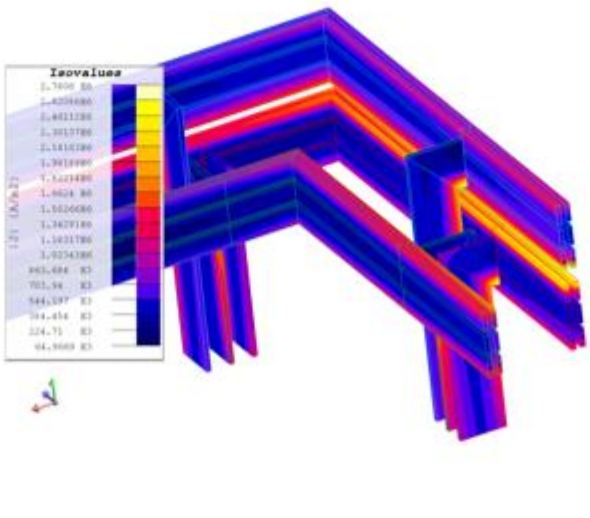
CAD package for conductor impedance
and near field simulations of electrical connections

Altair Flux™

Distribution bars tutorial

PEEC technical example



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Foreword

*(Please read before starting this tutorial)

Description of the document

The goal of this technical example is to familiarize the user with the Flux PEEC software by means of a simple system: an electrical distribution enclosure.
This document presents the general step and contains all the data needed to describe the geometry, physics, meshing and analyze obtained computation results.

Reference files

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

In particular, in the subfolder ***DistributionBars_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 of the studied system. It corresponds to what is described in chapter 2 of this tutorial.
State_Circuit.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 – first case. It corresponds to what is described in chapters 2 and 3 of this tutorial.
State_Solving.py	Commands to automatically create and solve the Flux PEEC project describing the first case of the studied system.

In the subfolder ***DistributionBars_PEEC_Case2***, the main Python files provided are:

Name	Content
State_Circuit.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 – second case. It corresponds to what is described in chapters 2, 3 and 5 (first paragraph) of this tutorial.
State_Solving.py	Commands to automatically create and solve the Flux PEEC project describing the second case of the studied system.

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1. Overview of the studied problem

Introduction

The aim of this tutorial is to better understand how to carry out an electrical model using Flux PEEC software package.

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

Contents

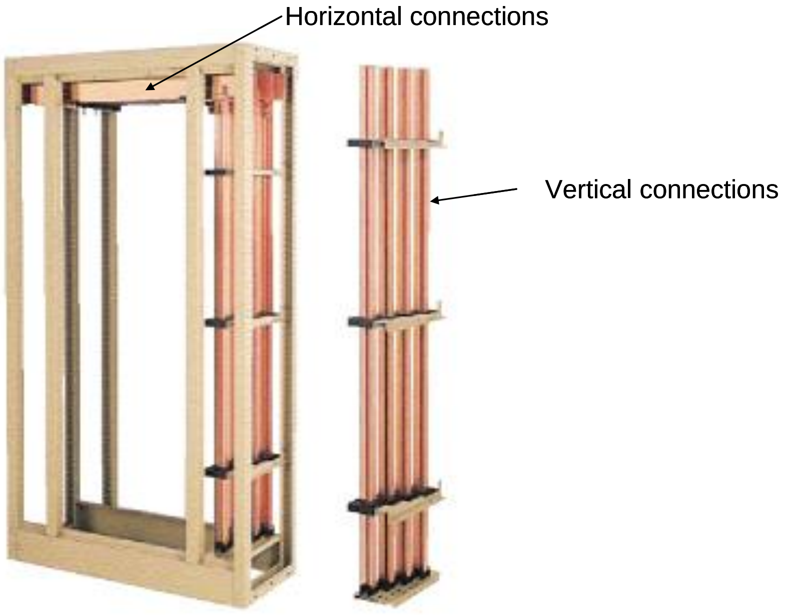
This section deals with the following topics:

1.1. Description of the device

Studied device

The studied device, illustrated below, is the power supply bars of an electrical distribution enclosure.

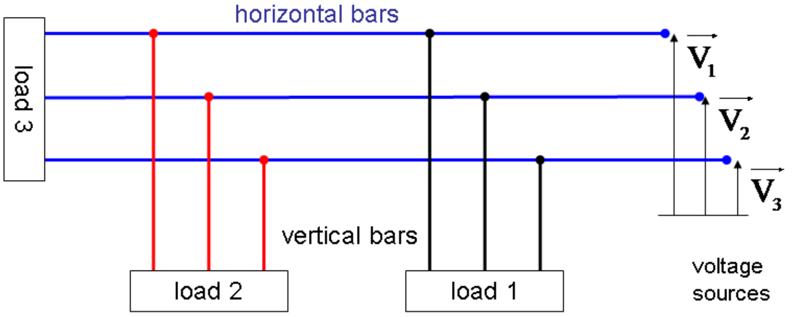
It includes the horizontal bars and the vertical ones; the latter are devoted to the supply of electrical loads.



Operation

The horizontal bars are connected to the three-phase voltage source.
Along the horizontal conductors, two groups of vertical conductors are connected in order to supply an electrical distribution enclosure. Neutral bars are not used in this tutorial example.

The electric scheme of the studied device is summarized in the figure below:



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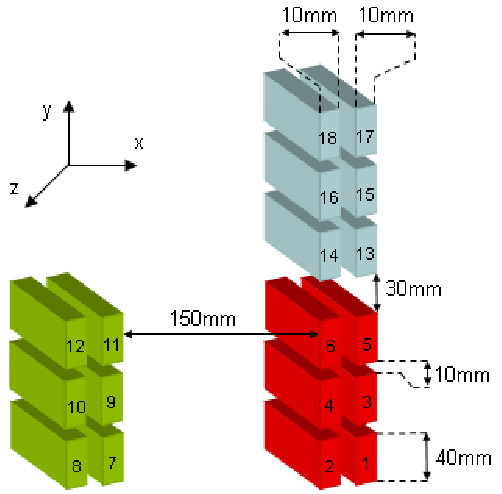
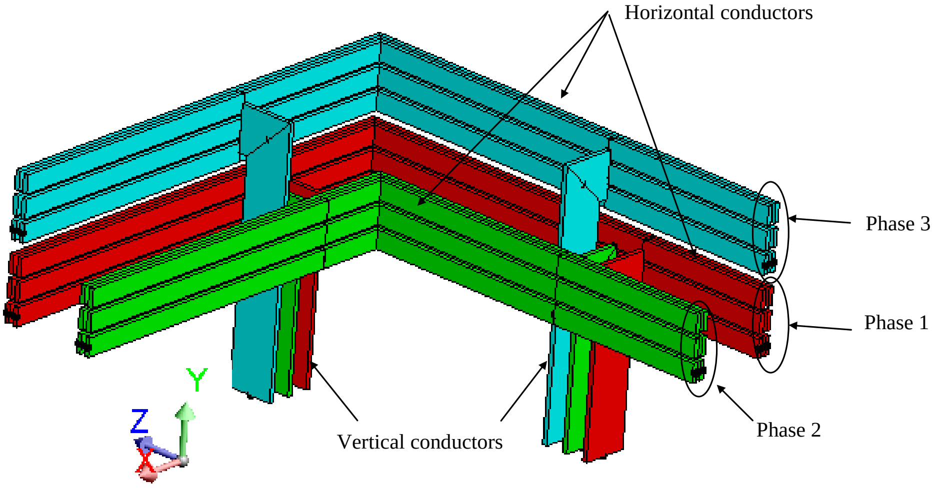
Geometry

Each horizontal phase is composed of six parallel bars of rectangular cross-section. On the other hand, each vertical conductor is composed of one massive bar of rectangular cross-section.

horizontal conductors:





Materials

Bars are made of **copper**, which is an electro-conductive nonmagnetic material.

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

Sources

A three-phase balanced voltage source supplies the distribution bars. It is considered electrically ideal, i.e. its internal impedance is equal to zero.

Loads

Each group of vertical bars is connected to a three-phase load. Another load is connected at the end of the horizontal bars to simulate another electrical distribution enclosure.

1.2. Studied cases

Studied cases

Two cases are carried out:
- all loads are balanced
- one of the three loads is unbalanced; the others two remain balanced

Case 1

The first case is the simplest one.

The three-phase voltage source supplying the system is balanced and ideal; its amplitude is equal to 230 V_{RMS}.
All the three loads are balanced, nevertheless loads 1 and 3 are purely resistive (0.5 Ω), whereas load 2 is composed by the series of a resistor (0.4 Ω) and an inductor (1 mH).

Case 2

The second case is built from case 1.

The voltage source and the loads 1 and 3 do not change with respect to the previous case, while the load 2 becomes unbalanced, since one of its elements is disconnected.

1.3. Theoretical aspects

Introduction

Under usual working conditions the current inside the conductors is quite high. Due to frequency and proximity effects the current density in the cross-section of the conductors is generally non-uniform. Some parts of conductors are less used than others. This implies copper overheating and additional losses.
That is why in this technical example the purpose is to evaluate the current density distribution, the global currents and the losses induced by these currents in the distribution bars.
This computation is a real help when designing a distribution enclosure. It allows a better sizing of the bars using an appropriate quantity of copper. Nowadays copper is a precious raw material and the less copper is used, the cheaper the device is.
Moreover, the study of the current density is a key point in bar design because losses are directly linked to this value and they must be minimized.
Conductors' modeling is the better way to evaluate geometrical solutions to reduce current density levels.

"Supplied Conductors" application

This Flux PEEC application is carried on to compute electric currents into the conductors of the device as well as losses.
This is done by means of the evaluation of an equivalent electric circuit for each conductor and by solving the corresponding electrical equations that include:

- the voltage source
- the model for the conducting bars
- and the loads

General process

The general process of Flux PEEC modeling is presented in the table below.

Stage	Description
1	Choice of an application and definition of a scenario
2	Conductors description
3	Electric circuit description (sources and loads)
4	Meshing
5	Solving process (according to the defined scenario)
6	Results post-processing

Continued on next page

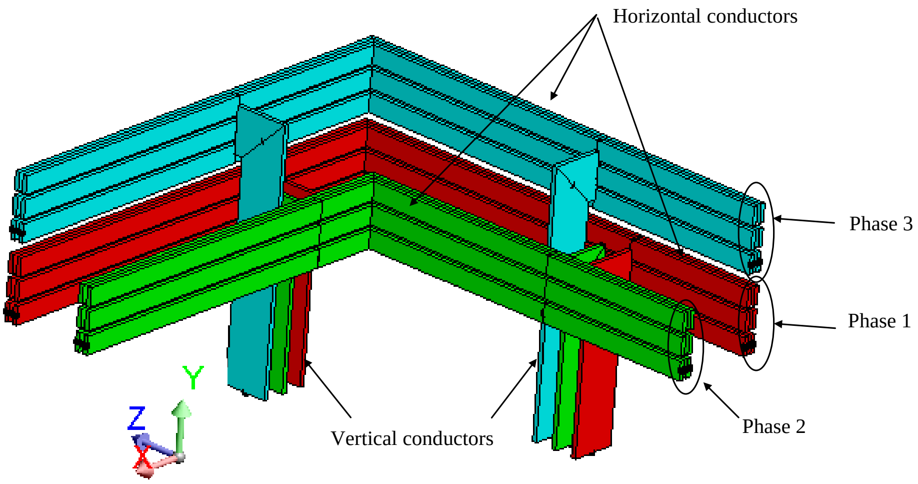
"Tube Conductors" description

If the conductors are straight and long enough (as it is the case in this study), the assumption is to consider that electric currents carrying the conductors are unidirectional. The cross-section of conductors is of rectangular shape. The so-called "**Tube Conductors"** mode is recommended to describe the device. The "Tube Conductors" mode is a simplified geometric description by means of geometric tubes. As a result, unidirectional conductors associated to geometric tubes are automatically created by Flux PEEC.

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 distribution bars** with the associated physics and meshing of the device.



Python file

The 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 of the studied system by running the Python file ***buildGeophys.py*** provided in the folder ***…\flux\Flux\DocExamples\ExamplesPEEC\Tutorial_Technical\DistributionBars\DistributionBars.zip\DistributionBars_PEEC_Case1***

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
2	Geometric and physical description of horizontal conductors
3	Geometric and physical description of vertical conductors
4	Preparation and generation of the meshing

Contents

This chapter deals with the following topics:

2.1. Choice and definition of the application

Introduction This section presents the physical definition of the application.

Contents This section deals with the following topics:

2.1.1. Start and define physics for the application

Goal

First, the Flux PEEC application is defined.

Definition of the application

The suitable application is **Supplied Conductors**.

Properties to be set are presented in the table below.

Type of application	Default material for conductors
Supplied Conductors	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

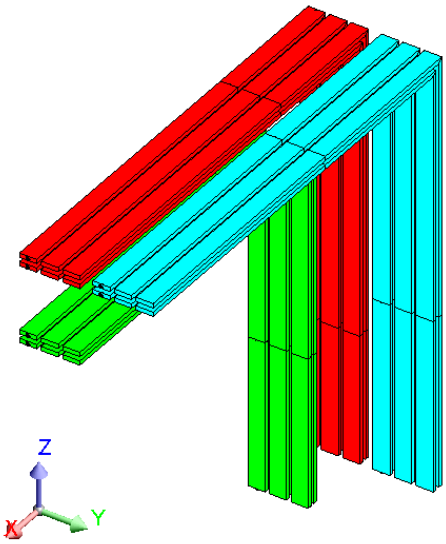
Properties of the scenario are reported in the table below.

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

2.2. Geometry and physics of the horizontal conductors

Introduction

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



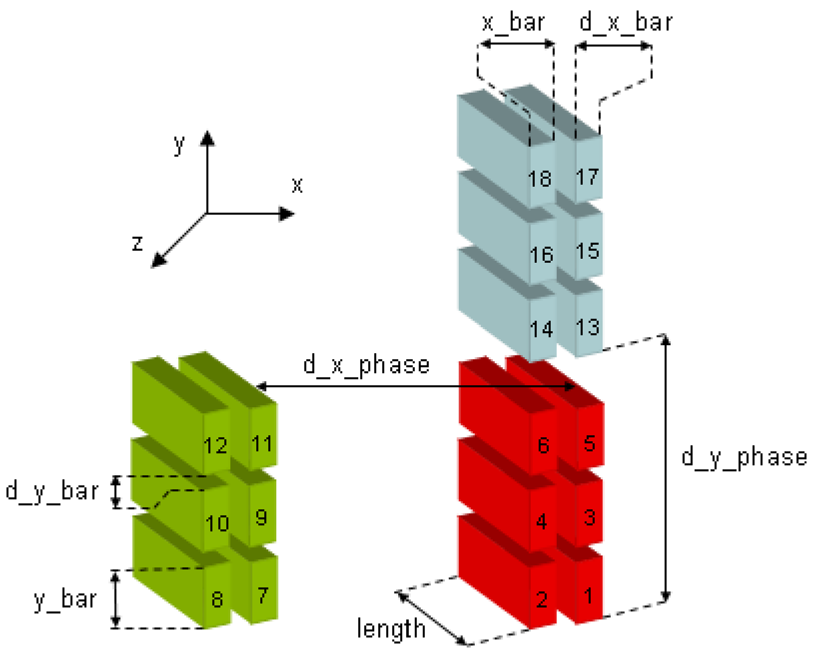
Contents

This section deals with the following topics:

2.2.1. Create geometric parameters

Goal

Geometric parameters are useful at different stages of the problem description (geometry, physics, post-processing…). They can also be used in formulas. In this study, nine geometric parameters are created to make easier and faster the geometry description of the **horizontal** and **vertical conductors**.



Data

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

Geometric parameter		
Name	**Comment**	**Expression**
X_BAR	Thickness of one bar (mm)	10
Y_BAR	Width of one horizontal bar (mm)	40
D_X	Inner distance along x between two bars of same phase (mm)	10
D_Y	Inner distance along y between two bars of same phase (mm)	10
D_X_BAR	Center-to-center distance along x between two bars of same phase (mm)	X_BAR+D_X
D_Y_BAR	Center-to-center distance along y between two bars of same phase (mm)	Y_BAR+D_Y
D_X_PHASE	Center-to-center distance along x between two phases (mm)	180
D_Y_PHASE	Center-to-center distance along y between two phases (mm)	170
LENGTH	Length of conductors (mm)	1000

☞ **Geometry → Geometric parameter → New**

2.2.2. Create tube points, geometric tubes and horizontal conductors of phase 1

Goal

The description of the horizontal conductors of phase 1 is based on the preliminary creation of tube points and geometric tubes.
Consequently, ten tube points are firstly defined. Then, two geometric tubes defined by a path of five tube points are created. It is worth to note that:

- the first, the third and the fifth tube points of each path are necessary to describe the geometry of the horizontal conductors;
- the second and the forth ones have to be inserted in order to prepare the electrical connections that will be later established with the vertical conductors.

The other geometric tubes necessary to describe conductors of phase 1 are generated by propagation from existing geometric tubes.
New unidirectional conductors are automatically created by Flux PEEC from corresponding geometric tubes.

Data (1)

The properties of the tube points to be created are presented in the table below.

Tube point defined by **parametric coordinates**

Number	**Coord. system**	**Coordinates**		
		First	**Second**	**Third**
1	XYZ1	0	0	0
2		0	0	300
3		0	0	LENGTH
4		300	0	LENGTH
5		LENGTH	0	LENGTH
6		D_X_BAR	0	0
7		D_X_BAR	0	300
8		D_X_BAR	0	LENGTH-D_X_BAR
9		300	0	LENGTH-D_X_BAR
10		LENGTH	0	LENGTH-D_X_BAR

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

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Data (2)

The properties of the first two geometric tubes are presented in the table below.

