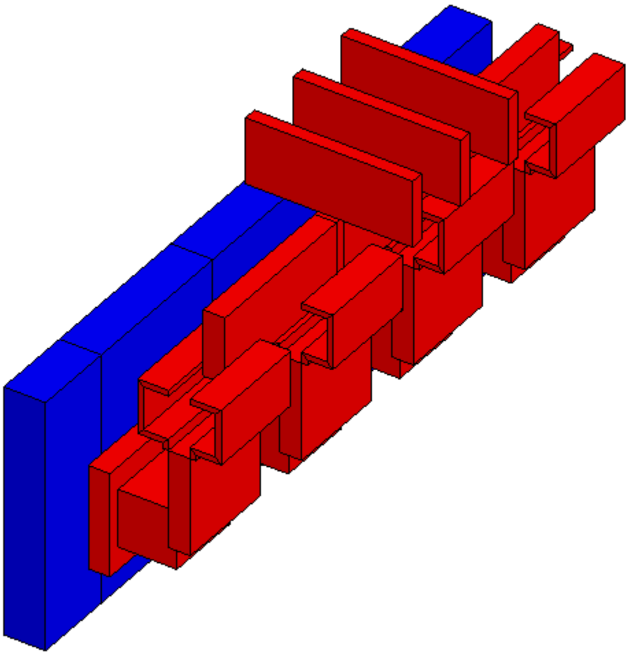
CAD package for conductor impedance
and near field simulations of electrical connections

Altair Flux™

Power diode bridge tutorial: circuit coupling of Flux PEEC models

PEEC technical example



ALTAIR

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Foreword

*(Please read before starting this tutorial)

Description of the document

This technical example explains all steps to model the connection inside a power diode cell using the Flux PEEC software and to export it into the Portunus circuit simulation software.

Reference files

The Flux PEEC projects corresponding to the different cases studied in this technical example are not directly provided to the user, nevertheless ha can easily create them by running the command files, written in Python language, available in the folder:
…\flux\Flux\DocExamples\ExamplesPEEC\Tutorial_Technical\PowerDiodeBridge\PowerDiodeBridge.zip

In particular, in the subfolder ***PowerDiodeBridge_PEEC_Case1***, the main Python files provided are:

Name	Content
buildGeophys.py	Commands to automatically create the Flux PEEC project containing the description of the geometry, the physics and the meshing, as well as the circuit of the studied system. It corresponds to what is described in Chapter 2 of this tutorial. Regarding the definition of the circuit, the strategy identified as "case 2" (see page 29) is implemented by this Python file.
State_Solving.py	Commands to automatically create and solve the Flux PEEC project describing the studied system. Regarding the definition of the circuit, the strategy identified as "case 2" (see page 29) is implemented by this Python file.

TABLE OF CONTENTS

1. Overview of the studied problem

Introduction

The aim of this technical example is to better understand how to model the electrical interconnections inside a power diode bridge using Flux PEEC software package, and how to export it towards the simulation circuit software Portunus.

This chapter contains a brief description of the device and studied cases and introduces the theoretical aspects of the modeling.

Contents

This section contains the following topics:

1.1. Description of the device

Studied device

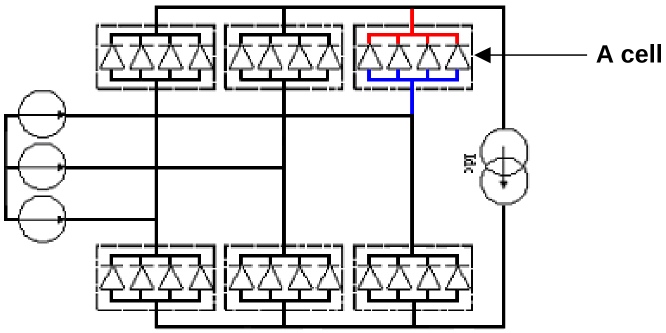
The studied device is a three-phase power diode bridge.

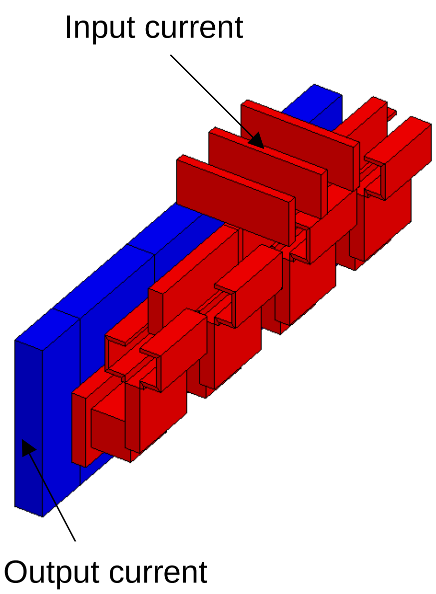
Description of the device

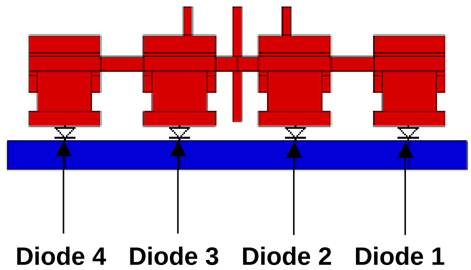
This power diode bridge (50 kA nominal current) is composed of six cells with four parallel diodes each.

Electrical interconnections of one cell are modeled with Flux PEEC and imported six times into Portunus to build the full power diode bridge schematic.

The geometry of a cell is represented in the figure below.







Materials

The conductors of this device are made of **copper**, an electro-conductive nonmagnetic material.

Material	Resistivity (20°C)
Copper	$\rho_{Cu} = 1{,}72.10^{-8}\ \Omega.m$

1.2. Studied cases

Studied cases

With Flux PEEC software which is based on the PEEC (Partial Element Equivalent Circuit) method, a resistive and inductive model of the studied cell is generated. It contains partial resistances, partial inductances and mutual couplings, whose values depend from the material resistivity and the geometric characteristics of the conductors that constitute the device.

The aim of this tutorial is to study the influence of the position of the input bars on the RMS value of the current that flows inside the four diodes. Three geometries are considered using a parametric simulation: results are then exported into the simulation circuit software Portunus to analyze which location of the input bars is the most optimized one. Manual and automatic methods are used for the creation and the positioning of the impedance probes.

1.3. Theoretical aspects

Introduction

Impedance computation of an interconnection structure is a key-point to design a power system, because the parasitic inductances of cabling are the origin of phenomena like unbalanced currents or voltage overshoots in semiconductors.

Consequently, a model including the parasitic behavior of the conductors gives a better evaluation of the current and voltage constraints on the components.

The purpose of this technical example is to evaluate how much the currents are balanced between the four diodes in parallel. In fact, because of the interconnections the current in one diode is not equal to the total current divided by 4.

“Conductor Impedances” application

First, resistances, inductances and couplings of and between the meshing elements are computed with PEEC method. This process is common to all the applications.

Then, with the “Conductor Impedances” application, a reduced equivalent model is set-up by using impedance probes: it is expressed by means of an impedance matrix.

Results with Portunus

The obtained equivalent impedance matrix is translated by Flux PEEC into a macro block for the circuit simulation software Portunus.

Thanks to this function, the electrical interconnection can now be considered as a “standard” component, like diodes, and invoked inside Portunus using an import function.

The evaluation of parasitic effects due to the geometry can be done thanks to the time-domain waveforms obtained with Portunus.

Continued on next page

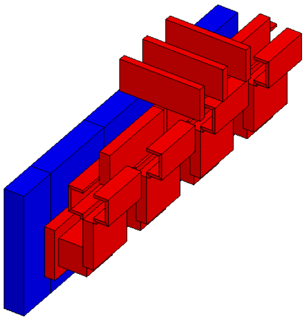
General process The general process of Flux PEEC modeling and the results obtained by coupling with Portunus are presented in the table below.

