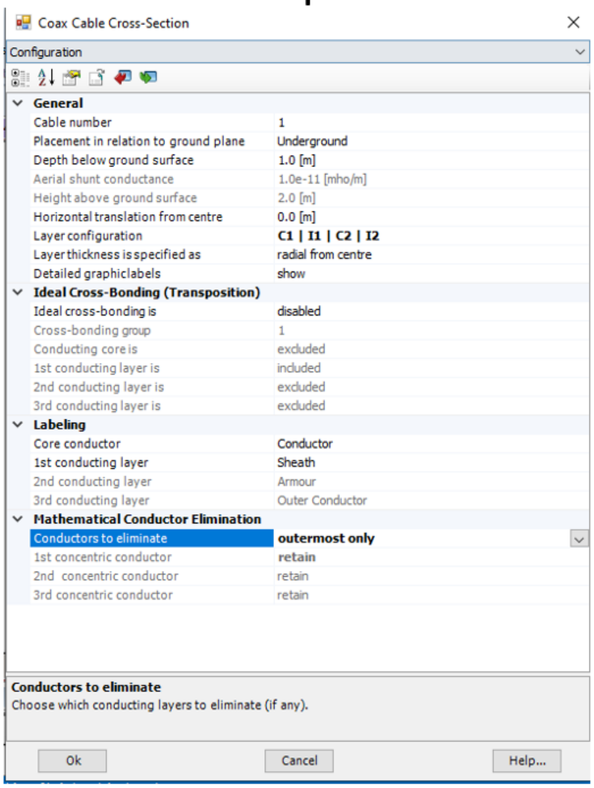
External electrical connection



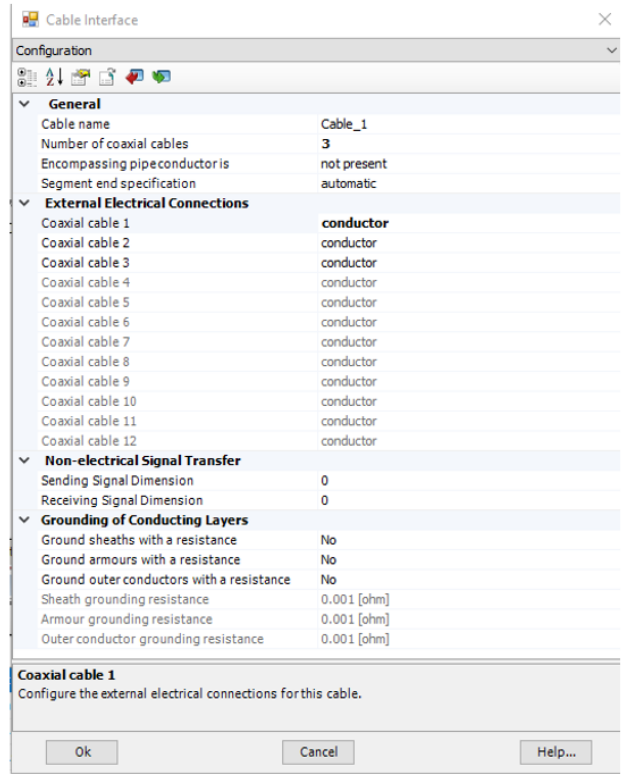
(Note: since ideal cross-bonding is enabled and “1st conducting layer” (or C2 or sheath) is “included”, sheath is eliminated)

Example for scenario (C)

Description



External electrical connection



(Note: since the outermost conductor (sheath or C2) is eliminated under mathematical conductor elimination , there is no sheath connection in external electrical connection

Note: The following table shows the external electrical connection for aerial cables (above ground).

Layer configuration	External electrical connection
C1	Conductor
C1-I1	Conductor
C1-I1-C2	Conductor/sheath
C1-I1-C2-I2	Conductor/sheath
C1-I1-C2-I2-C3	Conductor/sheath/armour
C1-I1-C2-I2-C3-I3	Conductor/sheath/armour
C1-I1-C2-I2-C3-I3-C4	Conductor/sheath/armour/outer conductor
C1-I1-C2-I2-C3-I3-C4-I4	Conductor/sheath/armour/outer conductor

Mathematical Elimination of Conductors

If the conductor or conducting layer is **continuously** connected to the earth, the voltage of the conductor is almost zero. Then the conductor can be removed from a mathematical procedure called Kron reduction.

The examples where conductor elimination is applied are,

1. Outermost layer of a cable is a conductor
2. Ground wires with elimination enabled in towers
3. Conductors with manual conductor elimination
4. Bare underground cable
5. Sheath/conducting layers in a ideally cross-bonded cable

Frequently Asked Questions

1. Does conductor elimination means that the relevant conductor is neglected?

The elimination does not mean that the sheath is neglected. Instead, the effect of the conductor is approximately considered.

For an example, below shows the series impedance matrix for an underground cable with conductor and a sheath before and after elimination of sheath conducting layer.

Series impedance matrix (Z) before elimination of sheath	
[0.764748540E-04 + j0.810698804E-03	0.593822682E-04 + j0.748018882E-03
0.593822682E-04 + j0.748018882E-03	0.245744440E-03 + j0.746664455E-03]
Series impedance matrix (Zred) after elimination of sheath	
[**0.190252698E-03 + j0.103492618E-03**]	

As you can see, before elimination, the size of the matrix is 2 (representing conductor and sheath), however after elimination, the size of the matrix is 1 (representing conductor only). After reduction the self impedance is changed (compare Z(1,1) with Zred(1,1)) to include the impedance of sheath indirectly.

2. Is there an electrical connection of the eliminated conductor to the network (in the cable or line interface)

No.

3. Where can we see conductor elimination?

The ground wires are regularly connected to the ground and hence can be eliminated in many simulation studies (except lightning studies or very high frequency transients).

If a long AC cable system is cross-bonded with many segments, then it can be modelled as a single cable model with ideally cross-bonding enabled. The sheath is emanated assuming sheath is transposed and connected to ground at regular intervals.

Advantages of Conductor Elimination

a. The complexity of the cable system is reduced; hence, it may be relatively easy to enforce/improve stability of the simulation.

b. The computation and memory requirements for the cable system is reduced. The simulation speed is increased.

DOCUMENT TRACKING

Rev.	Description	Date
0	Initial	18/Mar/2022
1	New Section 2.5 New Section 5 intro para Update to Sections 4.3, 5.1, 5.2, 5.3, 9 (intro) Update to Appendices 1, 2, 3	29/May/2023