Geometric tube defined by a **path**					
Name	**Path**	**List of tube points**	**Cross-section**	**Rectangle**	
				Side 1	**Side 2**
BAR_1	open	1, 2, 3, 4, 5	rectangular full	X_BAR	Y_BAR
BAR_2	open	6, 7, 8, 9, 10	rectangular full	X_BAR	Y_BAR

☞ Geometry → Tube geometry → Geometric tube → New

Data (3)

Geometric transformations are useful during the geometry description to create new objects from existing ones. In this study, a translation transformation will permit to easily create the other four geometric tubes of phase 1.
The properties of the transformation are presented in the table below.

Geometric transformation					
Name	**Type of geometric transformation**	**Translation vector**			**Coord. system**
		DX	**DY**	**DZ**	
TRANSF_Y	Translation vector	0	D_Y_BAR	0	XYZ1

☞ Geometry → Transformation → New

Data (4)

Remaining geometric tubes of phase 1 are created as propagated type by means of the above transformation.
The properties of these propagated geometric tubes are presented in the table below.

Propagated geometric tube		
Name	**Geometric transformation**	**Origin geometric tube**
BAR_3	TRANSF_Y	BAR_1
BAR_4	TRANSF_Y	BAR_2
BAR_5	TRANSF_Y	BAR_3
BAR_6	TRANSF_Y	BAR_4

☞ Geometry → Tube geometry → Geometric tube → New

Result

Six unidirectional conductors associated to the geometric tubes are automatically created by Flux PEEC.

2.2.3. Appearance of the horizontal conductors of phase 1

Goal

To better recognize the unidirectional conductors of phase 1, their color is modified from turquoise to red, by editing the tab “**Appearance**” of the corresponding entity.

Data

The modified properties of these unidirectional conductors are presented in the table below.

Unidirectional conductor associated to a **geometric tube**				
Name	**Material**	**Geometric tube**	**Appearance**	
			Color	**Visibility**
BAR_1	copper	BAR_1	**red**	visible
BAR_2	copper	BAR_2	**red**	visible
BAR_3	copper	BAR_3	**red**	visible
BAR_4	copper	BAR_4	**red**	visible
BAR_5	copper	BAR_5	**red**	visible
BAR_6	copper	BAR_6	**red**	visible

☞ **Physics → Unidirectional conductor → Edit**

2.2.4. Create tube points, geometric tubes and horizontal conductors of phase 2

Goal

The same strategy used for the creation of the horizontal conductors of phase 1 is now adopted for the phase 2.
Ten new tube points are firstly defined. Then, two geometric tubes defined by a path of five tube points are created. The other geometric tubes are generated by propagation from existing geometric tubes.
New unidirectional conductors are automatically created by Flux PEEC from corresponding geometric tubes.

Data (1)

The properties of the tube points are presented in the table below.

<table>
<tr><th colspan="5">Tube point defined by parametric coordinates</th></tr>
<tr><th rowspan="2">Number</th><th rowspan="2">Coord. system</th><th colspan="3">Coordinates</th></tr>
<tr><th>First</th><th>Second</th><th>Third</th></tr>
<tr><td>11</td><td rowspan="10">XYZ1</td><td>D_X_PHASE</td><td>0</td><td>0</td></tr>
<tr><td>12</td><td>D_X_PHASE</td><td>0</td><td>350</td></tr>
<tr><td>13</td><td>D_X_PHASE</td><td>0</td><td>LENGTH-D_X_PHASE</td></tr>
<tr><td>14</td><td>350</td><td>0</td><td>LENGTH-D_X_PHASE</td></tr>
<tr><td>15</td><td>LENGTH</td><td>0</td><td>LENGTH-D_X_PHASE</td></tr>
<tr><td>16</td><td>D_X_PHASE+ D_X_BAR</td><td>0</td><td>0</td></tr>
<tr><td>17</td><td>D_X_PHASE+ D_X_BAR</td><td>0</td><td>350</td></tr>
<tr><td>18</td><td>D_X_PHASE+ D_X_BAR</td><td>0</td><td>LENGTH-D_X_PHASE- D_X_BAR</td></tr>
<tr><td>19</td><td>350</td><td>0</td><td>LENGTH-D_X_PHASE- D_X_BAR</td></tr>
<tr><td>20</td><td>LENGTH</td><td>0</td><td>LENGTH-D_X_PHASE- D_X_BAR</td></tr>
</table>

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

Continued on next page

Data (2)

The properties of the first two geometric tubes of phase 2 are presented in the table below.

Geometric tube defined by a **path**					
Name	**Path**	**List of tube points**	**Cross-section**	**Rectangle**	
				Side 1	**Side 2**
BAR_7	open	11, 12, 13, 14, 15	rectangular full	X_BAR	Y_BAR
BAR_8	open	16, 17, 18, 19, 20	rectangular full	X_BAR	Y_BAR

☞ Geometry → Tube geometry → Geometric tube → New

Data (3)

Remaining geometric tubes of phase 2 are created as propagated type; it is worth to note that the same transformation used for the geometric tubes of phase 1 is employed, since the distances between conductors are equal.
The properties of these propagated geometric tubes are presented in the table below.

Propagated geometric tube		
Name	**Geometric transformation**	**Origin geometric tube**
BAR_9	TRANSF_Y	BAR_7
BAR_10	TRANSF_Y	BAR_8
BAR_11	TRANSF_Y	BAR_9
BAR_12	TRANSF_Y	BAR_10

☞ Geometry → Tube geometry → Geometric tube → New

Result

Six unidirectional conductors associated to the geometric tubes are automatically created by Flux PEEC.

2.2.5. Appearance of the horizontal conductors of phase 2

Goal

To better recognize unidirectional conductors of phase 2, their color is modified from turquoise to green, by editing the tab “**Appearance**” of the corresponding entity.

Data

The modified properties of these unidirectional conductors are presented in the table below.

Unidirectional conductor associated to a **geometric tube**				
Name	**Material**	**Geometric tube**	**Appearance**	
			Color	**Visibility**
BAR_7	copper	BAR_7	**green**	visible
BAR_8	copper	BAR_8	**green**	visible
BAR_9	copper	BAR_9	**green**	visible
BAR_10	copper	BAR_10	**green**	visible
BAR_11	copper	BAR_11	**green**	visible
BAR_12	copper	BAR_12	**green**	visible

Physics → Unidirectional conductor → Edit 

2.2.6. Create tube points, geometric tubes and horizontal conductors of phase 3

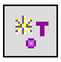
Goal

Ten new tube points are firstly defined. Then, two geometric tubes defined by a path of five tube points are created. The other geometric tubes are generated by propagation from these two geometric tubes. New unidirectional conductors are automatically created from corresponding geometric tubes.

Data (1)

The properties of the tube points to be created are presented in the table below.

Tube point defined by its **parametric coordinates**				
Number	**Coord. system**	**Coordinates**		
		First	**Second**	**Third**
21	XYZ1	0	D_Y_PHASE	0
22		0	D_Y_PHASE	400
23		0	D_Y_PHASE	LENGTH
24		400	D_Y_PHASE	LENGTH
25		LENGTH	D_Y_PHASE	LENGTH
26		D_X_BAR	D_Y_PHASE	0
27		D_X_BAR	D_Y_PHASE	400
28		D_X_BAR	D_Y_PHASE	LENGTH-D_X_BAR
29		400	D_Y_PHASE	LENGTH-D_X_BAR
30		LENGTH	D_Y_PHASE	LENGTH-D_X_BAR

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

Data (2)

The properties of the first two geometric tubes of phase 3 are presented in the table below.

Geometric tube defined by a **path**					
Name	**Path**	**List of tube points**	**Cross-section**	**Rectangle**	
				Side 1	**Side 2**
BAR_13	open	21, 22, 23, 24, 25	rectangular full	X_BAR	Y_BAR
BAR_14	open	26, 27, 28, 29, 30	rectangular full	X_BAR	Y_BAR

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

Continued on next page

Data (3)

Remaining geometric tubes of phase 3 are created as propagated type; it is worth to note that the same transformation used for the geometric tubes of phases 1 and 2 is employed, since the distances between conductors are equal.
The properties of these propagated geometric tubes are presented in the table below.

Propagated geometric tube		
Name	**Geometric transformation**	**Origin geometric tube**
BAR_15	TRANSF_Y	BAR_13
BAR_16	TRANSF_Y	BAR_14
BAR_17	TRANSF_Y	BAR_15
BAR_18	TRANSF_Y	BAR_16

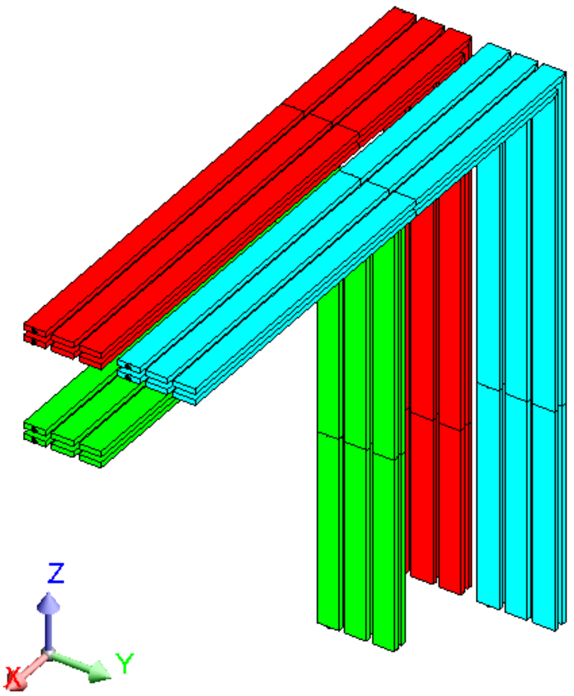
☞ **Geometry → Tube geometry → Geometric tube → New**

Result

Six unidirectional conductors associated to the geometric tubes are automatically created by Flux PEEC.
Their color is turquoise. To better recognize them it is not necessary to modify their color.

Result (2)

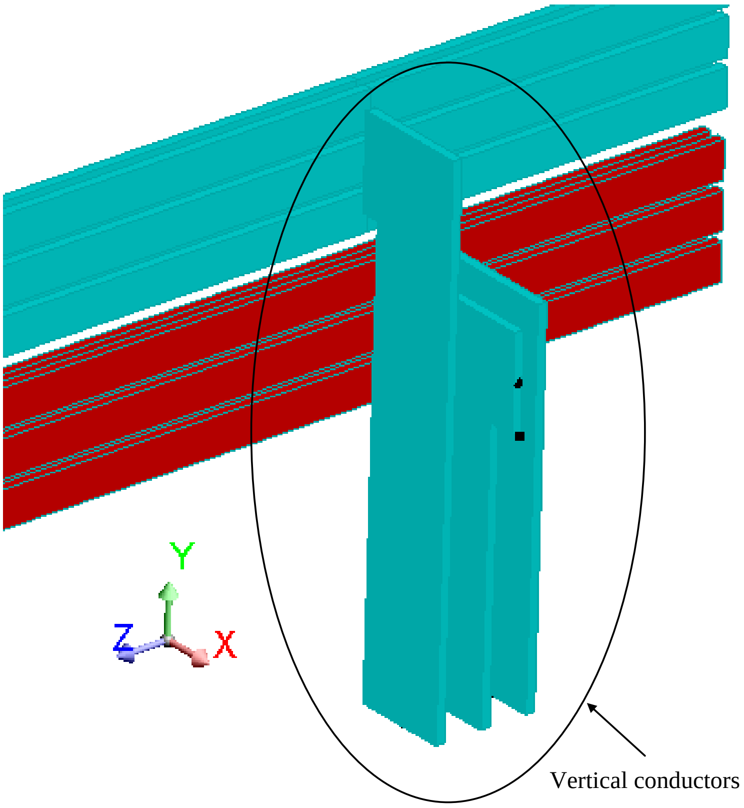
Eighteen horizontal unidirectional conductors associated to geometric tubes are shown in the figure below.



2.3. Geometry and physics of the vertical conductors

Introduction

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



Contents

This section deals with the following topics:

2.3.1. Create tube points, geometric tubes and vertical conductors

Goal

Two groups of three vertical conductors are necessary to connect loads 1 and 2 to the rest of the distribution enclosure. As for horizontal conductors, their description is based on tube points and geometric tubes.
Twelve new tube points are firstly defined in order to build three geometric tubes defined by a path of four tube points each. The associated unidirectional conductors model the first vertical group that connects load 1.
The second group of conductors is generated by propagation of these three geometric tubes by means of a new transformation of rotation type.

Data (1)

The properties of the tube points to be created are presented in the table below.

Tube point defined by its **parametric coordinates**				
Number	**Coord. system**	**Coordinates**		
		First	**Second**	**Third**
31	XYZ1	0	D_Y_BAR	300
32		D_X_BAR	D_Y_BAR	300
33		(D_X_PHASE+D_X_BAR)/2	D_Y_BAR	300
34		(D_X_PHASE+D_X_BAR)/2	-300	300
35		D_X_PHASE+D_X_BAR	D_Y_BAR	350
36		D_X_PHASE	D_Y_BAR	350
37		(D_X_PHASE+D_X_BAR)/2	D_Y_BAR	350
38		(D_X_PHASE+D_X_BAR)/2	-300	350
39		0	D_Y_PHASE+ D_Y_BAR	400
40		D_X_BAR	D_Y_PHASE+ D_Y_BAR	400
41		(D_X_PHASE+D_X_BAR)/2	D_Y_PHASE+ D_Y_BAR	400
42		(D_X_PHASE+D_X_BAR)/2	-300	400

☞ Geometry → Tube geometry → Tube point → New

Data (2)

The properties of the geometric tubes are presented in the table below.

Geometric tube defined by a **path**					
Name	**Path**	**List of tube points**	**Cross-section**	**Rectangle**	
				Side 1	**Side 2**
BAR_19	open	31, 32, 33, 34	rectangular full	104	X_BAR
BAR_20	open	35, 36, 37, 38	rectangular full	104	X_BAR
BAR_21	open	39, 40, 41, 42	rectangular full	104	X_BAR

☞ Geometry → Tube geometry → Geometric tube → New

Continued on next page

Data (3)

A rotation transformation defined by angles and pivot point coordinates is created in order to build then the geometric tubes of the second group of vertical conductors.
The properties of the transformation are presented in the table below.

Geometric transformation

Name	Type of geometric transformation	Coord. system	Coordinates of the pivot point			Rotation angles		
			1st	2nd	3rd	X axis	Y axis	Z axis
ROT_Y	Rotation by angles and pivot point coordinates	XYZ1	500	0	500	0	90	0

☞ Geometry → Transformation → New

Data (4)

The geometric tubes of the second group of vertical conductors are created by means of the above transformation. Their properties are presented in the table below.

Propagated geometric tube

Name	Geometric transformation	Origin geometric tube
BAR_22	ROT_Y	BAR_19
BAR_23	ROT_Y	BAR_20
BAR_24	ROT_Y	BAR_21

☞ Geometry → Tube geometry → Geometric tube → New

Continued on next page

Consequences

A terminal is automatically created by Flux PEEC at each tube point used by a geometric tube; they are labeled with the conductor's name followed by a suffix which indicates their place along the conductor.
For example, TERM_BAR_1_1 is the first terminal of the conductor BAR_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.

Consequently, all created conductors are provided with adequate terminals for their connection to the others and to the sources and loads.

Moreover, thanks to an automatic algorithm twelve equipotential connections between horizontal and vertical conductors are 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.

Each of the twelve connections joins, from an electrical point-of-view, one vertical conductor with three horizontal conductors of the same phase. For example, CO_AUTO_1 is the electrical connection between BAR_1, BAR_3, BAR_5 and BAR_19.

2.3.2. Appearance of the vertical conductors

Goal

To better recognize:
- vertical conductors belonging to phase 1, their color is modified to red
- vertical conductors belonging to phase 2, their color is modified to green

The color of the vertical conductors of phase 3 is turquoise by default.
These changes are performed by editing the tab "**Appearance**" of the corresponding entity.

Data (1)

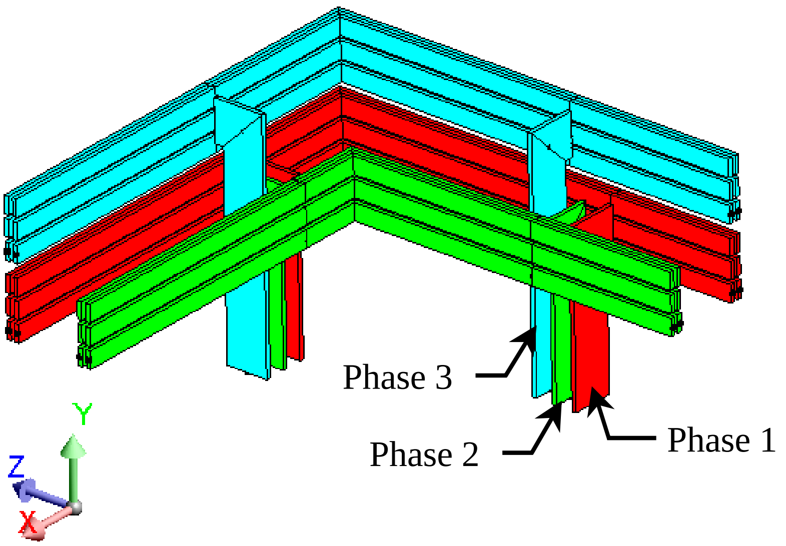
Modified properties of the vertical conductors of the three phases are presented in the table below.