Stage	Description
1	Choice of an application and definition of a scenario
2	Conductors description
3	Meshing
4	Description of impedance probes and connections
5	Solving process (according to the defined scenario) and export of an equivalent Flux PEEC model towards Portunus
6	Import of the Flux PEEC model into Portunus
7	Simulation of the full schematic in Portunus
8	Results post-processing in Portunus
9	Modification of the geometry in Flux PEEC
10	Loop on stages 5 to 9 for the different geometries to be analyzed
11	Comparison of the results obtained for all studied configurations

2. Geometry, physics and meshing of conductors

Introduction

This chapter presents all the different steps to be performed within Flux PEEC for the geometry description of the power diode cell with associated physics and meshing of the device.



Python file

Two reader willing to skip this part of the tutorial and to directly move to the next section can easily generate the Flux PEEC project containing the geometry, the physics and the meshing, as well as the circuit of the studied system by running the Python file ***buildGeophys.py*** provided in the folder ***…\flux\Flux\DocExamples\ExamplesPEEC\Tutorial_Technical\PowerDiodeBridge\PowerDiodeBridge.zip\PowerDiodeBridge_PEEC_Case_1***

In particular, the mentioned Python file implements the strategy called “case 2” (see below) for the definition of the impedance probes.

Overview

The geometry and physics description of the device will be performed in the four stages listed in the table below.

Stage	Description
1	Definition of the physical application and solving scenario
2	Geometry and material of the cell conductors
3	Generation of the meshing
4	Case 1: creation of the impedance probes and their manual connection to the conductors
5	Case 2: automatic definition of the impedance probes

Contents

This chapter deals with the following topics:

2.1. Definition of the application and solving scenario

Introduction

This section presents the definition of the physical application and solving scenario in the Flux PEEC simulation environment.

Contents

This section deals with the following topics:

2.1.1. Define physics for the application

Goal

A Flux PEEC application is defined to generate the impedance model of the cell. The required application is **Conductor Impedances**.

Definition of the application

Properties to be set for this application are reported in the table below.

Type of application	Default material for conductors
Conductor Impedances	copper

2.1.2. Define the scenario of the solving process

Goal

The value of frequency (50 Hz) for the solving process is set via the solving scenario (only one scenario per project).

Definition of the scenario

Properties of the scenario are reported in the table below.

Name	Parameter controlled	Control type	Value
Scenario_1	FREQUENCY	Mono-value	50

2.2. Geometry and physics of the conductors

Introduction

This section presents the geometry description and associated physics of the conductors.

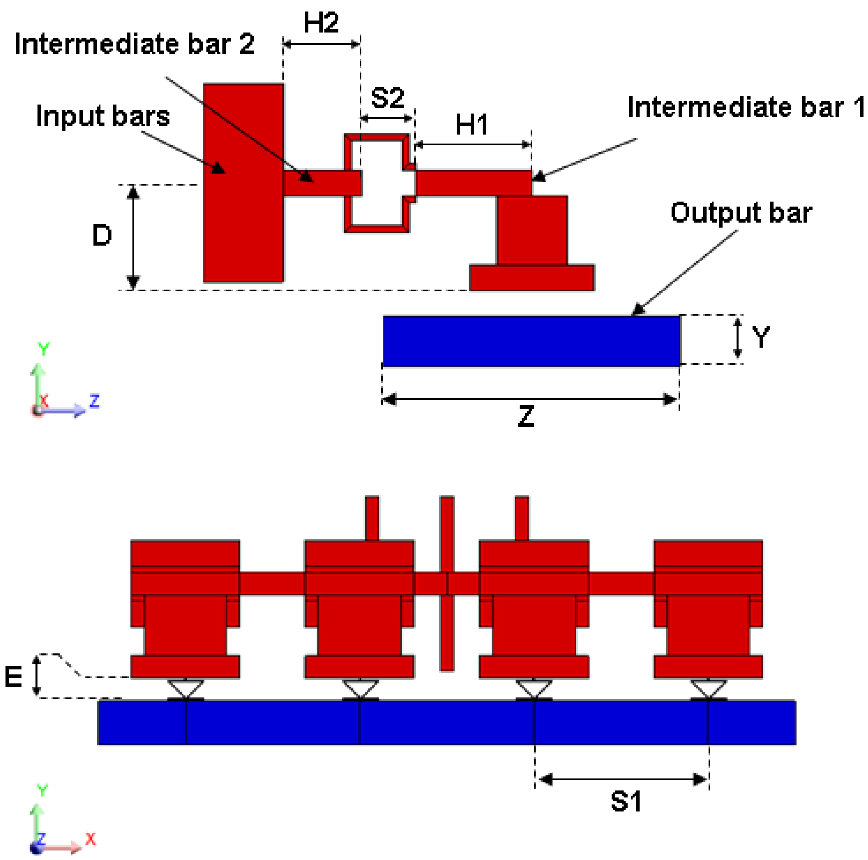
Contents

This section deals with the following topics:

2.2.1. Create geometric parameters

Goal

Nine geometric parameters are created to make easier and faster the geometry description of the cell of the power diode bridge.



Data

The properties of the geometric parameters are reported in the table below.

Geometric parameter		
Name	**Comment**	**Expression**
D	Distance between diodes and intermediate bars	109
E	Space for each diode	26
S1	Space between two diodes	200
S2	Space between intermediate bars 1 and 2	54
Y	Width of the output bar	50
Z	Height of the output bar	300
H1	Height of intermediate bar 1	117.5
H2	Height of intermediate bar 2	80
M	Location of the input bars according to **x** axis	200

☞ **Geometry → Geometric parameter → New**

2.2.2. Create tube points

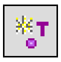
Goal Forty tube points are created.

Data (1) Geometric properties of tube points to create are reported in the table below.

Tube point defined by its parametric coordinates				
Number	**Coord. system**	**Coordinates**		
		First	**Second**	**Third**
1	XYZ1	0	0	0
2		0	26	0
3		0	D-13	0
4		0	D	0
5		0	D	-H1
6		0	D-16.5	-H1
7		0	D-16.5	-H1-10
8		0	D-46.5	-H1-10
9		0	D-46.5	-H1-S2-15
10		0	D-13	-H1-S2-15
11		0	D+16.5	-H1
12		0	D+16.5	-H1-10
13		0	D+46.5	-H1-10
14		0	D+46.5	-H1-S2-15
15		0	D+13	-H1-S2-15
16		-0.5*S1	-E-Y/2	0
17		0	-E-Y/2	0
18		S1	-E-Y/2	0
19		2*S1	-E-Y/2	0
20		3*S1	-E-Y/2	0
21		3.5*S1	-E-Y/2	0
22		0	D	-H1-H2/2-S2
23		0.5*S1-86	D	-H1-H2/2-S2
24		0.5*S1	D	-H1-H2/2-S2
25		0.5*S1+86	D	-H1-H2/2-S2
26		S1	D	-H1-H2/2-S2
27		1.5*S1-86	D	-H1-H2/2-S2
28		1.5*S1	D	-H1-H2/2-S2
29		1.5*S1+86	D	-H1-H2/2-S2
30		2*S1	D	-H1-H2/2-S2
31		2.5*S1-86	D	-H1-H2/2-S2
32		2.5*S1	D	-H1-H2/2-S2
33		2.5*S1+86	D	-H1-H2/2-S2
34		3*S1	D	-H1-H2/2-S2

Continued on next page

Tube point defined by its parametric coordinates				
Number	**Coord. system**	**Coordinates**		
		First	**Second**	**Third**
35	XYZ1	1.5*M-86	D	-H1-H2-S2
36		1.5*M-86	D	-H1-H2-S2-80
37		1.5*M	D	-H1-H2-S2
38		1.5*M	D	-H1-H2-S2-80
39		1.5*M+86	D	-H1-H2-S2
40		1.5*M+86	D	-H1-H2-S2-80

☞ **Geometry → Tube geometry → Tube point → New** 

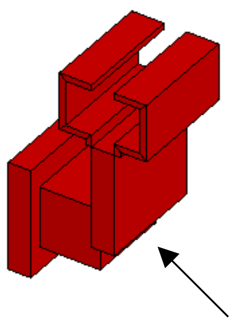
2.2.3. Create geometric tubes and corresponding conductors

Goal

Ten geometric tubes defined by a path are firstly created to model the five conductors (one for the DC voltage and four for the AC) around one of the diodes composing the cell.