Unidirectional conductor associated to a **geometric tube**				
Name	**Material**	**Geometric tube**	**Appearance**	
			Color	**Visibility**
BAR_19	copper	BAR_19	**red**	visible
BAR_22	copper	BAR_22	**red**	visible
BAR_20	copper	BAR_20	**green**	visible
BAR_23	copper	BAR_23	**green**	visible
BAR_21	copper	BAR_21	**turquoise**	visible
BAR_24	copper	BAR_24	**turquoise**	visible

☞ **Physics → Unidirectional conductor → Edit**

Result

The created unidirectional conductors are shown in the figure below.



2.4. Meshing of conductors

Introduction

This section explains the preparation and generation of the meshing.

Contents

This chapter deals with the following topics:

2.4.1. Mesh vertical conductors

Goal

Thanks to the peculiarity of the implemented PEEC method, meshing information can be defined for each conductor. The meshing tool automatically set this information according to the maximum solving frequency, but sometimes it is advisable that the user modifies some of the meshing parameters by editing the tab “**Meshing**” of these conductors.
In this studied example, it is the case for the six vertical conductors for which a uniform distribution of the meshing elements in the cross-section is defined. As a result the meshing is homogeneous.

Data

The meshing properties for the vertical conductors are reported in the table below.

Vertical unidirectional conductors			
Name	**Meshing**		
	Type	**Minimum number of elements**	
		Side 1	**Side 2**
BAR_19 to BAR_24	Uniform regular	13	2

Physics → Unidirectional conductor → Edit

2.4.2. Mesh horizontal conductors

Goal

Regarding horizontal conductors, the automatic meshing defined by Flux PEEC is maintained since they have smaller cross-section than vertical ones. On the other hand, in order to get a better visualization of the results (see chapters 4.5, 4.6, 5.2.4 and 5.2.5), the length of horizontal conductors is meshed for post-processing operations.

Data

The meshing properties for the horizontal conductors are reported in the table below.

Horizontal unidirectional conductors		
Name	**Meshing**	
	Type	**Discretisation in the length for post-processing**
BAR_1 to BAR_18	According to the solving configuration	20

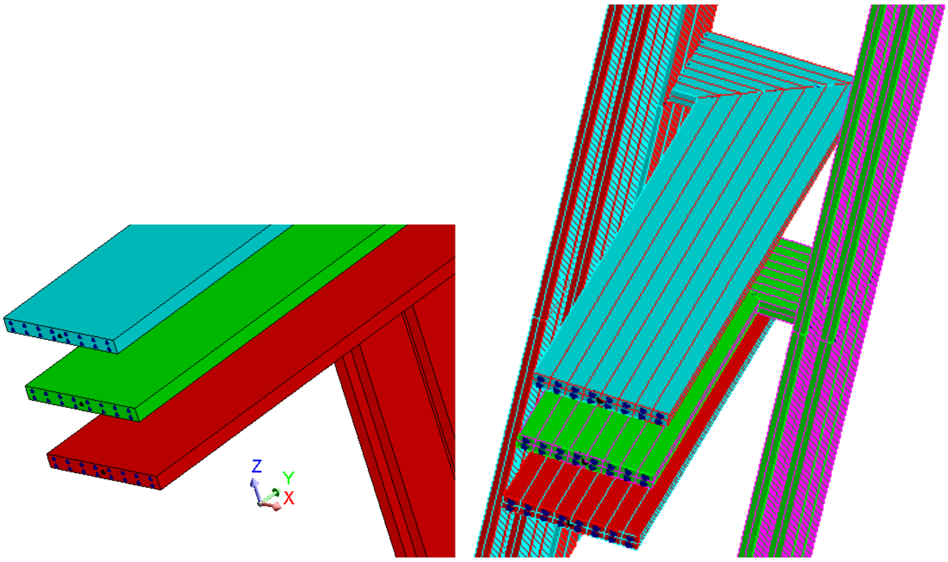
Physics → Unidirectional conductor → Edit

2.4.3. Generate the meshing

Action The meshing of the bars is generated using the **Mesh** command.

☞ Solving → Mesh

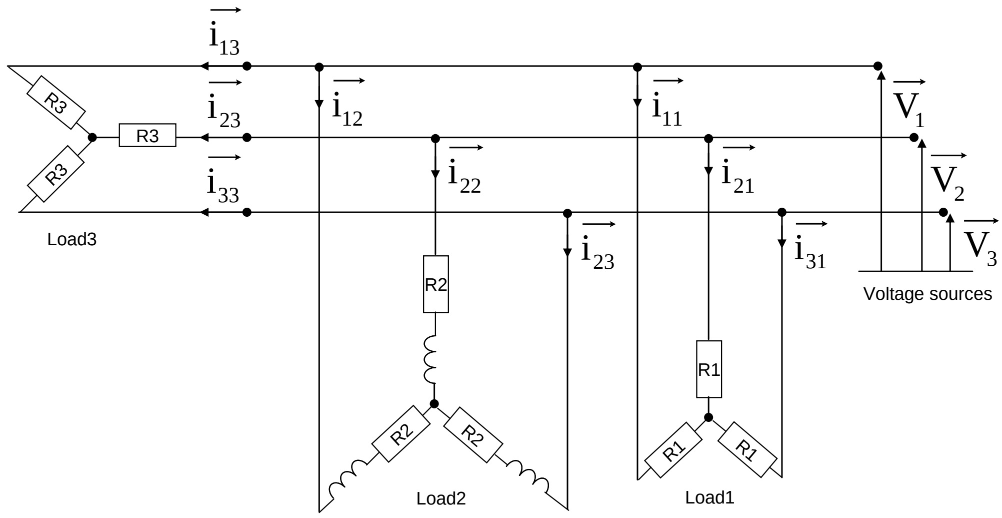
Result Obtained meshing is shown in the figure below.



3. Cases 1 and 2: description of the electric circuit

Introduction

This chapter shows how to build the global electric circuit of the studied cases.



Python file

The 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 circuit description of the studied system by running the Python file ***buildCircuit.py*** provided in the folder
…\flux\Flux\DocExamples\ExamplesPEEC\Tutorial_Technical\ DistributionBars\DistributionBars.zip\DistributionBars_PEEC_Case1

Contents

This chapter deals with the following topics:

3.1. Description of supply sources and passive components

Introduction

In general, applied electric circuit is made up of:
- conductors
- supply sources (voltage / current sources) and passive components (resistors, inductors, capacitors)
- electrical connections between conductors and components (connections are carried out via the terminals)

This section explains, for the studied system, the description of the voltage sources and the loads and the establishment of the electrical connections between the different elements.

Contents

This section deals with the following topics:

3.1.1. Create voltage sources

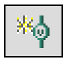
Goal

Three voltage sources – one voltage source per phase – are created for performing the electrical description of the distribution bar system.

Data

The properties of voltage sources are reported in the table below.

Voltage sources			
Name	**Comment**	**RMS value (V)**	**Phase in degrees**
V1	Voltage source 1	230	0
V2	Voltage source 2	230	-120
V3	Voltage source 3	230	120

☞ **Components and Electric Circuit → Voltage source → New** 

3.1.2. Create loads

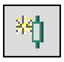
Goal

Three three-phase loads are created. They are composed of resistors and inductors (load 2 only).
Globally, the electric circuit contains nine resistors and three inductors.

Data (1)

The properties of the **first load** are presented in the table below.
It is a three-phase ideal resistor.

Resistor		
Name	**Comment**	**Value (Ω)**
R1_LOAD1	R1 of first load	0.5
R2_LOAD1	R2 of first load	0.5
R3_LOAD1	R3 of first load	0.5

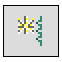
☞ Components and Electric Circuit → Resistor → New 

Data (2)

The properties of the **second load** are presented in the table below.
It is a three-phase RL.

Resistor		
Name	**Comment**	**Value (Ω)**
R1_LOAD2	R1 of second load	0.4
R2_LOAD2	R2 of second load	0.4
R3_LOAD2	R3 of second load	0.4

Inductor		
Name	**Comment**	**Value (H)**
L1_LOAD2	L1 of second load	0.001
L2_LOAD2	L2 of second load	0.001
L3_LOAD2	L3 of second load	0.001

☞ Components and Electric Circuit → Inductor → New 

Data (3)

The properties of the **third load** are presented in the table below.
It is a three-phase ideal resistor.

Resistor		
Name	**Comment**	**Value (Ω)**
R1_LOAD3	R1 of third load	0.5
R2_LOAD3	R2 of third load	0.5
R3_LOAD3	R3 of third load	0.5

3.2. Connect conductors and components

Introduction

This section explains how the previously described components (voltage sources and loads) are connected each other and with the conductors of the distribution bars.

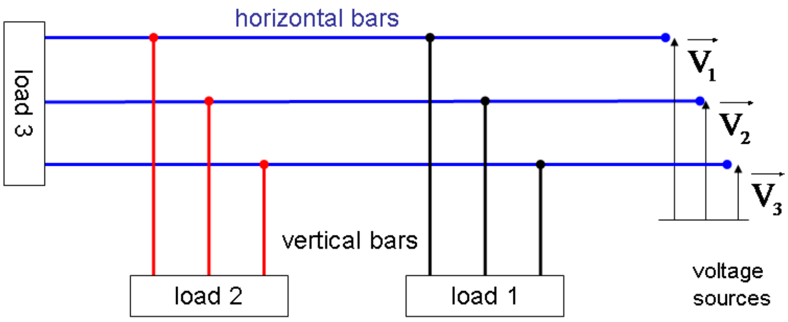
Contents

This section deals with the following topics:

3.2.1. Connect horizontal and vertical conductors

Goal

Bars of the horizontal conductors are connected to the vertical ones in order that loads are supplied by the voltage sources, as illustrated in the figure below.



As explained at paragraph 2.3.1 of this document, Flux PEEC has automatically created twelve equipotential connections between horizontal and vertical conductors.
Nevertheless, due to the section dimensions it is more advisable to set proximity-type connections which, in this case, better represent the real electromagnetic phenomena.

Data

For a more realistic modeling of the phenomena, existing connections are modified from equipotential-type to proximity-type.
Their properties are presented in the table below.

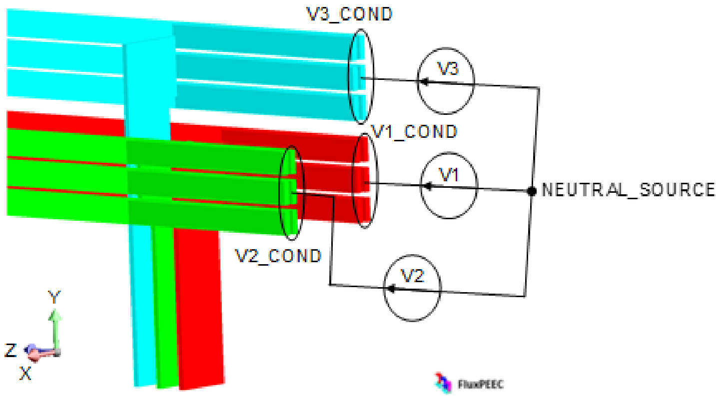
Connections	
Name	**Terminals connection**
CO_AUTO_1 to CO_AUTO_12	**proximity connection**

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

3.2.2. Connect voltage sources to the conductors

Goal

The three-phase voltage source is connected to the horizontal conductors.



Data

The properties of the connections are presented in the table below.

Equipotential connections		
Name	**Comment**	**Connected terminals**
V1_COND	Connection of V1 with horizontal bars of phase 1	TERM_V1_1 TERM_BAR_1_1 TERM_BAR_2_1 TERM_BAR_3_1 TERM_BAR_4_1 TERM_BAR_5_1 TERM_BAR_6_1
V2_COND	Connection of V2 with horizontal bars of phase 2	TERM_V2_1 TERM_BAR_7_1 TERM_BAR_8_1 TERM_BAR_9_1 TERM_BAR_10_1 TERM_BAR_11_1 TERM_BAR_12_1
V3_COND	Connection of V3 with horizontal bars of phase 3	TERM_V3_1 TERM_BAR_13_1 TERM_BAR_14_1 TERM_BAR_15_1 TERM_BAR_16_1 TERM_BAR_17_1 TERM_BAR_18_1
NEUTRAL_ SOURCE	Connection of neutral point of voltage sources	TERM_V1_2 TERM_V2_2 TERM_V3_2

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

Continued on next page

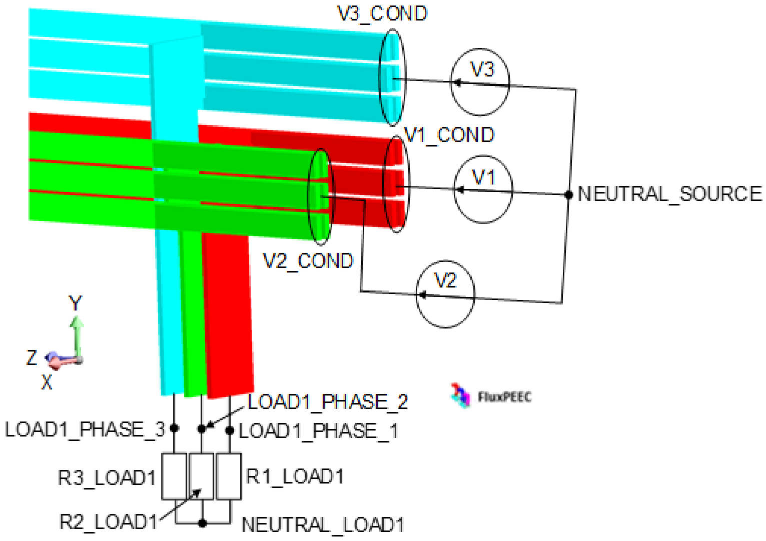
Caution

This electrical connection agreement (i.e., terminal number of the voltage sources) has to be followed to describe equipotential connections. Please connect the voltage source always in the same way in order that obtained results will correspond to the ones presented in this document.

3.2.3. Connect load 1

Goal

Three-phase load 1 is connected to the first group of vertical conductors of the distribution enclosure.



Data

The properties of the connections to be set are presented in the table below.

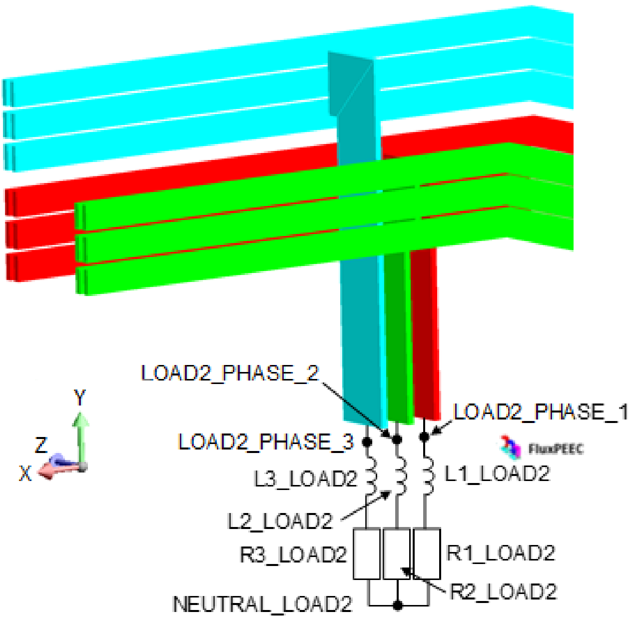
Equipotential connections		
Name	**Comment**	**Connected terminals**
LOAD1_PHASE_1	Connection of load 1 with phase 1	TERM_R1_LOAD1_1 TERM_BAR_19_4
LOAD1_PHASE_2	Connection of load 1 with phase 2	TERM_R2_LOAD1_1 TERM_BAR_20_4
LOAD1_PHASE_3	Connection of load 1 with phase 3	TERM_R3_LOAD1_1 TERM_BAR_21_4
NEUTRAL_LOAD1	Connection of neutral point of load 1	TERM_R1_LOAD1_2, TERM_R2_LOAD1_2 TERM_R3_LOAD1_2

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

3.2.4. Connect load 2

Goal

Three-phase load 2 is connected to the other group of vertical conductors of the distribution enclosure.
Inductors are connected from one side to the conductors and from the other side to the resistors; consequently seven equipotential connections have to be set up by the user.



Data

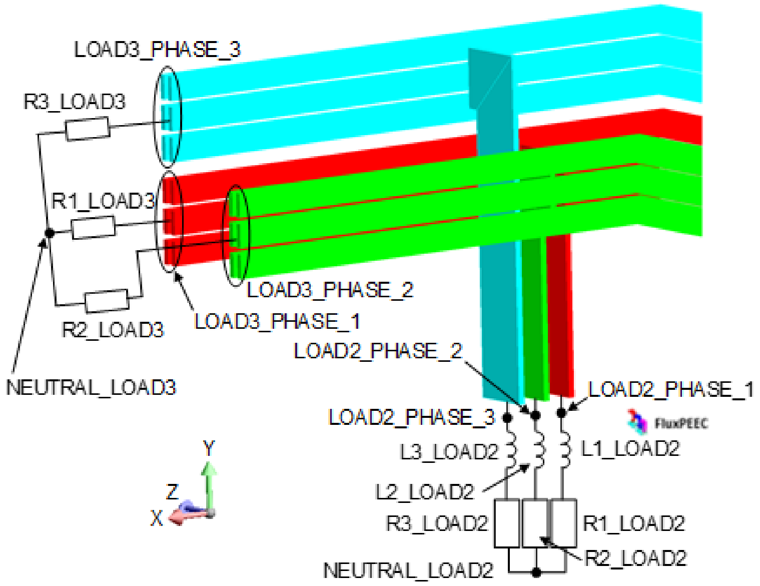
The properties of the connections are reported in the table below.

Equipotential connections		
Name	**Comment**	**Connected terminals**
LOAD2_PHASE_1	Connection of load 2 with phase 1	TERM_L1_LOAD2_1 TERM_BAR_22_4
LOAD2_PHASE_2	Connection of load 2 with phase 2	TERM_L2_LOAD2_1 TERM_BAR_23_4
LOAD2_PHASE_3	Connection of load 2 with phase 3	TERM_L3_LOAD2_1 TERM_BAR_24_4
NEUTRAL_LOAD2	Connection of neutral point of load 2	TERM_R1_LOAD2_2 TERM_R2_LOAD2_2 TERM_R3_LOAD2_2
LOAD2_1	Connection between R1 and L1 of load 2	TERM_R1_LOAD2_1 TERM_L1_LOAD2_2
LOAD2_2	Connection between R2 and L2 of load 2	TERM_R2_LOAD2_1 TERM_L2_LOAD2_2
LOAD2_3	Connection between R3 and L3 of load 2	TERM_R3_LOAD2_1 TERM_L3_LOAD2_2

3.2.5. Connect load 3

Goal

Three-phase load 3 is connected to the horizontal part of the structure.



Data

The properties of the connections are presented in the table below.

Equipotential connections		
Name	**Comment**	**Connected terminals**
LOAD3_PHASE_1	Connection of load 3 with phase 1	TERM_R1_LOAD3_1 TERM_BAR_1_5 TERM_BAR_2_5 TERM_BAR_3_5 TERM_BAR_4_5 TERM_BAR_5_5 TERM_BAR_6_5
LOAD3_PHASE_2	Connection of load 3 with phase 2	TERM_R2_LOAD3_1 TERM_BAR_7_5 TERM_BAR_8_5 TERM_BAR_9_5 TERM_BAR_10_5 TERM_BAR_11_5 TERM_BAR_12_5
LOAD3_PHASE_3	Connection of load 3 with phase 3	TERM_R3_LOAD3_1 TERM_BAR_13_5 TERM_BAR_14_5 TERM_BAR_15_5 TERM_BAR_16_5 TERM_BAR_17_5 TERM_BAR_18_5
NEUTRAL_LOAD3	Connection of neutral point of load 3	TERM_R1_LOAD3_2, TERM_R2_LOAD3_2 TERM_R3_LOAD3_2

4. Case 1: solving process and results post-processing

Case 1

The first case is a study with balanced loads.

In this study, the two loads are balanced. The currents will be evaluated as well as the current densities inside the conductors and the losses of the distribution enclosure.

Contents

This chapter deals with the following topics:

4.1. Solving process

Goal

The descriptions of geometry, physics and meshing, as well as of the circuit are carried out and saved in the Flux PEEC project **circuitbuilt.FLU**. Now the solving process can start.

Action

The command **Solve** launches the computation and evaluation of the currents flowing inside the conductors, the sources and the loads.
If requested, the user has to indicate a name for the Flux PEEC project.

☞ **Solving → Solve** 

4.2. Global currents

Introduction

This section deals with the evaluation of global currents inside the conductors, loads and voltage sources.

Results are not plotted by means of curves since there is only one frequency in the scenario; on the contrary they are displayed by editing the involved entities.

Contents

This section deals with the following topics:

4.2.1. Current inside electrical components

Goal

The evaluation of the current flowing inside electrical components is carried out: it provides in fact interesting information about the current in each phase of the distribution system:

- current inside voltage sources represents the global current flowing into all parallel conductors constituting one phase;
- current inside loads represents the current flowing in each part of a phase.

Moreover, the current inside a voltage source is equal to the sum of the currents in loads 1, 2 and 3 of the same phase.

Action/Data (1)

Real and imaginary parts of the current inside **Voltage Sources**, as well as its magnitude and its phase, are available by editing the tab "**Results**" of the corresponding entities **V1**, **V2** and **V3**.

☞ **Components and Electric Circuit → Voltage source → Edit**

The obtained results for **Voltages Sources V1**, **V2** and **V3** are reported in the table below.

Analysis (1)

Voltage source	Re (A)	Im (A)	Magnitude (A)	Phase (°)
V1	1275.36	-279.64	1305.66	-12.37
V2	-879.99	-964.58	1305.68	-132.37
V3	-395.37	1244.21	1305.52	107.63

Currents inside **Voltage Sources** are balanced: same magnitude and 120° phase between each current. It is worth to note that a phase difference (about 12.37°) exists between voltage and current flowing inside a source, because of the inductive behavior of the conductors and the inductors of load 2.

Action/Data (2)

Real and imaginary parts of the current inside **load 1**, as well as its magnitude and its phase, are available by editing the tab "**Results**" of the corresponding entities **R1_LOAD1**, **R2_LOAD1** and **R3_LOAD1**.

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

The obtained results for **load 1** are reported in the table below.

Continued on next page

Analysis (2)

Resistor of load 1	Re (A)	Im (A)	Magnitude (A)	Phase (°)
R1_LOAD1	459.96	-0.08	459.96	-0.01
R2_LOAD1	-230.08	-398.30	459.98	-120.01
R3_LOAD1	-229.88	398.38	459.95	119.99

Currents inside **load 1** are balanced: same magnitude and 120° phase between each current.

Analysis (3)

In the same manner, the currents inside **loads 2** and **3** can be obtained. The results are reported in the tables below.

Resistor of load 2	Re (A)	Im (A)	Magnitude (A)	Phase (°)
R1_LOAD2	355.46	-279.37	452.11	-38.17
R2_LOAD2	-419.72	-168.09	452.13	-158.17
R3_LOAD2	64.25	447.47	452.06	81.83

Resistor of load 3	Re (A)	Im (A)	Magnitude (A)	Phase (°)
R1_LOAD3	459.94	-0.19	459.94	-0.02
R2_LOAD3	-230.20	-398.18	459.93	-120.03
R3_LOAD3	-229.74	398.37	459.86	119.97

Currents inside both loads are balanced: same magnitude and 120° phase between each current.

Conclusion

Computation of the global currents gives the evaluation of the voltage distribution between all the loads connected along the horizontal bars of the system.

4.2.2. Current inside conductors

Goal

The determination of global currents inside the conductors gives an evaluation of the current distribution inside the horizontal parallel conductors. Considering skin and proximity effects and regarding design constraints, it is in fact interesting to study how the currents are distributed into the conductors of a same phase.

Action

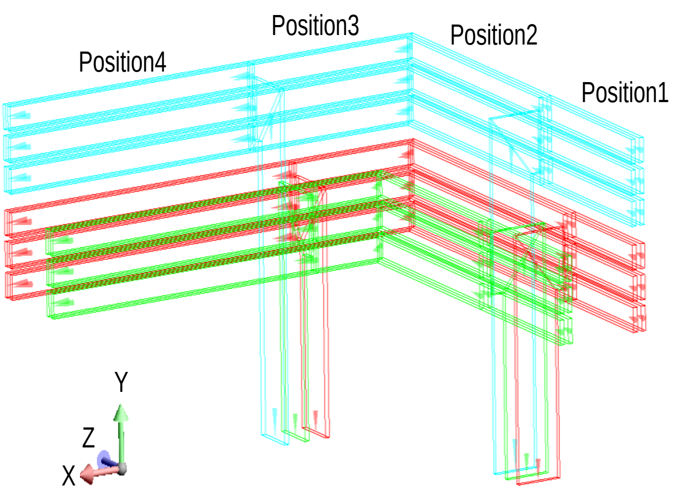
Real and imaginary parts of the current inside **unidirectional conductors**, as well as its magnitude and its phase, are available by editing the tab “**Results**” of the corresponding entity.

☞ **Physics → Unidirectional conductor → Edit**

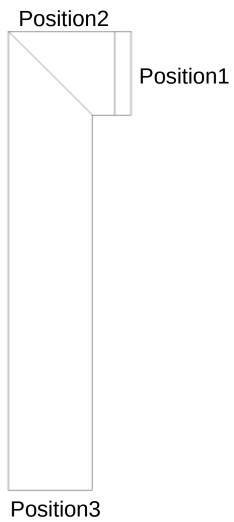
Both horizontal and vertical conductors are cut into several parts (four and three, respectively) due to their geometric shape and the connections established between the bars in order to distribute the current and supply the loads. The figure below reminds how the conductors are cut into several parts.

For both horizontal and vertical conductors, currents measured at positions 2 and 3 will be equal, since there is any other element connected in that area. Positions 1 and 4 for horizontal conductors correspond to the parts where **Voltages sources** and **load 3** are located, respectively.
Moreover, position 3 of vertical conductors corresponds to the part where the loads 1 and 2 are connected.

Horizontal conductors



Vertical conductors



Continued on next page

Data (1)

The results related to the phase 1 are reported in the table below.

Since the voltage source **V1** is connected at position 1 of horizontal conductors, the sum of the currents inside conductors BAR_1 to BAR_6 is equal to the current inside **V1** (i.e., 1275.36 - j 279.64 A). In the same manner, at position 4 the sum of the currents inside conductors BAR_1 to BAR_6 is equal to the current inside **R1_LOAD3** (i.e., 459.94 - j 0.19 A).

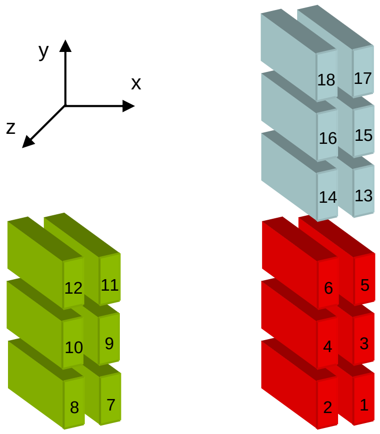
For vertical conductors, currents inside BAR_19 and BAR_22 at position 3 are equal to the current inside **R1_LOAD1** (i.e., 459.96 - j 0.08 A) and **R1_LOAD2** (i.e., 355.46 - j 279.37 A), respectively.

Horizontal conductors					
Current	Conductor	Re (A)	Im (A)	Magnitude (A)	Phase (°)
Position 1	BAR_1	183.62	-23.84	185.16	-7.40
	BAR_2	213.52	73.52	225.82	19.00
	BAR_3	101.81	-73.50	125.57	-35.83
	BAR_4	135.92	22.81	137.82	9.53
	BAR_5	315.25	-191.23	368.72	-31.24
	BAR_6	325.24	-87.39	336.77	-15.04
Positions 2/3	BAR_1	111.73	-21.98	113.88	-11.13
	BAR_2	144.25	35.29	148.50	13.75
	BAR_3	53.65	-53.04	75.44	-44.67
	BAR_4	86.75	2.00	86.77	1.32
	BAR_5	190.87	-147.61	241.29	-37.72
	BAR_6	228.15	-94.22	246.84	-22.44
Position 4	BAR_1	69.01	14.83	70.59	12.13
	BAR_2	59.29	50.81	78.09	40.60
	BAR_3	43.57	-11.29	45.01	-14.53
	BAR_4	35.66	25.59	43.89	35.66
	BAR_5	128.79	-56.62	140.68	-23.73
	BAR_6	123.62	-23.51	125.83	-10.77
Vertical conductors					
Current	Conductor	Re (A)	Im (A)	Magnitude (A)	Phase (°)
Position 1	BAR_19	244.43	-65.95	253.17	-15.10
	BAR_22	114.88	-169.55	204.80	-55.88
Positions 2/3	BAR_19	459.96	-0.08	459.96	-0.01
	BAR_22	355.46	-279.37	452.11	-38.17

Continued on next page

Analysis (1)

Whatever the position is, currents in the six horizontal parallel conductors are unbalanced: BAR_5 and BAR_6 are the most overloaded ones because of the proximity with phase 3 (see picture below). BAR_1 and BAR_2 are impacted by the skin effect inside phase 1, whereas BAR_3 and BAR_4 are the less overloaded ones because they are protected from parasitic effects by the other conductors around them.



Continued on next page

Data (2)

The results related to the phase 2 are reported in the table below.

Since the voltage source **V2** is connected at position 1 of horizontal conductors, the sum of the currents inside conductors BAR_7 to BAR_12 is equal to the current inside **V2** (i.e., -879.99 - j 964.58 A). In the same manner, at position 4 the sum of the currents inside conductors BAR_7 to BAR_12 is equal to the current inside **R2_LOAD3** (i.e., -230.20 - j 398.18 A).

For vertical conductors, currents inside BAR_20 and BAR_23 at position 3 are equal to the current inside **R2_LOAD1** (i.e., -230.08 - j 398.30 A) and **R2_LOAD2** (i.e., -419.72 - j 168.10 A), respectively.

Horizontal conductors					
Current	Conductor	Re (A)	Im (A)	Magnitude (A)	Phase (°)
Position 1	BAR_7	-195.95	-210.29	287.43	-132.98
	BAR_8	-155.14	-136.10	206.38	-138.74
	BAR_9	-141.76	-130.24	192.50	-137.43
	BAR_10	-102.63	-52.73	115.39	-152.81
	BAR_11	-150.47	-261.52	301.72	-119.81
	BAR_12	-134.04	-173.69	219.40	-127.66
Positions 2/3	BAR_7	-142.55	-101.99	175.28	-144.41
	BAR_8	-112.20	-84.70	140.58	-142.95
	BAR_9	-96.78	-58.12	112.89	-149.01
	BAR_10	-68.18	-34.14	76.25	-153.40
	BAR_11	-122.39	-159.54	201.08	-127.49
	BAR_12	-107.82	-127.79	167.20	-130.16
Position 4	BAR_7	-46.53	-78.55	91.29	-120.64
	BAR_8	-44.86	-62.70	77.10	-125.58
	BAR_9	-29.98	-48.12	56.70	-121.92
	BAR_10	-29.34	-30.18	42.09	-134.20
	BAR_11	-37.11	-99.30	106.01	-110.49
	BAR_12	-42.38	-79.33	89.94	-118.11
Vertical conductors					
Current	Conductor	Re (A)	Im (A)	Magnitude (A)	Phase (°)
Position 1	BAR_20	-103.63	-115.90	155.47	-131.80
	BAR_23	-171.61	-74.42	187.05	-156.56
Positions 2/3	BAR_20	-230.08	-398.30	459.98	-120.01
	BAR_23	-419.72	-168.10	452.13	-158.17

Analysis (2)

Currents in the six horizontal parallel conductors are unbalanced: BAR_11 and BAR_7 are the most overloaded conductors followed by BAR_12.

Continued on next page

Data (3)

The results related to the phase 3 are reported in the table below.

Since the voltage source **V3** is connected at position 1 of horizontal conductors, the sum of the currents inside conductors BAR_13 to BAR_18 is equal to the current inside **V3** (i.e., -395.37 + j 1244.21 A). In the same way, at position 4 the sum of the currents inside conductors BAR_13 to BAR_18 is equal to the current inside **R3_LOAD3** (i.e., -229.74 + j 398.37 A).

For vertical conductors, currents inside BAR_21 and BAR_24 at position 3 are equal to the current inside **R3_LOAD1** (i.e., -229.88 + j 398.38 A) and **R3_LOAD2** (i.e., 64.25 + j 447.47 A), respectively.

Horizontal conductors					
Current	Conductor	Re (A)	Im (A)	Magnitude (A)	Phase (°)
Position 1	BAR_13	-184.00	245.94	307.15	126.80
	BAR_14	-187.23	321.37	371.94	120.23
	BAR_15	6.69	111.68	111.88	86.58
	BAR_16	5.00	169.46	169.54	88.31
	BAR_17	-16.64	174.23	175.02	95.46
	BAR_18	-19.18	221.52	222.35	94.95
Positions 2/3	BAR_13	-110.80	161.17	195.58	124.51
	BAR_14	-111.23	226.02	251.91	116.20
	BAR_15	14.94	60.20	62.03	76.07
	BAR_16	17.50	113.41	114.75	81.23
	BAR_17	13.89	117.73	118.55	83.27
	BAR_18	10.22	167.30	167.61	86.51
Position 4	BAR_13	-92.60	76.53	120.13	140.43
	BAR_14	-94.64	94.18	133.81	135.14
	BAR_15	-10.25	38.06	39.42	105.07
	BAR_16	-11.14	48.93	50.18	102.82
	BAR_17	-10.03	66.56	67.32	98.57
	BAR_18	-11.08	74.10	74.92	98.51
Vertical conductors					
Current	Conductor	Re (A)	Im (A)	Magnitude (A)	Phase (°)
Position 1	BAR_21	-111.98	192.74	222.91	120.16
	BAR_24	30.91	157.96	160.95	78.93
Positions 2/3	BAR_21	-229.88	398.38	459.95	119.99
	BAR_24	64.25	447.47	452.06	81.83

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Analysis (3)

As expected BAR_13 and BAR_14 are strongly overloaded all along the way: from voltage sources to load 3. These conductors are mainly affected by proximity effects with BAR_5 and BAR_6 of phase 1.

From previous tables it can be noticed that even if the three phases are balanced, important current unbalances between the six horizontal conductors of a same phase exist. This means that proximity and skin effects have to be taken into account during the design and sizing of a distribution enclosure. A cooling system can be for example optimized based on these computed results. This is made possible by the computation of the current density, losses and magnetic flux on conductors. These computations are detailed in the following sections.

4.3. Current density

Introduction

This section deals with the current density evaluation.

The purpose of this case is to compute the current density in the cross section of conductors to evaluate the skin and proximity effects.