Other geometric tubes are then created by propagation of the existing geometric tubes.

New unidirectional conductors are automatically generated by Flux PEEC from corresponding geometric tubes.



Conductors of the diode 4

Data (1)

The properties of the geometric tubes to create are reported in the table below.

Geometric tube defined by a path					
Name	**Path**	**List of tube points**	**Cross-section**	**Rectangle**	
				Side 1	**Side 2**
DIODE4_COND_1	open	1, 2	rectangular full	125	125
DIODE4_COND_2	open	2, 3	rectangular full	70	95
DIODE4_COND_3	open	4, 5	rectangular full	26	125
DIODE4_COND_4	open	6, 7, 8, 9, 10	rectangular full	7	125
DIODE4_COND_5	open	11, 12, 13, 14, 15	rectangular full	7	125
DC_COND	open	16, 17, 18, 19, 20, 21	rectangular full	Y	Z
AC_COND_4	open	22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34	rectangular full	26	H2
AC_COND_3	open	35, 36	rectangular full	200	16
AC_COND_2	open	37, 38	rectangular full	200	16
AC_COND_1	open	39, 40	rectangular full	200	16

☞ **Geometry → Tube geometry → Geometric tube → New**

Continued on next page

Data (2)

The properties of the transformation are reported in the table below.

Geometric transformation					
Name	Type of geometric transformation	Translation vector			Coord. system
		DX	DY	DZ	
TRANSF_DIODE	Translation vector	S1	0	0	XYZ1

☞ Geometry → Transformation → New

Data (3)

Remaining geometric tubes describing the bridge cell are created as propagated type by means of the above transformation.
The properties of these propagated geometric tubes are reported in the table below.

Propagated geometric tube		
Name	Geometric transformation	Origin geometric tube
DIODE3_COND_1	TRANSF_DIODE	DIODE4_COND_1
DIODE3_COND_2		DIODE4_COND_2
DIODE3_COND_3		DIODE4_COND_3
DIODE3_COND_4		DIODE4_COND_4
DIODE3_COND_5		DIODE4_COND_5
DIODE2_COND_1		DIODE3_COND_1
DIODE2_COND_2		DIODE3_COND_2
DIODE2_COND_3		DIODE3_COND_3
DIODE2_COND_4		DIODE3_COND_4
DIODE2_COND_5		DIODE3_COND_5
DIODE1_COND_1		DIODE2_COND_1
DIODE1_COND_2		DIODE2_COND_2
DIODE1_COND_3		DIODE2_COND_3
DIODE1_COND_4		DIODE2_COND_4
DIODE1_COND_5		DIODE2_COND_5

☞ Geometry → Tube geometry → Geometric tube → New

Result

Twenty-five unidirectional conductors associated to the geometric tubes are automatically created by Flux PEEC.

Continued on next page

Terminals and automatic connections

Terminals are automatically created by Flux PEEC at each tube point used by a geometric tube and labeled with the conductor’s name followed by a suffix which indicates their place along the conductor.

For example, TERM_DIODE4_COND_1_1 and TERM_DIODE4_COND_1_2 are the first and the second terminals of the conductor DIODE4_COND_1.

It has to be highlighted that terminals are also created for the geometric tubes defined as propagated type, even if, in such case, the tube points do not exist. These terminals are exactly placed at the same location than it is inside the geometric tubes of origin.

Thanks to an automatic algorithm, nineteen equipotential connections between conductors are automatically created by Flux PEEC. In fact, this algorithm firstly detects all the intersections between the surfaces of the conductors and then automatically generates a new equipotential connection if at least two surfaces involved in the intersection have terminals.

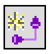
For example, CO_AUTO_1 is the electrical connection between TERM_DIODE4_COND_1_2 (the second terminal of the conductor DIODE4_COND_1) and TERM_DIODE4_COND_2_1 (the first terminal of the conductor DIODE4_COND_2).

Manual connection

In this study, in order to complete the electrical description of the system, one more connection between conductors needs to be manually created by the user, after the nineteen automatically generated by Flux PEEC.

It involves the three conductors AC_COND_1, AC_COND_2 and AC_COND_3 devoted to AC feed the cell and cannot be detected by the tool because the conductor carrying the AC phase is not represented in this model.

Equipotential connection		
Name	**Comment**	**Connected terminals**
AC_SOURCE	Connection of three feeding bars to AC source	TERM_AC_COND_1_2 TERM_AC_COND_2_2 TERM_AC_COND_3_2

☞ **Components and Electric Circuit → Connection → New** 

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Data (4)

For a better comprehension of the model some terminals are renamed as indicated in the table below.

Unidirectional conductor terminal	
Previous name	**New proposed name**
TERM_DC_COND_2	CATHODE_DIODE_4
TERM_DC_COND_3	CATHODE_DIODE_3
TERM_DC_COND_4	CATHODE_DIODE_2
TERM_DC_COND_5	CATHODE_DIODE_1
TERM_DIODE4_COND_1_1	ANODE_DIODE_4
TERM_DIODE3_COND_1_1	ANODE_DIODE_3
TERM_DIODE2_COND_1_1	ANODE_DIODE_2
TERM_DIODE1_COND_1_1	ANODE_DIODE_1

☞ **Components and Electric Circuit → Terminal → Edit**

2.3. Meshing of conductors

Introduction This section explains the preparation and generation of the meshing.

Contents This chapter deals with the following topics:

2.3.1. Generate the meshing

Description

When a unidirectional conductor is created, the meshing method is automatically configured as the "**according to the solving configuration**" type.

The meshing technique is based on the skin depth value for the conductor.

In this application, this meshing method defined by default is used to solve the scenario.

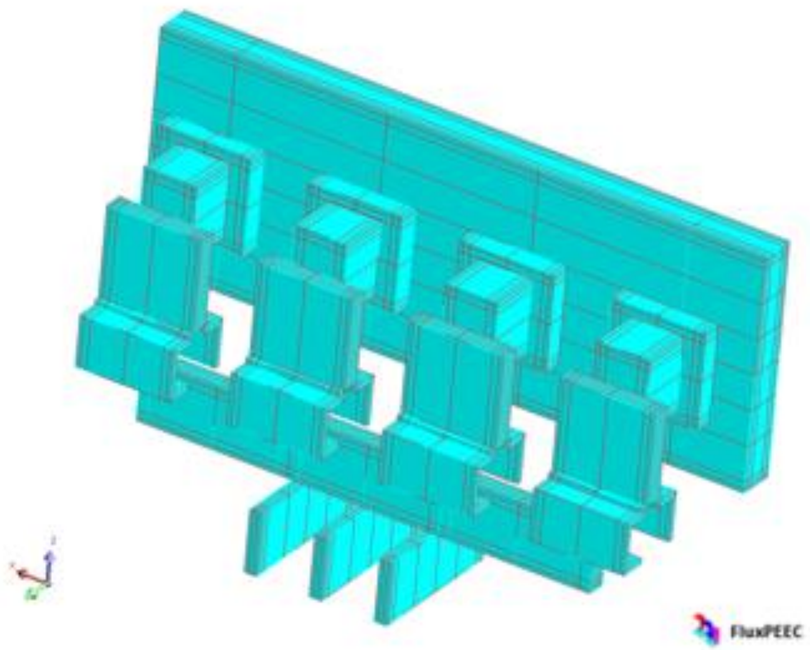
Action

Meshing of all conductors constituting the cell is generated using the **Mesh** command.

☞ **Solving → Mesh**

Result

Obtained meshing is shown in the figure below.



2.4. Case 1: manual creation and connection of the impedance probes

Introduction

This section explains how to manually create and connect impedance probes.

Overview

This description is carried out in two stages listed in the table below.