Principal results

The current density will be evaluated:
- on conductors
- on a 2D grid

Contents

This section deals with the following topics:

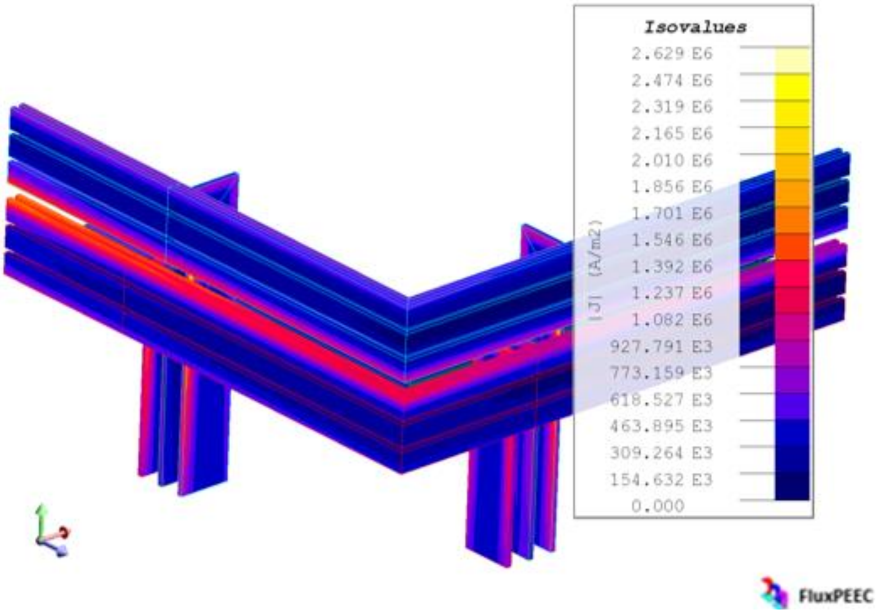
4.3.1. Current density on conductors

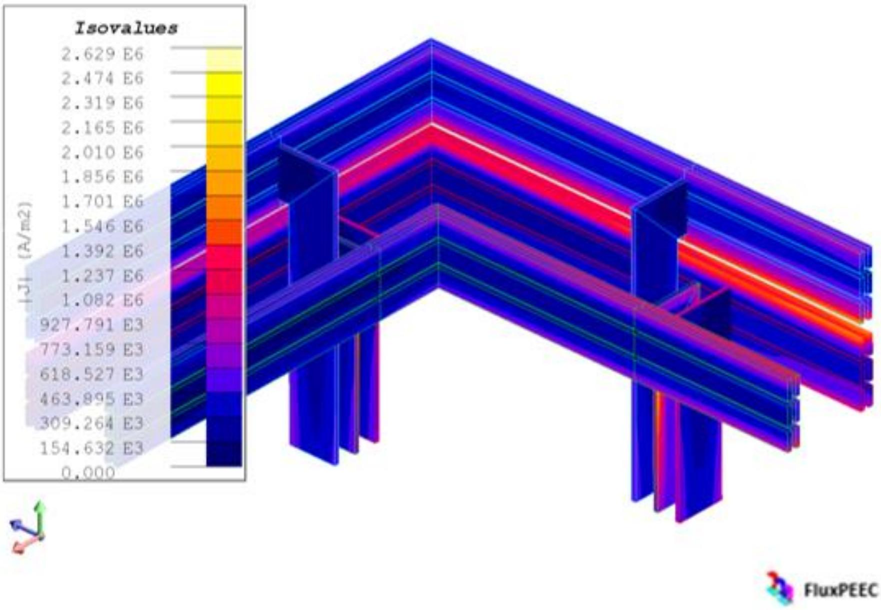
Goal The current density magnitude is evaluated on conductors and displayed.

Action Display the current density on all unidirectional conductors.

Post Processing → Isovalues → Isovalues on conductors → Current density	

Results





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Analysis

On the previous figures it can be seen that:

- conductors 5 and 6 of phase 1 and conductors 13 and 14 of phase 3 are overloaded,
- current is non-uniform into vertical conductors.

Proximity and skin effects are here clearly identified. Proximity effect is the most influential one: horizontal conductors of phase 2 are far enough from the other two phases to have lower overload effects than the bars of phases 1 and 3, especially strong in the central area where BAR_5, BAR_6, BAR_13 and BAR_14 are located.

4.3.2. Current density on 2D grids

Goal (1)

The current density magnitude is evaluated on two 2D grids defined by user.

Action/Data (1)

The first 2D grid has a rectangular shape and is located in a XY-plane near the voltage sources. Its properties are presented in the table below.

<table>
<tr><th colspan="5">Rectangular in the XY-plane</th></tr>
<tr><th>Name</th><th colspan="2">Comment</th><th colspan="2">Origin of the 2D grid</th></tr>
<tr><td rowspan="7">XY_SOURCE</td><td colspan="2" rowspan="3">2D grid to draw current density magnitude in the cross section of conductors near the voltage sources</td><td>First coordinate</td><td>-5</td></tr>
<tr><td>Second coordinate</td><td>-20</td></tr>
<tr><td>Third coordinate</td><td>400</td></tr>
<tr><th colspan="2">Characteristics along X</th><th colspan="2">Characteristics along Y</th></tr>
<tr><td>Dimension along positive X</td><td>30</td><td>Dimension along positive Y</td><td>140</td></tr>
<tr><td>Dimension along negative X</td><td>0</td><td>Dimension along negative Y</td><td>0</td></tr>
<tr><td>Number of discretization elements</td><td>18</td><td>Number of discretization elements</td><td>56</td></tr>
</table>

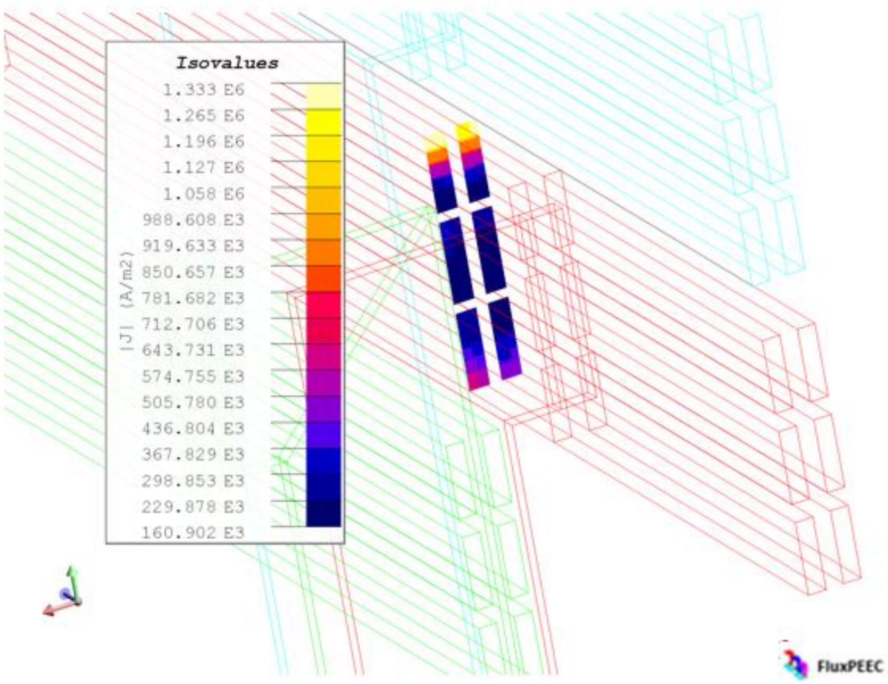
☞ **Post Processing → Supports → 2D grid → New**

Action (2)

Display the current density isovalues on the 2D grid **XY_SOURCE**.

☞ **Post Processing → Isovalues → Isovalues on 2D grids → Current density**

Isovalues (1)



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Goal (2)

The current density magnitude is now visualized by means of arrows (instead of color shades) on grid **XY_SOURCE**.

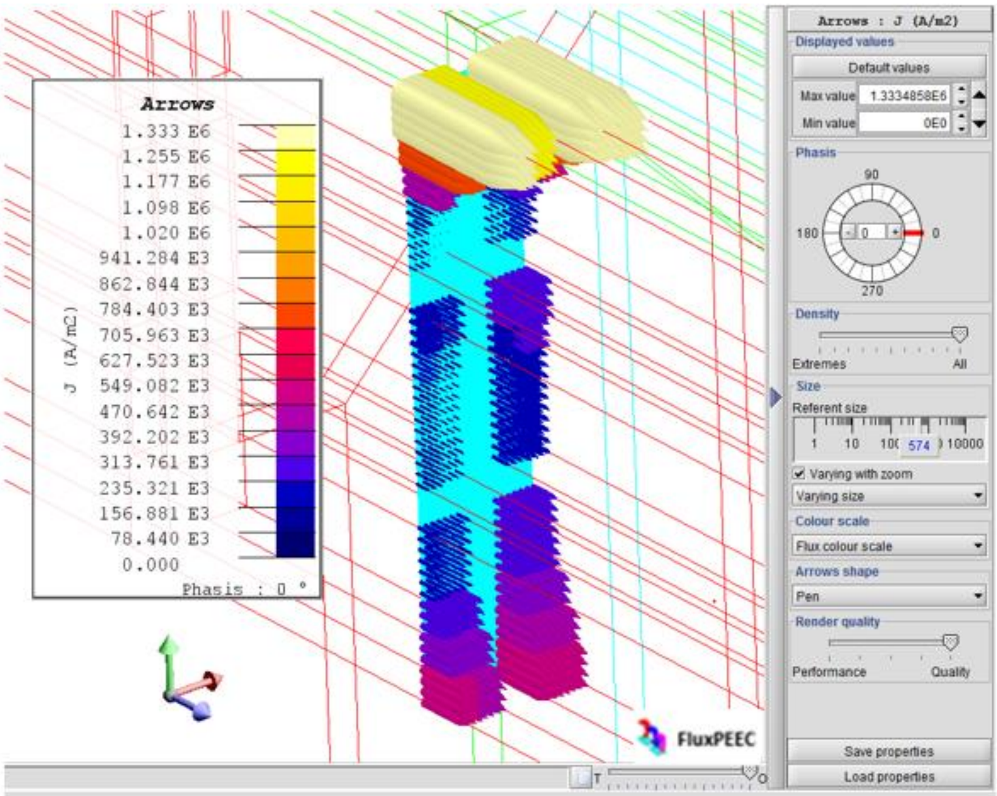
Action (3)

Display the current density arrows on 2D grid **XY_SOURCE**.

☞ | **Post Processing → Arrows → Arrows on 2D grids → Current density**

Select "*Varying size*" to better visualize the current density variation.

Arrows (1)



Analysis (1)

Current density is not uniform because of proximity effects mainly between phases 1 and 3. It clearly appears here that conductors BAR_5 and BAR_6 of phase 1 are flown by much more current than BAR_1 to 4.

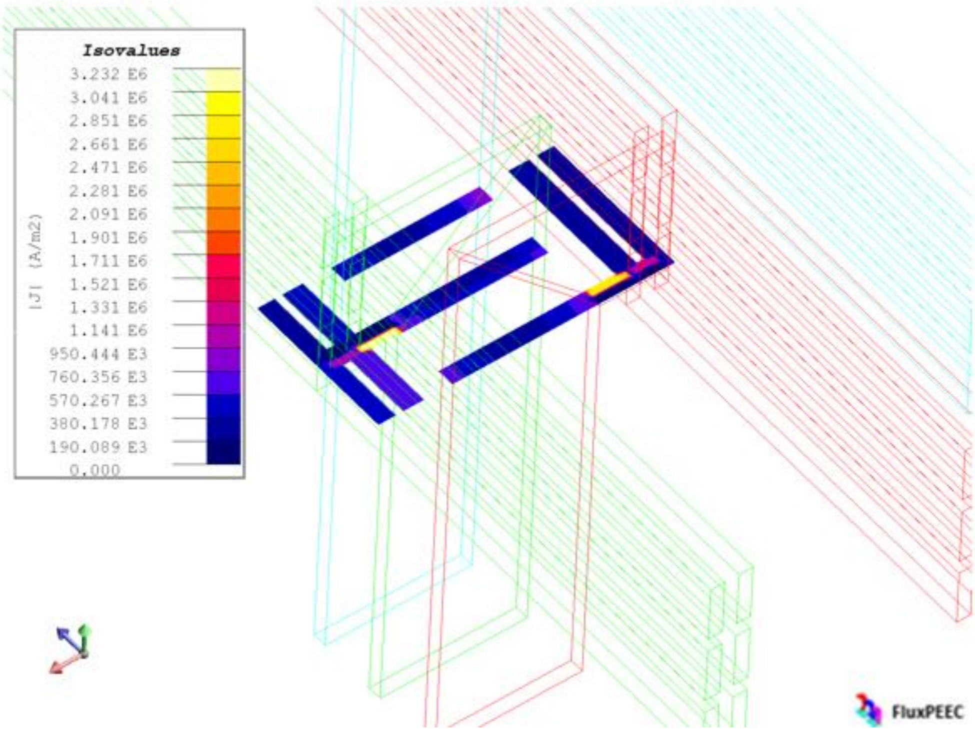
Continued on next page

Action/Data (4) The second 2D grid is located in a XZ-plane near **load 1**.
Its properties are presented in the table below.

Rectangular in the XZ-plane				
Name	**Comment**		**Origin of the 2D grid**	
XZ_LOAD1	2D grid to draw current density magnitude in the cross section of conductors near load 1		First coordinate	-5
			Second coordinate	0
			Third coordinate	320
	Characteristics along X		**Characteristics along Z**	
	Dimension along positive X	210	Dimension along positive Z	85
	Dimension along negative X	0	Dimension along negative Z	25
	Number of discretization elements	84	Number of discretization elements	44

Action (5) Display the current density isovalues on the 2D grid **XZ_LOAD1**.

Isovalues (2)



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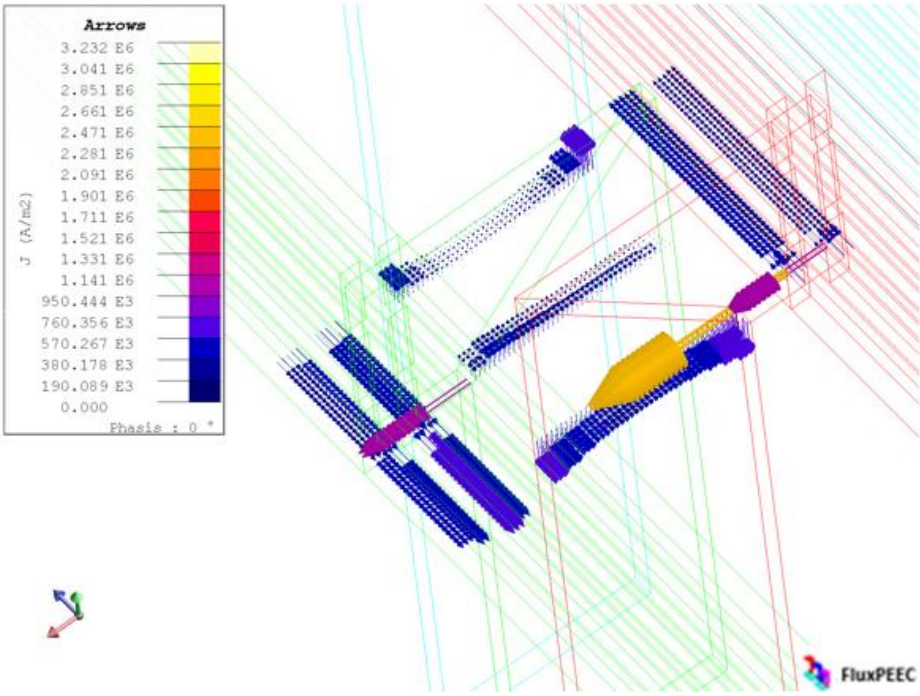
Action (5) Display now the current density arrows on the 2D grid **XZ_LOAD1**.

Arrows (2)



Analysis (2) The overloaded conductors are clearly represented on these 2D grids. Because of the geometric discontinuity, current density shows increased values in the neighborhoods of the connections between horizontal and vertical conductors. Once again, these results show that geometric arrangements of conductors can imply a copper over-sizing.

4.4. Global losses

Introduction

This section deals with the evaluation of global losses induced by the intrinsic electrical characteristics of conductors constituting the system of distribution bars, i.e., the material resistivity.

Action

Joule losses of each **unidirectional conductor** are available by editing the tab “**Results**” of the corresponding entity, whereas global losses of the system or a part of it are computable as post-processing result by Flux PEEC.

☞ **Post Processing → Global computations → Losses in a list of conductors**

Data

The results are reported in the table below.

Conductor	Value (W)	Conductor	Value (W)	Conductor	Value (W)
BAR_1	1.452	BAR_7	2.753	BAR_13	5.649
BAR_2	2.116	BAR_8	1.693	BAR_14	7.606
BAR_3	0.531	BAR_9	1.060	BAR_15	0.458
BAR_4	0.680	BAR_10	0.428	BAR_16	1.172
BAR_5	7.022	BAR_11	3.529	BAR_17	1.660
BAR_6	6.602	BAR_12	2.307	BAR_18	2.627
BAR_19	1.872	BAR_20	1.860	BAR_21	2.518
BAR_22	1.815	BAR_23	1.775	BAR_24	2.380
Total phase 1	**22.090**	**Total phase 2**	**15.405**	**Total phase 3**	**24.070**
Total	**61.565**				

Analysis

Losses are linked to the current density. Considering the results of losses computation, unbalanced currents between the three phases are once again highlighted and phase 2 dissipates less power than the others. Even if these losses are low, they can reduce the lifecycle assessment of the product.

4.5. Magnetic flux density

Introduction

This section deals with the evaluation of magnetic flux density on and around conductors.