Stage	Description
1	Creation of impedance probes
2	Connection between impedance probes and conductors

Contents

This chapter deals with the following topics:

2.4.1. The concept of impedance probes

Introduction

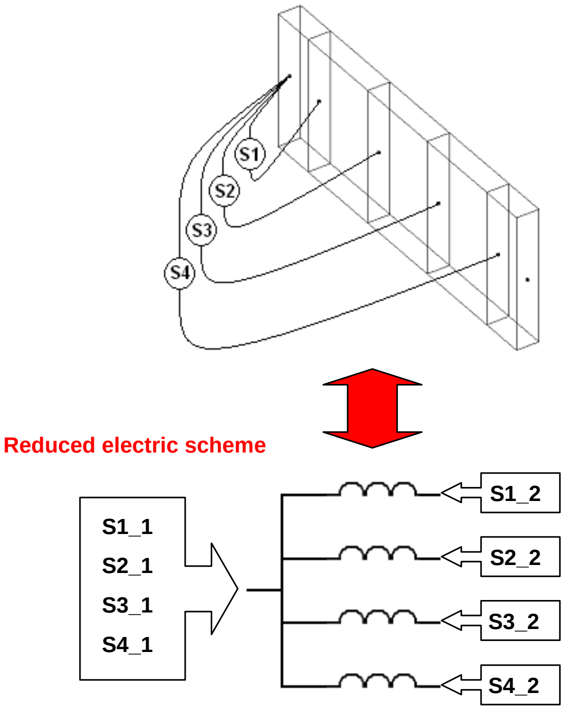
This section explains how to build a reduced equivalent electrical circuit and an associated macro-block by using impedance probes.

Description of the method

Each meshing element can be seen as a basic equivalent electrical circuit with a resistor and an inductance connected to the meshing nodes. The values of these equivalent electrical components depend on geometry (meshes dimensions and distance between the meshes) and physics (frequency, material) parameters. Impedance probes are used to compute and extract the values of the equivalent impedance between several chosen points of the geometry. These points are named terminals as explained in section 2.2.3. Impedance values are computed by taking into account self impedance of the meshing elements and also all mutual effects between them.

For example, in the case shown on the figure below: a conductor with five accessing pins is considered. The first point on the left is taken as the reference and four impedance probes are connected between this point and the four other electrical entries.

The equivalent circuit of this meshed geometry is reduced to a 4*4 impedance matrix.
To simplify the figure, only self-inductances are represented (resistors and mutual inductances do not appear on it).



2.4.2. Creation of impedance probes

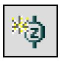
Goal

Eight impedance probes are created for extracting an equivalent model of the cell, adapted to be imported in a Portunus schematic.

Data (1)

The properties of the impedance probes are listed in the table below.

Impedance probes
Name
S1
S2
S3
S4
S5
S6
S7
S8

☞ **Components and Electric Circuit → Impedance probe → New** 

Consequences

For each impedance probe, two terminals are automatically created by Flux PEEC: they enable the connection of the probe with the conductors constituting the structure.

2.4.3. Connection between impedance probes and conductors

Goal

This step is to connect impedance probes to the conductors in order to indicate to the tool the points where the equivalent macro-block has to be computed.

Data (1)

One connection (AC_SOURCE) has been yet previously created, but it needs to be updated by adding the terminals of the impedances probes that are located at the same place.

Equipotential connections	
Name	**Connected terminals**
AC_SOURCE	TERM_AC_COND_1_2 TERM_AC_COND_2_2 TERM_AC_COND_3_2 TERM_S1_1 TERM_S2_1 TERM_S3_1 TERM_S4_1

☞ **Components and Electric Circuit → Connection → Edit**

Continued on next page

Data (2)

Nine new equipotential connections are needed to complete the electric circuit; their properties are presented in the table below.

Equipotential connections	
Name	**Connected terminals**
TERMCONNECTION_21	ANODE_DIODE_1 TERM_S1_2
TERMCONNECTION_22	ANODE_DIODE_2 TERM_S2_2
TERMCONNECTION_23	ANODE_DIODE_3 TERM_S3_2
TERMCONNECTION_24	ANODE_DIODE_4 TERM_S4_2
CURRENT_LOAD	TERM_DC_COND_1 TERM_S5_2 TERM_S6_2 TERM_S7_2 TERM_S8_2
TERMCONNECTION_26	CATHODE_DIODE_1 TERM_S5_1
TERMCONNECTION_27	CATHODE_DIODE_2 TERM_S6_1
TERMCONNECTION_28	CATHODE_DIODE_3 TERM_S7_1
TERMCONNECTION_29	CATHODE_DIODE_4 TERM_S8_1

☞ **Components and Electric Circuit → Connection → New**

Action

Go directly to chapter 3.

2.5. Case 2: automatic definition of the impedance probes

Introduction

This section explains how to automatically create and connect impedance probes thanks to a dedicated algorithm.

Python file

It is just reminded here that this part of the tutorial is included into the Python file ***buildGeophys.py*** provided in the folder ***…\flux\Flux\DocExamples\ExamplesPEEC\Tutorial_Technical\PowerDiodeBridge\PowerDiodeBridge.zip\PowerDiodeBridge_PEEC_Case_1***

The execution of this Python file creates the Flux PEEC project allowing the user to directly move to Chapter 3 of this tutorial.

Contents

This chapter deals with the following topics:

2.5.1. Identification of macro-block terminals

Goal

Terminals where impedance probes need to be connected must be identified before launching the algorithm for the automatic creation and connection of impedances probes.

Data

The properties of terminals identified as pins of the macro-component to be exported are presented in the table below.

Terminals	
Name	**Pin of macro component**
TERM_DC_COND_1	Yes
TERM_AC_COND_2_2	Yes
CATHODE_DIODE_1	Yes
CATHODE_DIODE_2	Yes
CATHODE_DIODE_3	Yes
CATHODE_DIODE_4	Yes
ANODE_DIODE_1	Yes
ANODE_DIODE_2	Yes
ANODE_DIODE_3	Yes
ANODE_DIODE_4	Yes

☞ **Components and Electric Circuit → Terminal → Edit**

Consequence

A graphical symbol appears on each terminal in order to indicate it as a pin of the macro-component.

2.5.2. Automatic creation and connection of impedance probes

Goal

Flux PEEC automatically creates and connects the suitable number of impedance probes.

Action

The automatic algorithm is launched using the dedicated command.

Components and Electric Circuit → Automatic creation of impedance probes	

Result (1)

Eight impedance probes are automatically created. Names of the impedance probes are presented in the table below.

Impedance probes
Name
Z_AUTO_1
Z_AUTO_2
Z_AUTO_3
Z_AUTO_4
Z_AUTO_5
Z_AUTO_6
Z_AUTO_7
Z_AUTO_8

Continued on next page

Result (2)

The probes are automatically linked to the conductors by means of equipotential connections: one of them (AC_SOURCE) has simply been updated since it yet existed, whereas nine new connections have been created. Their properties are presented in the table below.

Equipotential connections	
Name	**Connected terminals**
AC_SOURCE	TERM_AC_COND_1_2 TERM_AC_COND_2_2 TERM_AC_COND_3_2 TERM_Z_AUTO_1_2
CO_AUTO_20	ANODE_DIODE_3 TERM_Z_AUTO_1_1 TERM_Z_AUTO_2_1 TERM_Z_AUTO_3_1 TERM_Z_AUTO_4_1
CO_AUTO_21	ANODE_DIODE_1 TERM_Z_AUTO_2_2
CO_AUTO_22	ANODE_DIODE_2 TERM_Z_AUTO_3_2
CO_AUTO_23	ANODE_DIODE_4 TERM_Z_AUTO_4_2
CO_AUTO_24	CATHODE_DIODE_3 TERM_Z_AUTO_5_1 TERM_Z_AUTO_6_1 TERM_Z_AUTO_7_1 TERM_Z_AUTO_8_1
CO_AUTO_25	CATHODE_DIODE_2 TERM_Z_AUTO_5_2
CO_AUTO_26	CATHODE_DIODE_1 TERM_Z_AUTO_6_2
CO_AUTO_27	CATHODE_DIODE_4 TERM_Z_AUTO_7_2
CO_AUTO_28	TERM_DC_COND_1 TERM_Z_AUTO_8_2

Data

For a better comprehension of the model one connection is renamed as indicated in the table below.

Equipotential connection	
Previous name	**New proposed name**
CO_AUTO_28	CURRENT_LOAD

☞ **Components and Electric Circuit → Connection → Edit**

3. Solving process and export of Flux PEEC model

Introduction

This chapter explains how to solve the Flux PEEC project and export the equivalent model for Portunus. Whatever the strategy for the definition of the impedance probes the reader has adopted, he can continue the tutorial from this point.

Contents

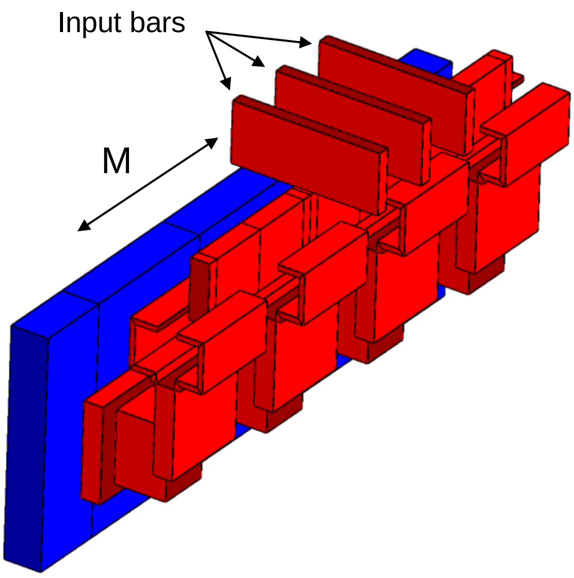
This chapter deals with the following topics:

3.1. Modify the solving process scenario

Goal

The study performed in this technical example is devoted to analyze the influence of the location of the three input bars in order to find out the best position that limits the discrepancies between currents flowing in the diodes.

To this aim the geometric parameter M makes it possible to move input bars along the intermediate bar 2. The solving scenario is modified accordingly.



Data

Solving scenario properties to be set are presented in the table below.

Solving scenario				
Controlled parameter	**Parameter control**			
	Lower limit	**Higher limit**	**Variation method**	**Step value**
M	66.6	333.4	Step value	133.4

☞ **Solving → Solving scenario → Edit**

Consequence

During the solving process, the parameter M will take three values corresponding to three different positions for input bars:

- position 1: M = 66.6
- position 2: M = 200
- position 3: M = 333.4

3.2. Solve the project

Goal	The Flux PEEC project is solved under the modified scenario.
Action	The command **Solve** launches the impedance computation algorithm according to the values of the geometric parameter M.
☞	**Solving → Solve**
Consequence (1)	For each value assumed by the parameter M, the solving process consists of two main parts: in the first one, the size of the computed impedance matrix is equal to the number of meshing subdivisions.
Consequence (2)	In the second part, the size of the impedance matrix is reduced to the number of impedance probes, in order to present to the user only the useful results.

3.3. Export of Flux PEEC model

Goal

The electrical equivalent circuit, built with Flux PEEC, is exported as a macro-block for Portunus.

Action (1)

Select the first step of the computation, corresponding to the value 66.6 for the parameter M.

Post Processing → Select computation step	

Action (2)

Generate the Portunus equivalent macro-block of the Flux PEEC model. Indicate **PowerDiodeBridge_Position_1** as directory name for saving the created files.

Post Processing → Results export → RL macroblock for Portunus	

Consequence

The **Portunus files export** command creates a folder named **PowerDiodeBridge_Position_1.PORTUNUS** with a file inside:
- **F0_PowerDiodeBridge_Position_1.I2P**

This **I2P** file contains the equivalent model to be imported in Portunus; it is worth to note that if several Flux PEEC impedance probes are connected on the same equipotential connection, only one terminal is exported. In fact the others are not necessary since their potential is exactly the same.

Action

If the Flux PEEC model has been created by means of the automatic algorithm for impedance probes (case 2), for a better comprehension it is suggested to open with a text editor the file **PowerDiodeBridge_Position_1.I2P** and modify the following terminal names:

Terminals	
Previous name	**New proposed name**
TERM_AC_COND_2_2	AC_SOURCE
TERM_DC_COND_1	CURRENT_LOAD

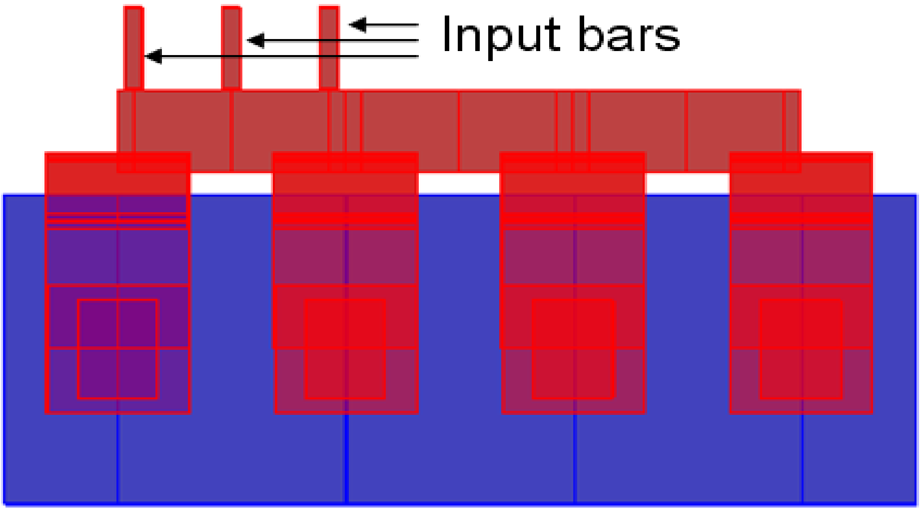
4. Position 1: coupling with Portunus and post-processing

Introduction

This section explains how to import the Flux PEEC model of a cell of the power diode bridge into Portunus software. Using the imported macro-block, unbalances of currents can be quantified with time domain simulations.

Flux PEEC geometry

The geometry of the cell studied with Flux PEEC and used in this chapter corresponds to position 1 of the input bars; it is showed below.



Overview

Detailed results obtained with Portunus will be presented as described in the table below.

Stage	Description
1	Import of Flux PEEC model into Portunus
2	Loading of the Portunus scheme
3	Simulation in Portunus

Contents

This chapter deals with the following topics:

4.1. Import of Flux PEEC model into Portunus

Goal

Flux PEEC model is imported into Portunus.

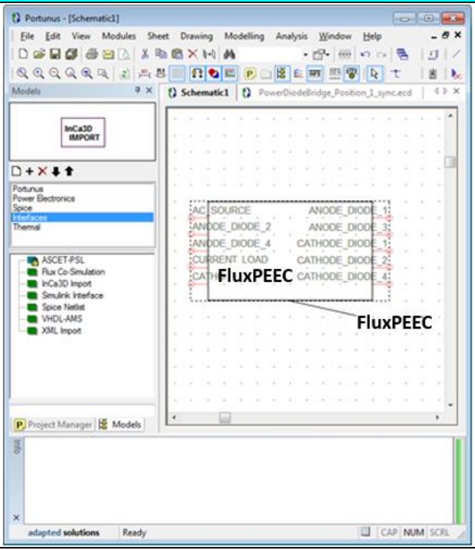
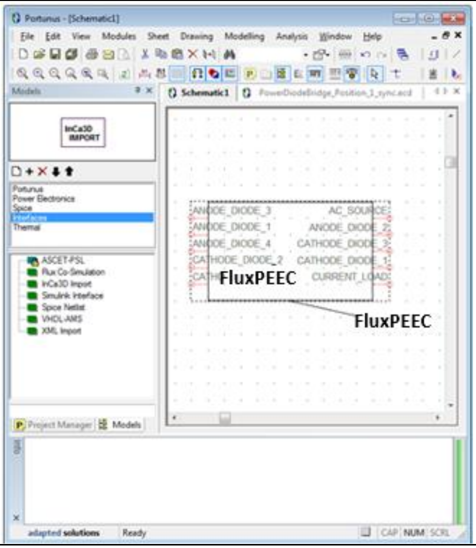
Actions

The actions to perform for importing Flux PEEC model into Portunus is listed below.