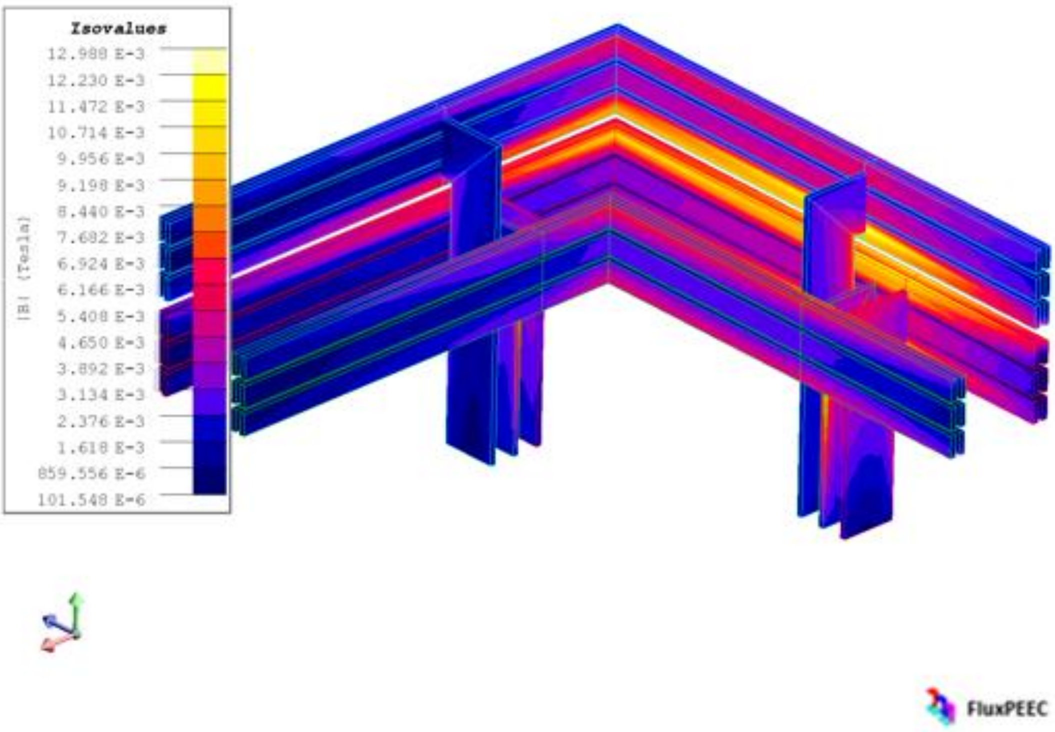
Action (1)

Display the magnetic flux density on all unidirectional conductors.

Post Processing → Isovalues → Isovalues on conductors → Magnetic flux density	

Isovalues on conductors

In order to get better results, the length of unidirectional conductors can be meshed during the post processing phase.
Isovalues of induction **B** on conductors are presented in the figure below.



Analysis (1)

The magnetic induction is correlated to the current density. As illustrated by the figure, the magnetic induction is not uniform.
Considering design constraints, if magnetic induction levels are too high, the power bars could be shielded according to the devices connected to the vertical parts.

Continued on next page

2D grids / Data

Two new rectangular 2D grids are defined in YZ and XZ planes, respectively, to visualize the magnetic flux isovalues.
Their properties are reported in the table below.

Rectangular in the YZ-plane				
Name	**Comment**		**Origin of the 2D grid**	
YZ	2D grid to draw the magnitude of the magnetic flux density near conductors		First coordinate	-10
			Second coordinate	-40
			Third coordinate	0
	Characteristics along Y		**Characteristics along Z**	
	Dimension along positive Y	350	Dimension along positive Z	350
	Dimension along negative Y	0	Dimension along negative Z	0
	Number of discretization elements	30	Number of discretization elements	30

Rectangular in the XZ-plane				
Name	**Comment**		**Origin of the 2D grid**	
XZ	2D grid to draw the magnitude of the magnetic flux density near conductors		First coordinate	350
			Second coordinate	-40
			Third coordinate	825
	Characteristics along X		**Characteristics along Z**	
	Dimension along positive X	110	Dimension along positive Z	150
	Dimension along negative X	110	Dimension along negative Z	150
	Number of discretization elements	40	Number of discretization elements	60

Action (2)

Display the magnetic flux density on 2D grids: firstly **YZ** and then **XZ**.

☞ **Post Processing → Isovalues → Isovalues on 2D grids → Magnetic flux density** 

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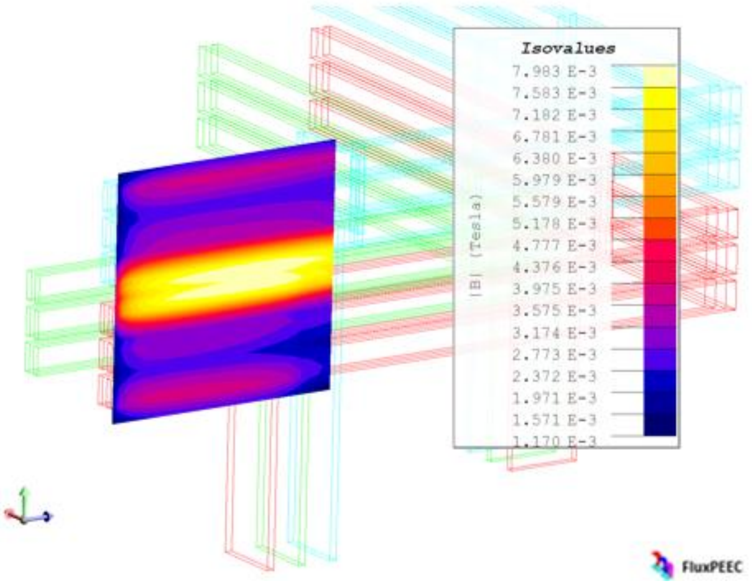
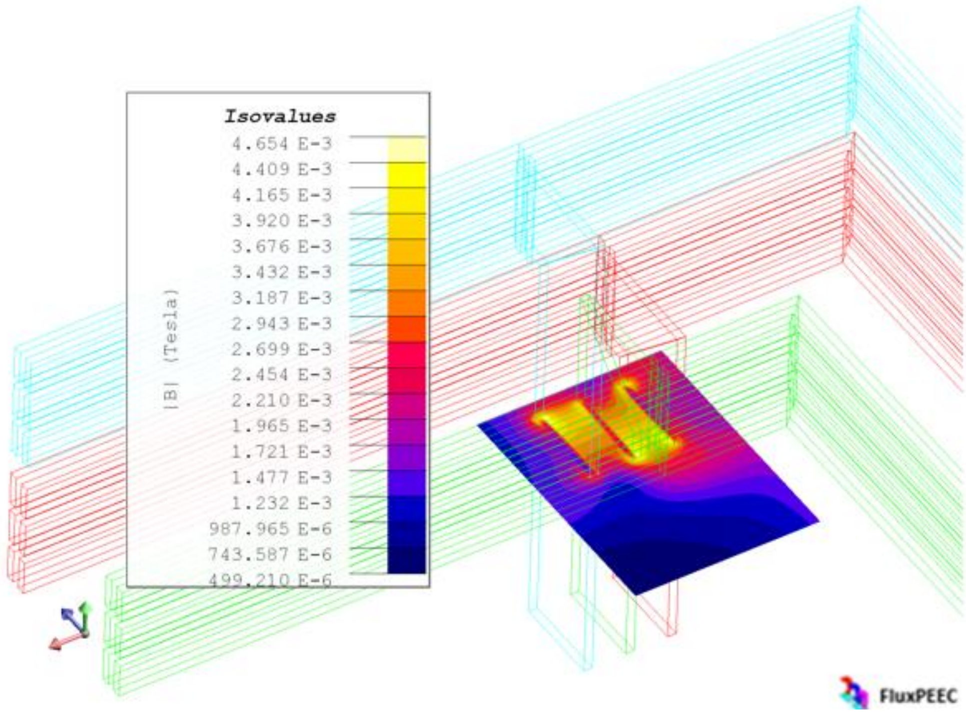
Isovalues on a 2D grid (1)

Magnitude of magnetic field density on **YZ** grid is presented in the figure below.



Isovalues on a 2D grid (2)

Magnitude of magnetic field density on **XZ** grid is presented in the figure below.



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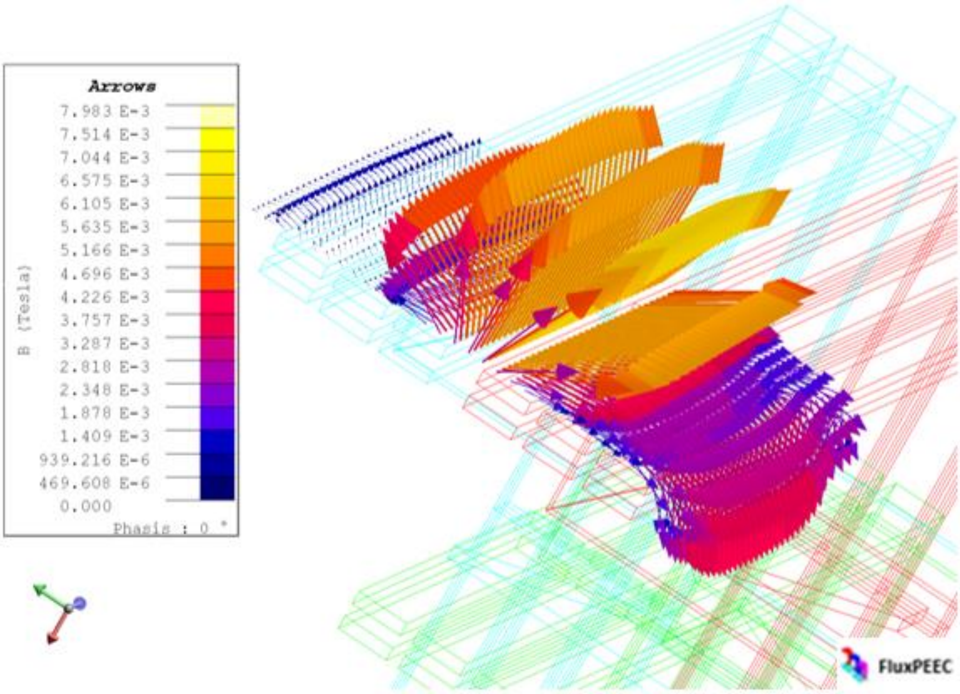
Action (3)

Display the magnetic flux density arrows on the 2D grid **YZ**.

☞ **Post Processing → Arrows → Arrows on 2D grids → Magnetic flux density**	

Arrows on a 2D grid

Arrows for magnetic induction on **YZ** grid are presented in the figure below.



Analysis (2)

The magnetic induction is correlated to the current density. As illustrated by the figures, the magnetic induction is not uniform. These results show how important the consequences of proximity effects can be.
Considering design constraints, if magnetic induction levels are too high, a solution could be to shield the power bars according to the devices connected to the vertical parts.

4.6. Laplace forces

Introduction

This section deals with the evaluation of Laplace force density on conductors.

Depending on working conditions (in case of defaults for example), currents flowing inside the conductors constituting the distribution system can create important Laplace force between the bars. These mechanical efforts can lead to the destruction of the device.

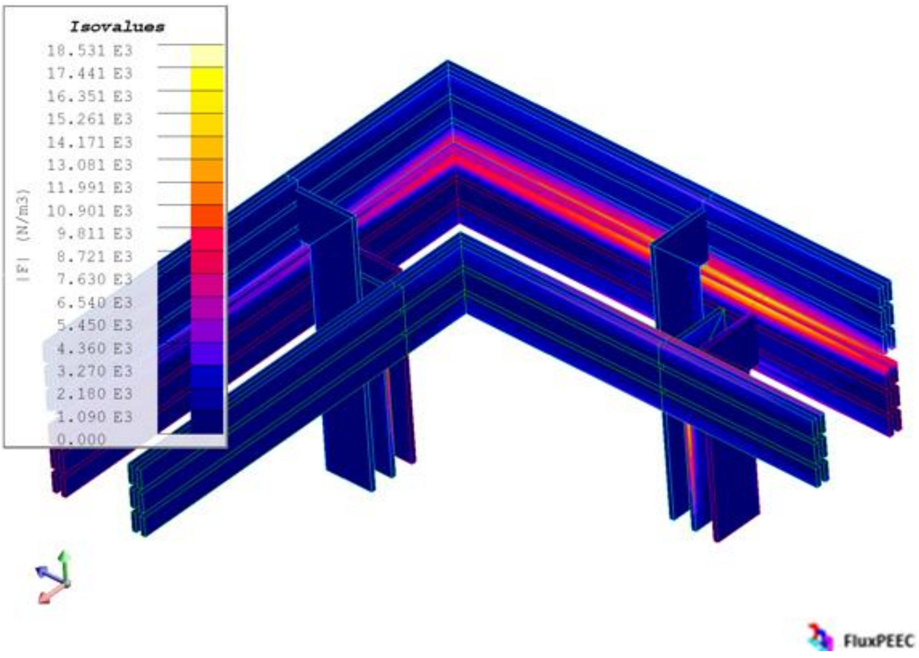
Action

Display the average Laplace force density on all unidirectional conductors.

☞ **Post Processing → Isovalues → Isovalues on conductors → Laplace force volumic density → Average Laplace force density**

Isovalues on conductors

In order to get more accurate results, the length of unidirectional conductors can be meshed during the post processing phase.
Isovalues of average Laplace force density on conductors are presented in the figure below.



Analysis (1)

Isovalues on conductors show that Laplace force is high on the vertical conductors close to the horizontal ones. Inside one phase, efforts between the conductors are not so high.
Moreover, the density is higher between horizontal conductors of phases 1 and 3 near the voltage sources. In order to reduce this mechanical constraint, the distance between the two phases should be increased.

Continued on next page

Theory / Laplace force vectors

As Flux PEEC works in the AC harmonic domain, sinusoidal sources with a pulsation ω are represented using the complex numbers notation; currents inside the conductors can also be described with a pulsation equal to ω as well as the magnetic flux density.

As Laplace force is done by the cross product of current and magnetic flux densities, its computation generates a real number, which is called **average Laplace force**, and a complex number representing a 2ω sinusoidal variation, which is called **2ω pulsating Laplace force**.

These two results, average and 2ω pulsating Laplace forces, are 3D spatial vectors (one real and one complex) whose components are automatically computed by Flux PEEC post-processor.

Action (2)

Compute the average Laplace force vector of all unidirectional conductors.

☞ **Post Processing → Global computations → Laplace forces in a list of conductors → Average Laplace force density**

Laplace force on conductors

The average Laplace force vectors on conductors are computed and reported in the table below.

Unidirectional conductor	3D spatial components of average Laplace force vectors (N)
BAR_1	(0.113,0.203,-0.036)
BAR_2	(-0.319,0.215,0.118)
BAR_3	(0.070,-0.004,-0.019)
BAR_4	(-0.172,0.015,0.062)
BAR_5	(0.476,-1.111,-0.178)
BAR_6	(-0.652,-0.921,0.244)
BAR_7	(0.395,0.287,-0.109)
BAR_8	(-0.187,0.228,0.049)
BAR_9	(0.238,-0.012,-0.061)
BAR_10	(-0.079,-0.004,0.022)
BAR_11	(0.474,-0.434,-0.142)
BAR_12	(-0.215,-0.335,0.063)
BAR_13	(0.522,1.053,-0.198)
BAR_14	(-0.578,1.286,0.223)
BAR_15	(0.098,0.012,-0.030)
BAR_16	(-0.214,0.023,0.084)
BAR_17	(0.188,-0.216,-0.068)
BAR_18	(-0.292,-0.273,0.125)
BAR_19	(-0.048E-03,-0.012,-0.090)
BAR_20	(-0.003,-0.012,0.111)
BAR_21	(0.007,0.988E-03,0.225)
BAR_22	(-0.113,-0.008,-0.002)
BAR_23	(0.029,-0.012,0.008)
BAR_24	(0.231,-0.002,-0.001)

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Analysis (2)

The Laplace force vectors give complementary information.
They can be useful to compute and study the direction of mechanical efforts and to know where mechanical supports have to be added.

5. Case 2: solving process and results post-processing

Case 2

The second case is a study with an unbalanced load.

In this study, load 2 is unbalanced, since one of its elements is disconnected.

Contents

This chapter deals with the following topics:

5.1. Case 2: general description and solving process

Goal	Some electrical properties of the device studied for case 1 are modified. One connection is deleted and consequently the load number 2 is unbalanced.
Action (1)	The connection ***LOAD2_PHASE1*** is deleted. Consequently, the inductor ***L1_LOAD2*** and the resistor ***R1_LOAD2*** are no more connected with the conductor BAR_22.
Action (2)	A new solving process is carried out.

5.2. Case 2: results

Introduction

This section deals with the results related to case 2 with an unbalanced load.

Principal results

The main results are:
- global currents
- current density
- losses

Contents

This section deals with the following topics:

5.2.1. Global currents

Goal

The evaluation of currents inside electrical components is carried out: currents in voltage sources are the total currents of each phase (sum of the currents in loads 1, 2 and 3).
Then, currents flowing inside all conductors of the system are also analyzed.

Action/Data (1)

Real and imaginary parts of the current inside **Voltage Sources**, as well as its magnitude and its phase, are available by editing the tab “**Results**” of the corresponding entities **V1**, **V2** and **V3**.

☞ **Components and Electric Circuit → Voltage source → Edit**

Obtained results are reported in the table below.

Voltage source	Re (A)	Im (A)	Magnitude (A)	Phase (°)
V1	919.97	-0.20	919.97	-0.013
V2	-702.30	-1104.30	1308.70	-122.45
V3	-217.68	1104.50	1125.75	101.15

Analysis (1)

Global currents in **Voltage Sources** are unbalanced due to the disconnected phase of **load 2**.

Action/Data (2)

The currents inside components of the **load 1** are evaluated and reported in the table below.