Step	Action
1	In Portunus data tree, go to **Interfaces --> Flux PEEC Import**
2	With the mouse move the Flux PEEC coupling element on the main sheet of Portunus
3	Double-click on the Flux PEEC element in order to open its dialog window
4	Click on **Import** and select the file **F0_PowerDiodeBridge_Position_1.I2P**
5	Click on **OK** to link the file to the model

Description

When the **I2P** file is linked to the Flux PEEC element, the Portunus schematic looks like in the figure below.

Imported components	
Case 1: manual impedance probes	Case 2: automatic impedance probes
	

4.2. Create the full power diode bridge schematic

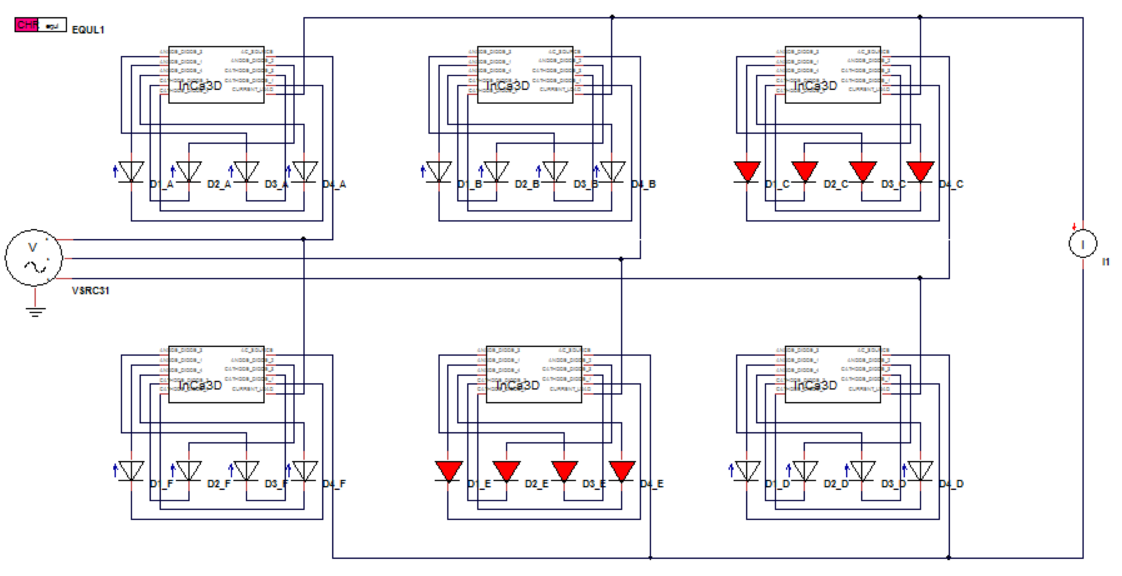
Action

The complete schematic of the three-phase diode bridge is now built as shown in the figure below, by using the I2P model obtained with Flux PEEC.

Description of the full Portunus model

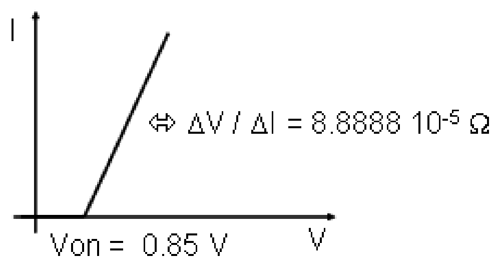
Six Flux PEEC coupling elements are used to realize six "switching functions"; each of them is composed of four diodes in parallel.

The diode bridge is supplied by a sinusoidal voltage source and the load is represented by an equivalent model made of a DC current generator.



Properties of diodes

In this application, the properties of the diodes are represented in the figure below. It is called **equivalent line** in Portunus.



Properties of generators

The voltage generator is a three phase sinusoidal source with RMS value of 230 V and frequency of 50 Hz.

The current generator representing the nominal working point of the load is a continuous source of 50 kA.

4.3. Set parameters and run the simulation

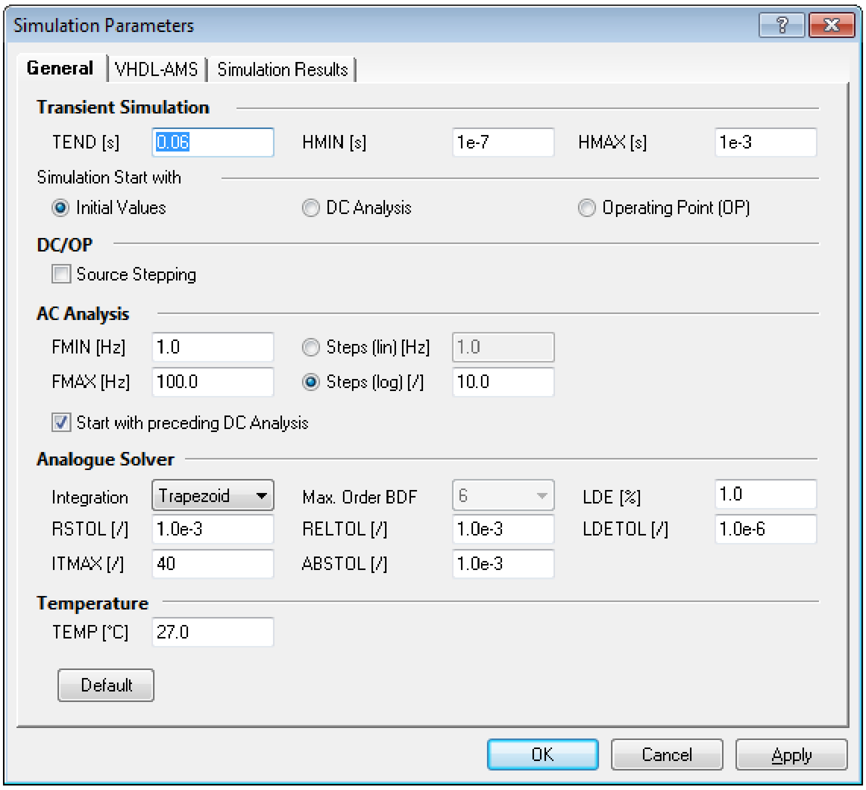
Goal

Portunus parameters are edited to configure the analysis to perform and a simulation is started.

Actions

The actions to perform for running the Portunus simulation of the diode bridge are listed below.

Note that this procedure has to be applied also for next simulations (**Positions 2 and 3**) presented in the following chapters of this tutorial.

Step	Action
1	In the **Analysis** menu, click on **Simulation Parameters**
2	In the dialog box, set the parameters: • TEND (end-time for the simulation) equal to 60 ms (equivalent to three periods of the signal) • and HMIN (minimum simulation step size) to 0.1 µs 
3	All other parameters are left to their default value.
4	In the **Analysis** menu, click on **Transient Analysis** to run the simulation

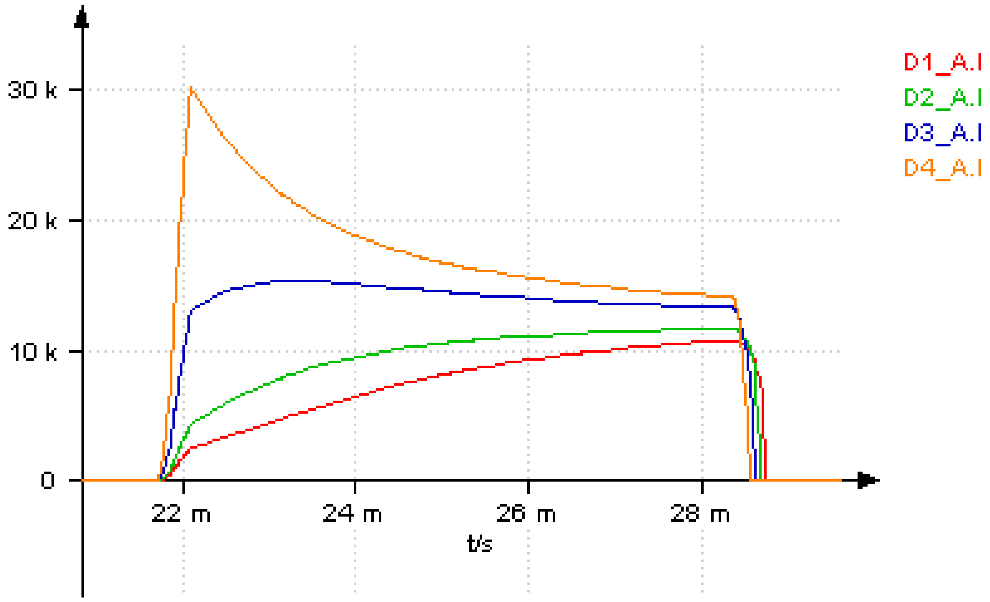
4.4. Post-processing

Goal

The current balance between the four parallel diodes of one cell is evaluated.