Resistor of load 1	Re (A)	Im (A)	Magnitude (A)	Phase (°)
R1_LOAD1	459.98	-0.065	459.98	-0.008
R2_LOAD1	-230.09	-398.31	459.99	-120.01
R3_LOAD1	-229.89	398.37	459.95	119.99

Analysis (2)

Global currents inside **load 1** are balanced: same magnitude and 120° phase between each current.
The disconnected phase of **load 2** does not have a significant impact on these currents.

Continued on next page

Action/Data (3)

Global currents inside **load 2** are evaluated; results are presented in the table below.

Resistor of load 2	Re (A)	Im (A)	Magnitude (A)	Phase (°)
R1_LOAD2	0	0	0	0
R2_LOAD2	-241.98	-307.78	391.52	-128.17
R3_LOAD2	241.98	307.78	391.52	51.83

Analysis (3)

Global currents inside **load 2** are of course unbalanced.
Only 391 Amp are carried out through load 2 instead of 452 Amp initially.
The lost of active power is here evaluated at around 50%.

Action/Data (4)

Global currents inside **load 3** are evaluated; results are reported in the table below.

Resistor of load 3	Re (A)	Im (A)	Magnitude (A)	Phase (°)
R1_LOAD3	460.00	-0.14	460.00	-0.017
R2_LOAD3	-230.23	-398.21	459.97	-120.03
R3_LOAD3	-229.77	398.35	459.86	119.98

Analysis (4)

Global currents inside **load 3** are balanced: same magnitude and 120° phase between each current.
The disconnected phase of **load 2** does not have a significant impact on these currents.

Continued on next page

Action/Data (5) In the second part of this analysis, currents inside **unidirectional conductors** are assessed. Their real and imaginary parts, as well as their magnitude and phase, are available by editing the tab "**Results**" of the corresponding entity.

☞ **Physics → Unidirectional conductor → Edit**

The results related to the phase 1 are reported in the table below.

Horizontal conductors					
Current	Conductor	Re (A)	Im (A)	Magnitude (A)	Phase (°)
Position 1	BAR_1	137.32	20.71	138.87	8.58
	BAR_2	151.58	118.65	192.50	38.05
	BAR_3	80.81	-40.21	90.26	-26.45
	BAR_4	99.46	57.57	114.92	30.06
	BAR_5	228.28	-130.93	263.16	-29.84
	BAR_6	222.53	-25.99	224.04	-6.66
Positions 2/3	BAR_1	72.42	21.84	75.64	16.78
	BAR_2	74.29	84.02	112.15	48.51
	BAR_3	39.21	-19.46	43.77	-26.40
	BAR_4	43.28	41.72	60.11	43.95
	BAR_5	110.21	-92.36	143.80	-39.96
	BAR_6	120.58	-35.88	125.81	-16.57
Position 4	BAR_1	69.10	12.92	70.30	10.59
	BAR_2	65.42	46.72	80.40	35.54
	BAR_3	42.57	-14.49	44.97	-18.80
	BAR_4	40.41	20.12	45.14	26.46
	BAR_5	122.85	-49.53	132.46	-21.96
	BAR_6	119.64	-15.88	120.68	-7.56
Vertical conductors					
Current	Conductor	Re (A)	Im (A)	Magnitude (A)	Phase (°)
Position 1	BAR_19	224.56	-60.44	232.55	-15.06
	BAR_22	-12.68	-38.88	40.90	-108.07
Positions 2/3	BAR_19	459.98	-0.07	459.98	-0.01
	BAR_22	0	0	0	0

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Analysis (5)

As expected, global current at positions 2 and 3 of BAR_22 is equal to 0, because this part of conductor is in open-circuit.
Currents flowing inside BAR_1 to BAR_6 at positions 1, 2 and 3 are really impacted by the unbalanced **load 2**, whereas currents at position 4 are less modified. This behavior is explainable with the fact that fault on **load 2** is situated downstream on the distribution system.

Data (6)

The results related to the phase 2 are reported in the table below.

Horizontal conductors					
Current	Conductor	Re (A)	Im (A)	Magnitude (A)	Phase (°)
Position 1	BAR_7	-146.38	-239.22	280.46	-121.46
	BAR_8	-127.57	-163.55	207.42	-127.95
	BAR_9	-112.40	-150.33	187.71	-126.79
	BAR_10	-94.16	-70.43	117.58	-143.20
	BAR_11	-110.31	-284.86	305.47	-111.17
	BAR_12	-111.48	-195.90	225.40	-119.64
Positions 2/3	BAR_7	-92.18	-131.60	160.67	-125.01
	BAR_8	-84.49	-112.93	141.04	-126.80
	BAR_9	-66.39	-79.55	103.61	-129.85
	BAR_10	-59.45	-53.13	79.73	-138.21
	BAR_11	-83.93	-180.48	199.04	-114.94
	BAR_12	-85.78	-148.31	171.33	-120.04
Position 4	BAR_7	-49.01	-77.60	91.78	-122.27
	BAR_8	-41.52	-63.26	75.67	-123.28
	BAR_9	-33.18	-45.98	56.70	-125.82
	BAR_10	-26.93	-29.68	40.08	-132.23
	BAR_11	-39.77	-100.54	108.12	-111.58
	BAR_12	-39.82	-81.16	90.40	-116.13
Vertical conductors					
Current	Conductor	Re (A)	Im (A)	Magnitude (A)	Phase (°)
Position 1	BAR_20	-103.49	-115.52	155.10	-131.86
	BAR_23	-121.44	-140.27	185.54	-130.89
Positions 2/3	BAR_20	-230.09	-398.31	460.00	-120.01
	BAR_23	-241.98	-307.79	391.52	-128.17

Analysis (6)

Currents of phase 2 are almost not impacted by the unbalanced **load 2**. These conductors are too far from those of phases 1 and 3.

Continued on next page

Data (7)

Results for phase 3, horizontal and vertical bars, are reported in the table below.

Horizontal conductors					
Current	Conductor	Re (A)	Im (A)	Magnitude (A)	Phase (°)
Position 1	BAR_13	-108.11	205.19	231.93	117.79
	BAR_14	-122.34	281.22	306.68	113.51
	BAR_15	18.08	96.96	98.63	79.44
	BAR_16	8.51	155.51	155.74	86.87
	BAR_17	-2.70	159.04	159.07	90.97
	BAR_18	-11.11	206.59	206.89	93.08
Positions 2/3	BAR_13	-42.00	122.64	129.64	108.90
	BAR_14	-45.09	186.07	191.46	103.62
	BAR_15	24.30	45.30	51.41	61.79
	BAR_16	25.23	97.31	100.53	75.47
	BAR_17	26.79	103.25	106.66	75.46
	BAR_18	22.98	151.55	153.28	81.38
Position 4	BAR_13	-89.24	75.24	116.73	139.87
	BAR_14	-95.39	93.65	133.68	135.53
	BAR_15	-9.01	39.04	40.07	102.99
	BAR_16	-13.70	50.79	52.60	105.10
	BAR_17	-8.97	65.75	66.36	97.77
	BAR_18	-13.45	73.88	75.10	100.32
Vertical conductors					
Current	Conductor	Re (A)	Im (A)	Magnitude (A)	Phase (°)
Position 1	BAR_21	-101.83	190.00	215.57	118.19
	BAR_24	116.32	91.16	147.78	38.09
Positions 2/3	BAR_21	-229.89	398.37	459.95	119.99
	BAR_24	241.98	307.78	391.52	51.83

Analysis (7)

Currents flowing inside BAR_13 to BAR_18 at position 4 remain almost the same than case 1. However other parts of the system are quite impacted, because of the proximity of conductors of phase 1 where the fault is located.

5.2.2. Current density

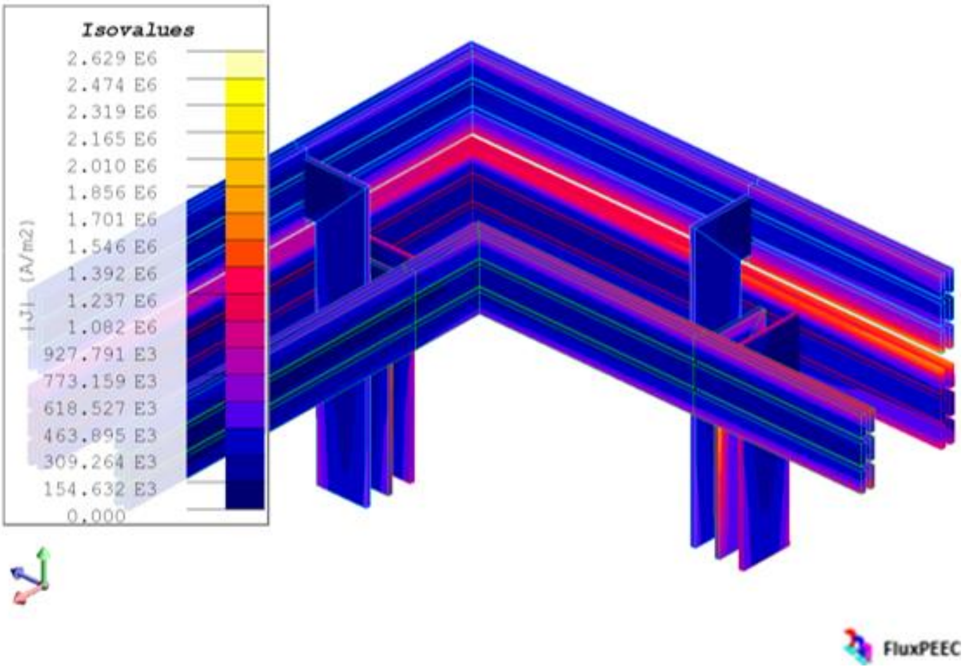
Goal

The current density magnitude is evaluated on all the conductors, then displayed by means of isovalues and compared to results of case 1.

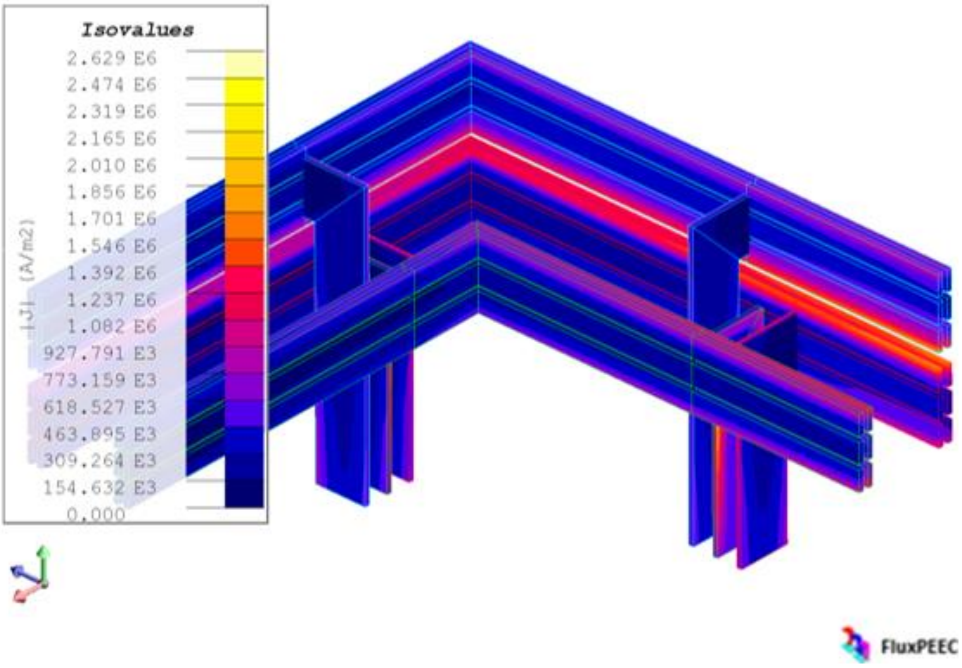
☞ **Post Processing → Isovalues → Isovalues on conductors → Current density**

Results

Case 1



Case 2



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Analysis

The results show that:

- conductors BAR_5 and BAR_6 of phase 1 are still overloaded
- conductors BAR_13 and BAR_14 of phase 3 are still overloaded
- but much lesser than for case 1

As expected there is no current inside BAR_22.

5.2.3. Losses

Goal

Computation of losses gives the expected results: almost no losses in conductor BAR_22.
The global losses have decreased.
The losses distribution is modified compared to case 1.

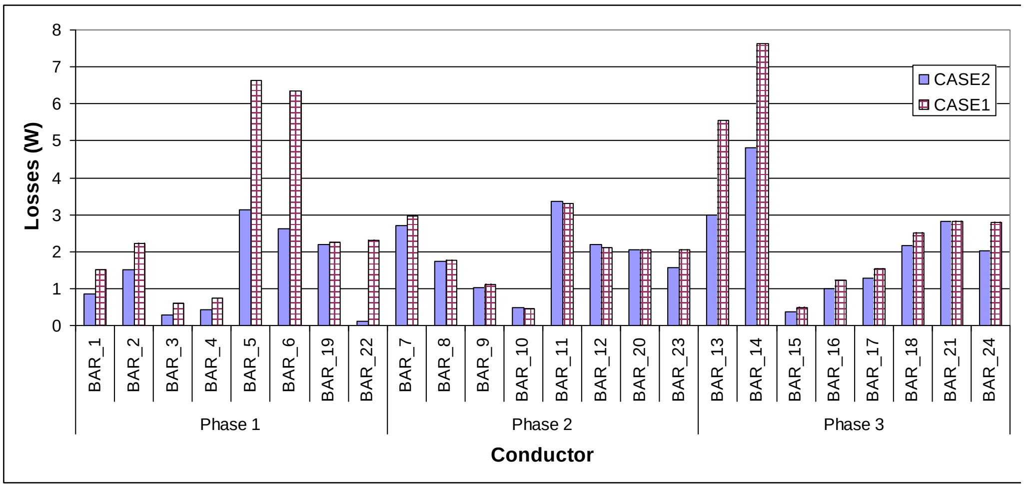
Data

Losses are presented in the table below.

Conductor	Value (W)	Conductor	Value (W)	Conductor	Value (W)
BAR_1	0.833	BAR_7	2.537	BAR_13	3.025
BAR_2	1.431	BAR_8	1.685	BAR_14	4.754
BAR_3	0.258	BAR_9	0.974	BAR_15	0.347
BAR_4	0.422	BAR_10	0.444	BAR_16	0.963
BAR_5	3.287	BAR_11	3.559	BAR_17	1.393
BAR_6	2.718	BAR_12	2.393	BAR_18	2.264
BAR_19	1.870	BAR_20	1.860	BAR_21	2.513
BAR_22	0.051	BAR_23	1.304	BAR_24	1.779
Total phase 1	**10.870**	**Total phase 2**	**14.756**	**Total phase 3**	**17.038**
Total	**42.664**				

Analysis

Unbalance of currents between the three phases is once again highlighted. Losses of phase 1 where **load 2** is disconnected are lower than the other two phases. It is clearly shown that BAR_5, BAR_6, BAR_13 and BAR_14 are the most impacted conductors by the unbalanced load.



This explains why losses of phase 2 remain almost the same and why losses of phases 1 and 3 are dramatically reduced.

5.2.4. Magnetic flux density

Introduction

This section deals with the evaluation of magnetic flux density on conductors and everywhere else in space.

Action (1)

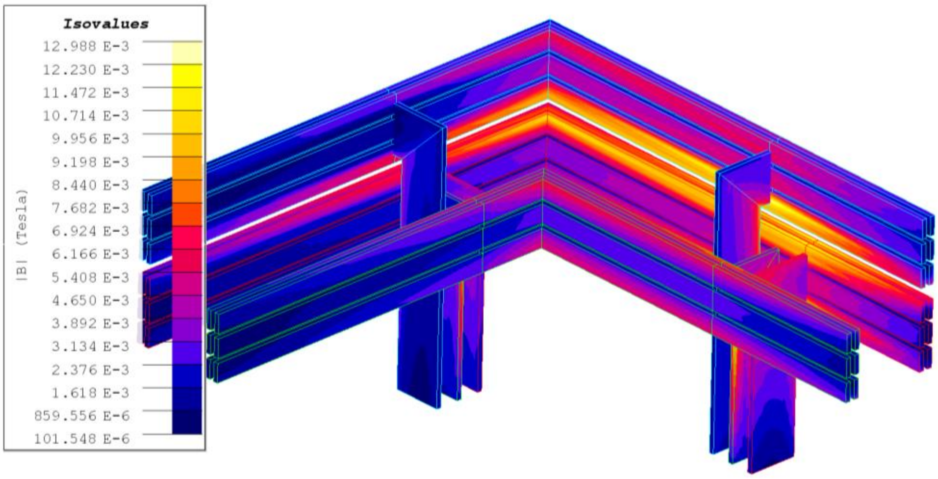
Display the magnetic flux density on all unidirectional conductors.

☞ **Post Processing → Isovalues → Isovalues on conductors → Magnetic flux density**

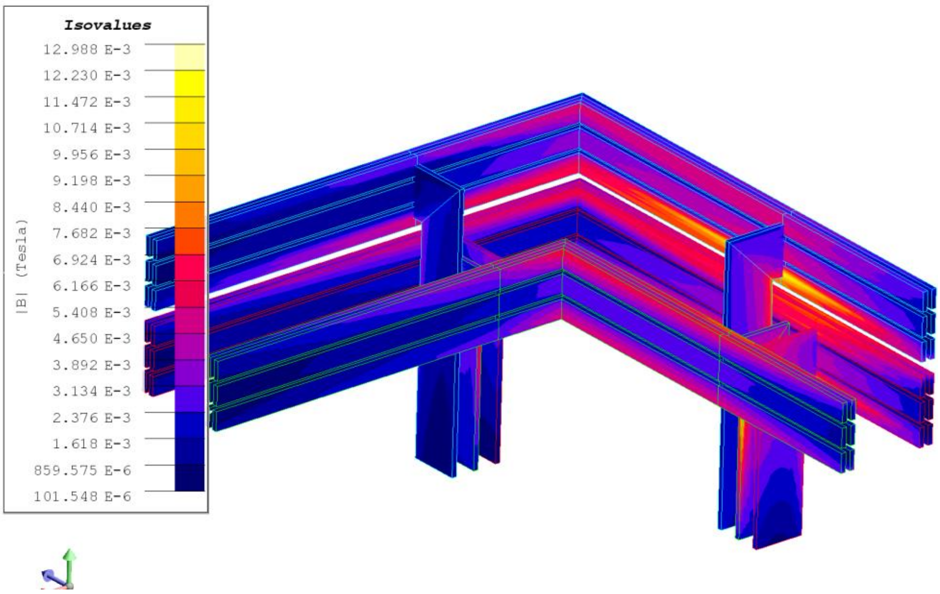
Isovalues on conductors

In order to get more accurate results, the length of unidirectional conductors can be meshed during the post-processing.
Isovalues of induction **B** on conductors are presented in the figure below and compared with results of case 1.