Temporal results

Unbalanced currents are shown on the waveforms below.



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RMS result

RMS values of currents are usually used to choose a model of diode.

Action

Click on the **Characteristics** icon in the bottom zone of the curves to display the main features of computed waveforms. Then, select one period of the signal, for example, between 20 ms to 40 ms.

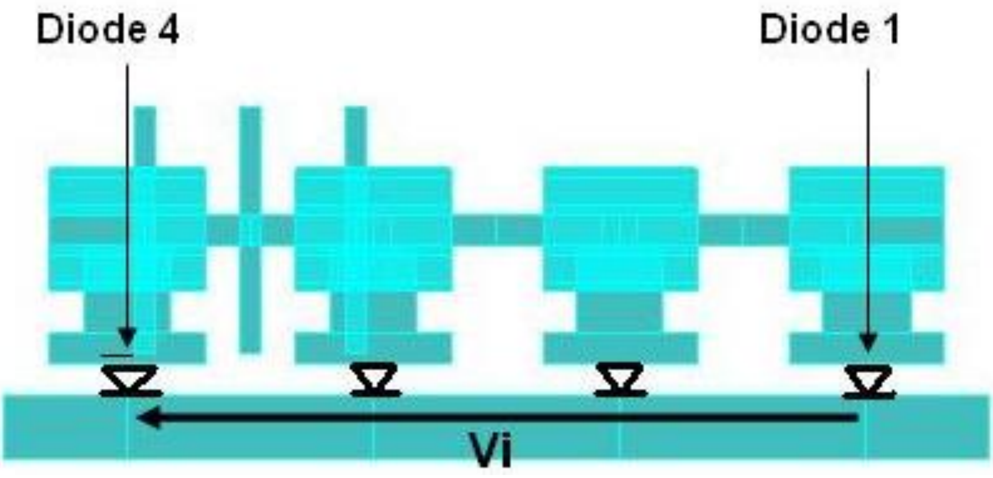
As a result the RMS values are posted immediately in the **characteristics** box.

Diode n°	RMS value of the current (kA)
1	4.78
2	5.82
3	8.12
4	10.52

Conclusion on the results

How the currents are balanced is linked to the geometry of the cell. In this case the RMS value of the current flowing in diode n°4 is 120% greater than the current in diode n°1. This is due to the voltage drops created by the parasitic coupled inductances.

For example, an inductive voltage Vi appears along the DC conductor between the diodes n°1 and n°4. This voltage added to the threshold voltage modifies the dynamic of the diodes and consequently current is not uniformly distributed.



5. Position 2: Flux PEEC generation of a new equivalent model

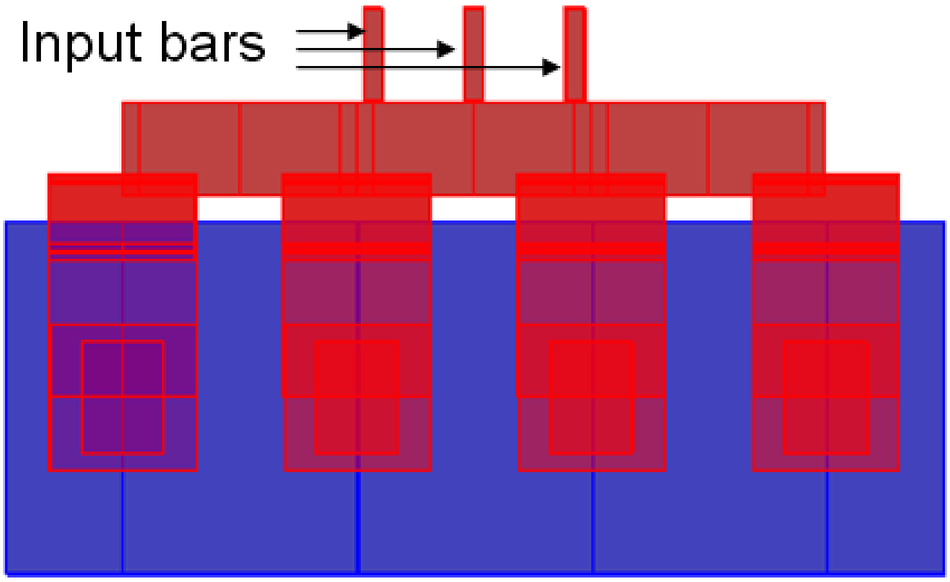
Introduction

This chapter presents how to generate within Flux PEEC environment a second macro-block for the cell geometry; it concerns the position 2 of the input bars, i.e. M = 200

Modifications on the RMS values of the currents flowing in the diodes are also estimated.

Geometry

The second geometry where input bars are located at position 2 is showed below.



Contents

This chapter deals with the following topics:

5.1. Geometry changing and export of a new Flux PEEC model

Goal

Move the location of input bars from position 1 to position 2 and generate the corresponding equivalent model for Portunus.

Action (1)

In Flux PEEC software environment select the second step of the computation, corresponding to M = 200.

☞ **Post Processing → Select computation step**

Action (2)

Generate the Portunus equivalent macro-block of the Flux PEEC model. Indicate **PowerDiodeBridge_Position_2** as directory name for saving the created files.

☞ **Post Processing → Results export → RL macroblock for Portunus**

Consequence

The **Portunus files export** command creates a folder named **PowerDiodeBridge_Position_2.PORTUNUS** with a file inside:
- **F0_PowerDiodeBridge_Position_2.I2P**

Action (3)

If the Flux PEEC model has been created by means of the automatic algorithm for impedance probes (case 2), for a better comprehension it is suggested to open with a text editor the file **PowerDiodeBridge_Position_2.I2P** and modify the following terminal names:

Terminals	
Previous name	**New proposed name**
TERM_AC_COND_2_2	AC_SOURCE
TERM_DC_COND_1	CURRENT_LOAD

5.2. Position 2: coupling with Portunus and post-processing of results

Introduction

New results are obtained with the second Flux PEEC model imported into Portunus schematic of the diode bridge.

Actions

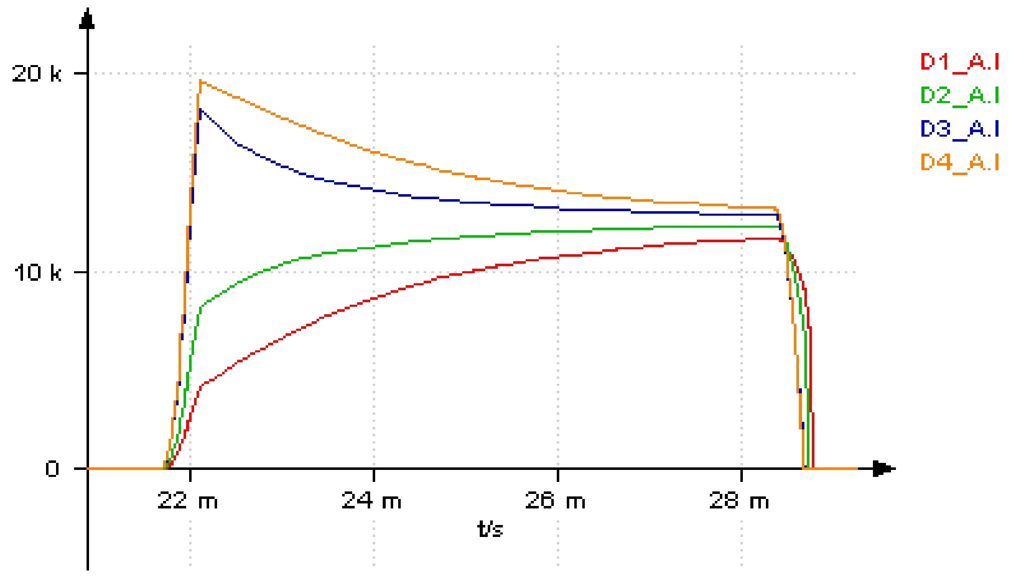
To create the new schematic to simulate, open each Flux PEEC element and replace the existing file with the new one:
F0_PowerDiodeBridge_Position_2.I2P

Transient simulation

Run a **Transient Analysis** with the same parameters of the previous simulation (see paragraph 4.3).

Temporal result

Unbalanced currents are shown on the waveforms below.



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RMS result

RMS values of currents in all diodes of one cell are obtained by means of the **Characteristics** icon in the time interval between 20 ms and 40 ms.

Diode n°	RMS value of the current (kA)
1	5.60
2	6.57
3	7.97
4	8.72

Conclusion

In this second case, the RMS value of the current in diode n°4 is only 56% greater than the current in diode n°1. The discrepancies between currents are reduced with respect to the geometry where input bars were located at position 1.

5.3. Comparison between the two positions of input bars

Goal

RMS values of current in the diodes between the two positions of the input bars are compared.

Notes

With input bars located at position 1, the maximum difference between RMS values is 120%, whereas in case of position 2 this difference falls to 56%, because the geometry is improved.

Nevertheless, the performances can be more optimized.

Diode n°	RMS value of the current (kA)	
	Position 1	Position 2
1	4.78	5.60
2	5.82	6.57
3	8.12	7.97
4	10.52	8.72

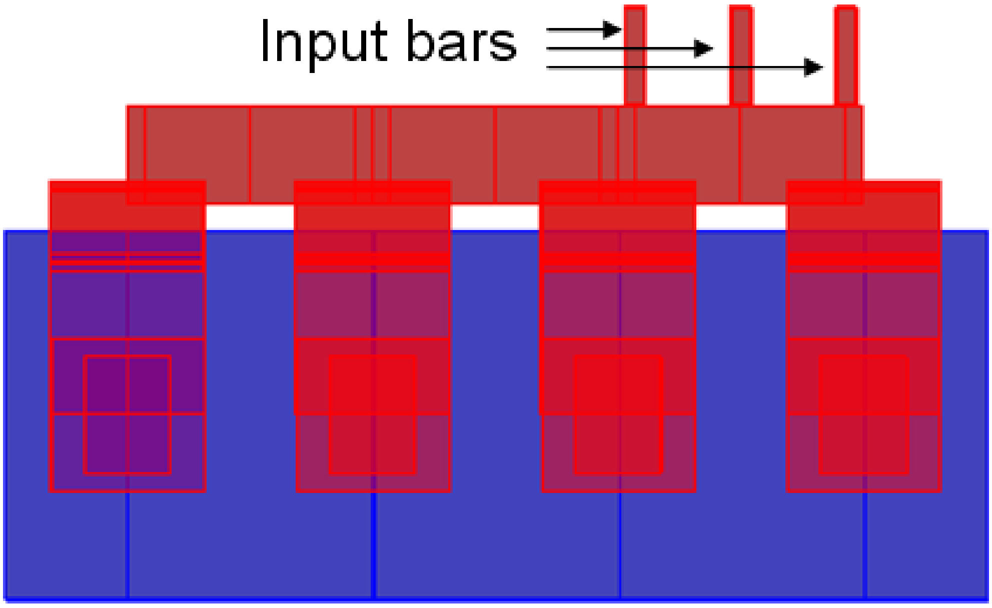
6. Position 3: optimized geometry

Introduction

This chapter presents the results obtained if the input bars are positioned at the third location. A new Flux PEEC model is generated and used in the Portunus schematic.

Geometry

The third geometry where input bars are located at position 3 is showed below.



Contents

This chapter deals with the following topics:

6.1. Optimized geometry export

Goal

Move the location of input bars to position 3 and generate the corresponding equivalent model for Portunus.

Action (1)

In Flux PEEC software environment select the second step of the computation, corresponding to M = 333.4

Post Processing → Select computation step

Action (2)

Generate the Portunus equivalent macro-block of the Flux PEEC model. Indicate **PowerDiodeBridge_Position_3** as directory name for saving the created files.

Post Processing → Results export → RL macroblock for Portunus

Consequence

The **Portunus files export** command creates a folder named **PowerDiodeBridge_Position_3.PORTUNUS** with a file inside:
- **F0_PowerDiodeBridge_Position_3.I2P**

Action (3)

If the Flux PEEC model has been created by means of the automatic algorithm for impedance probes (case 2), for a better comprehension it is suggested to open with a text editor the file **PowerDiodeBridge_Position_3.I2P** and modify the following terminal names:

Terminals	
Previous name	**New proposed name**
TERM_AC_COND_2_2	AC_SOURCE
TERM_DC_COND_1	CURRENT_LOAD

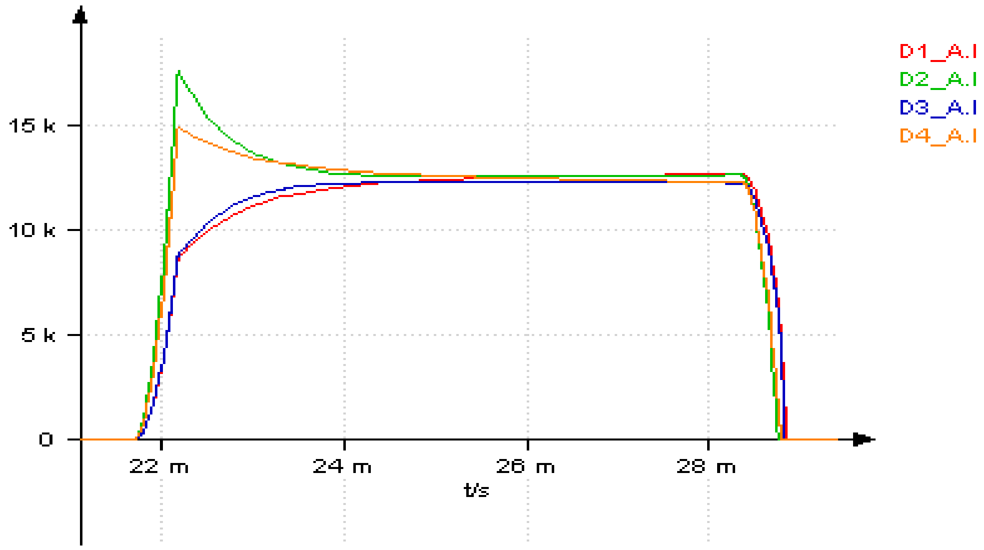
6.2. Position 3: coupling with Portunus and post-processing of results

Introduction New results are obtained with the third Flux PEEC model in Portunus.

Actions To create the new schematic to simulate, open each Flux PEEC element and replace the existing file with the new one:
F0_PowerDiodeBridge_Position_3.I2P

Transient simulation Run a **Transient Analysis** with the same parameters of the previous simulations (see paragraph 4.3).

Temporal result Unbalanced currents are shown on the waveforms below.



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RMS result

RMS values of currents in all diodes of one cell are obtained by means of the **Characteristics** icon in the time interval between 20 ms and 40 ms.

Diode n°	RMS value of the current (kA)
1	6.93
2	7.48
3	6.88
4	7.31

Conclusion

In this third case, the RMS value of the current in diode n°4 is only 5.4% greater than the current in diode n°1. The maximum difference occurs, this time, between diodes n°2 and n°3: 8.7%

The discrepancies between currents are very limited: geometry is well optimized.

6.3. Comparison between the three positions of input bars

Goal

RMS values of current in the diodes according to the three positions of the input bars are compared.

Notes

With input bars located at position 1, the maximum difference between RMS values is 120%. It decreases to 56% for position 2 and falls down to 8.7% for position 3, which is definitely the best location for input bars because all diodes of the power bridge works in a similar way.

Diode n°	RMS value of the current (kA)		
	Position 1	Position 2	Position 3
1	4.78	5.60	6.93
2	5.82	6.57	7.48
3	8.12	7.97	6.88
4	10.52	8.72	7.31