Case 1



Case 2



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2D grids / Data

Two new rectangular 2D grids are defined in YZ and XZ planes, respectively, to visualize the magnetic flux isovalues.
Their properties are reported in the table below.

Rectangular in the YZ-plane				
Name	**Comment**		**Origin of the 2D grid**	
YZ	2D grid to draw the magnitude of the magnetic flux density near conductors		First coordinate	-10
			Second coordinate	-40
			Third coordinate	0
	Characteristics along Y		**Characteristics along Z**	
	Dimension along positive Y	350	Dimension along positive Z	350
	Dimension along negative Y	0	Dimension along negative Z	0
	Number of discretization elements	30	Number of discretization elements	30

Rectangular in the XZ-plane				
Name	**Comment**		**Origin of the 2D grid**	
XZ	2D grid to draw the magnitude of the magnetic flux density near conductors		First coordinate	350
			Second coordinate	-40
			Third coordinate	825
	Characteristics along X		**Characteristics along Z**	
	Dimension along positive X	110	Dimension along positive Z	150
	Dimension along negative X	110	Dimension along negative Z	150
	Number of discretization elements	40	Number of discretization elements	60

Action (2)

Display the magnetic flux density on 2D grids: firstly **YZ** and then **XZ**.

☞ **Post Processing → Isovalues → Isovalues on 2D grids → Magnetic flux density**

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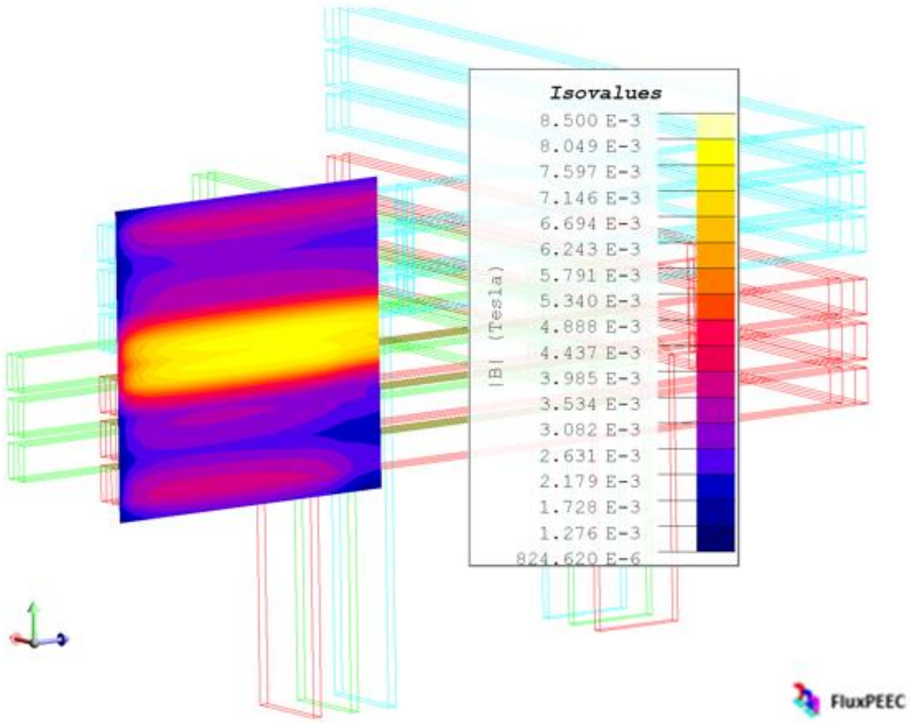
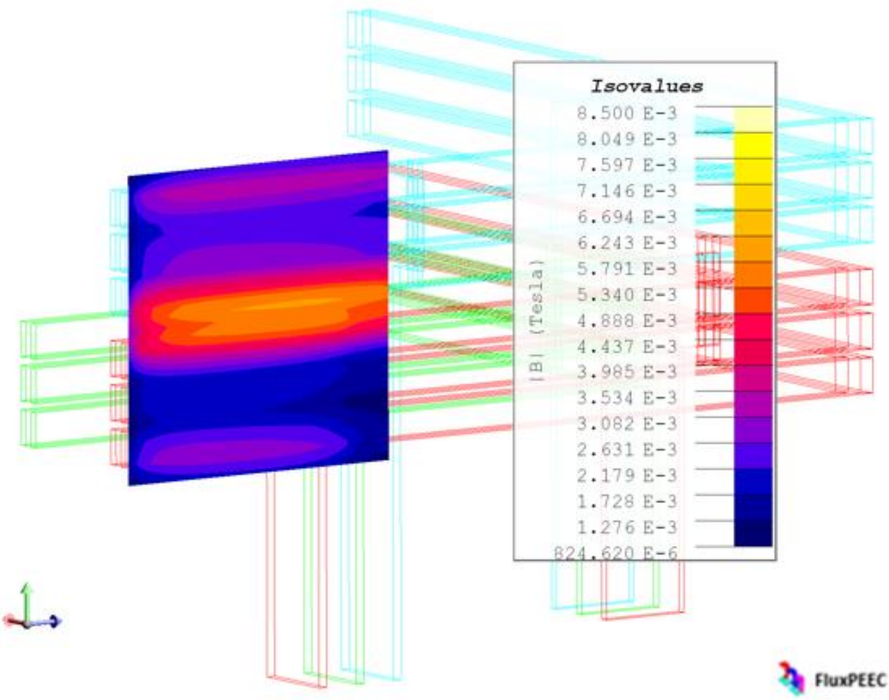
Isovalues on a 2D grid (1)

Magnitude of magnetic field density on **YZ** grid is presented in the figure below and compared to results of case 1.

Case 1



Case 2



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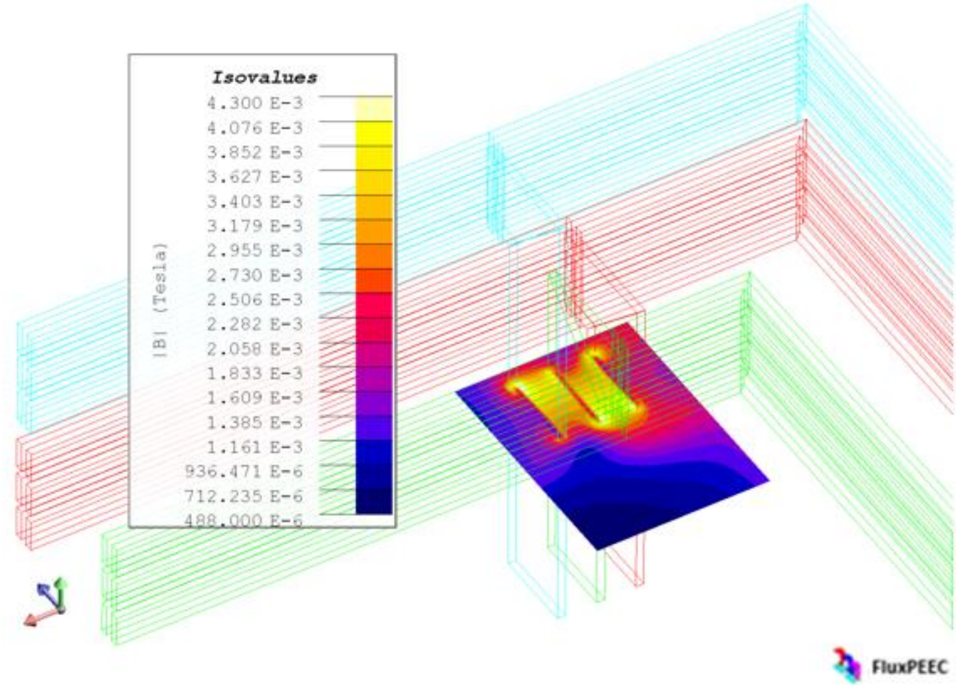
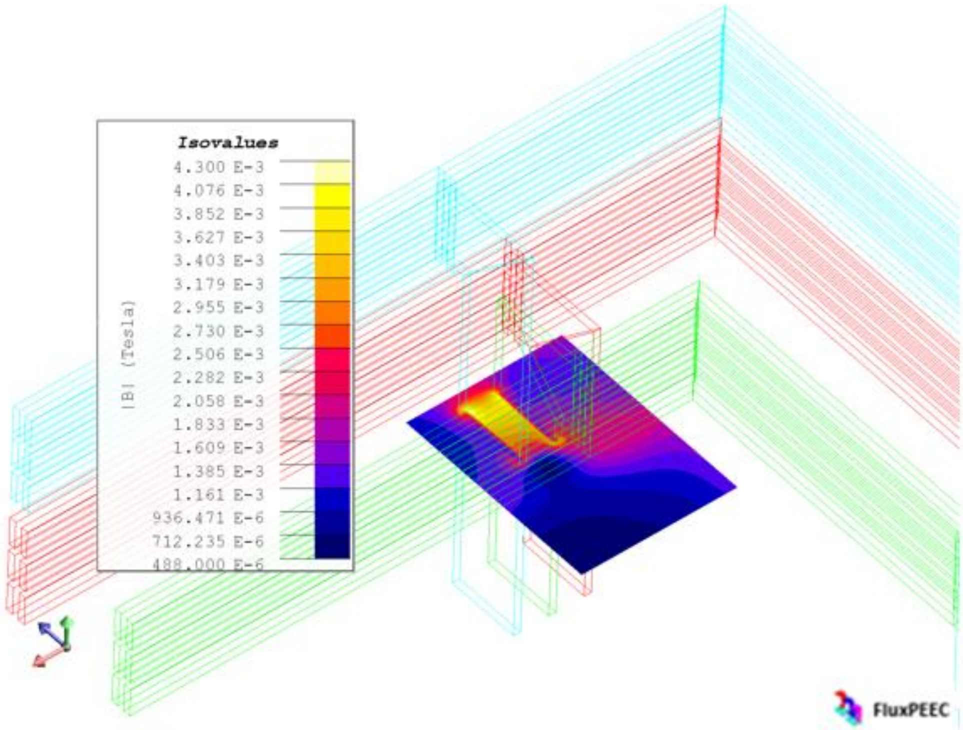
Isovalues on a 2D grid (2)

Magnitude of magnetic field density on **XZ** grid is presented in the figure below and compared to results of case 1.

Case 1



Case 2



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Analysis

Major isovalues of the magnetic field density are principally located where current density is the highest.
Furthermore, the showed results highlight the fact that the disconnected phase 1 of load 2 has also an impact on the other parts of the system: for example, the magnetic emissions near the voltage sources (2D grid **YZ)** are much lower in case 2 than in case 1.
The second grid (**XZ**) is used to visualize the magnetic field density in the area near vertical conductors BAR_22, BAR_23 and BAR_24: as expected there are very small levels of induction **B** between BAR_22 and BAR_23 in case 2 because phase 1 (BAR_22) is disconnected from load 2.

5.2.5. Laplace forces

Introduction

This section deals with the evaluation of Laplace force density on conductors.

Depending on working conditions (in case of defaults for example), currents inside conductors can create important Laplace forces (mechanical efforts) that may significantly damage the device.

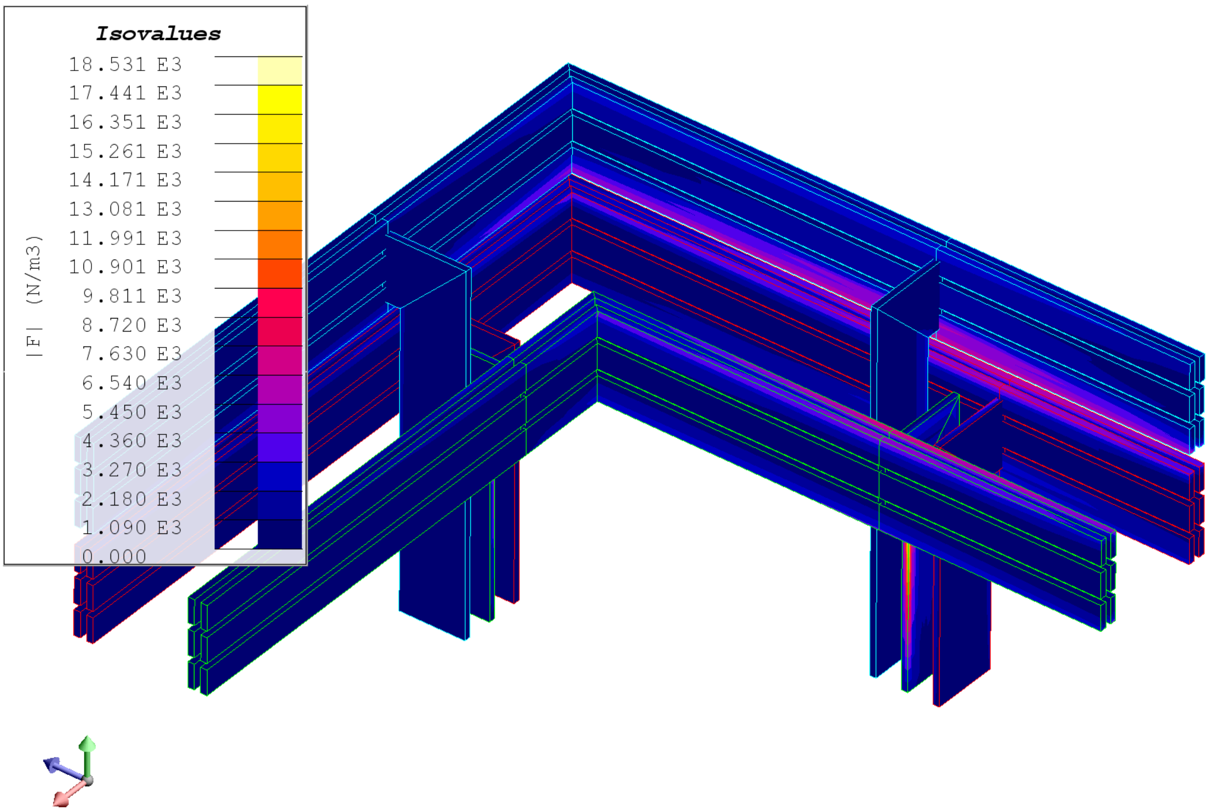
Action

Display the average Laplace force density on all unidirectional conductors.

☞ **Post Processing → Isovalues → Isovalues on conductors → Laplace force volumic density → Average Laplace force density**

Isovalues on conductors

In order to get more accurate results, the length of unidirectional conductors can be meshed during the post-processing phase.
Isovalues of average Laplace force density on conductors are presented in the figure below.



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6. Other cases

Goal

Based on this device modeling, different cases could be studied:

- unbalance of load 1 and/or 3,
- some conductors of a phase are disconnected,
- fault on voltage source,
- different positions of conductors,
- …

Starting from the two provided cases, the reader can practice by himself.

7. Appendix

Introduction

This appendix section deals with the computation of ideal currents flowing inside the loads for case 1 with the assumptions of perfect conductors, i.e. neglecting parasitic resistive and inductive behaviors that are contrariwise taken into account by Flux PEEC simulations.

Contents

This chapter deals with the following topics:

7.1. Ideal current inside load 1

Introduction

This section deals with computation of ideal currents flowing inside resistor of **load 1** for the previously-studied case 1.

Electrical equations

With reference to the electric scheme of page 33, the following equations hold:

$$\begin{cases} \underline{V_1} = R_1 \cdot \underline{I_{11}} \\ \underline{V_2} = R_1 \cdot \underline{I_{21}} \\ \underline{V_3} = R_1 \cdot \underline{I_{31}} \end{cases}$$

Data

Resistors: $R_1 = 0.5\ \Omega$
Voltage sources: $V = 230\ V_{RMS}$

Solving

Magnitude of currents: $I_{i1} = 230/0.5 = 460\ A_{RMS}$

$$\begin{cases} \underline{I_{11}} = \underline{V_1} / R_1 = 460\ \text{ A} \\ \underline{I_{21}} = \underline{V_2} / R_1 = -230 - \text{j}\,398.4\ \text{ A} \\ \underline{I_{31}} = \underline{V_3} / R_1 = -230 + \text{j}\,398.4\ \text{ A} \end{cases} \rightarrow \begin{cases} \left|\underline{I_{11}}\right| = 460\ \text{ A} \\ \left|\underline{I_{21}}\right| = 460\ \text{ A} \\ \left|\underline{I_{31}}\right| = 460\ \text{ A} \end{cases} \quad \text{and} \quad \begin{cases} \arg(\underline{I_{11}}) = 0° \\ \arg(\underline{I_{21}}) = -120° \\ \arg(\underline{I_{31}}) = 120° \end{cases}$$

7.2. Ideal current inside load 2

Introduction

This section deals with computation of ideal currents inside elements (resistors and inductors) of **load 2** for case 1.

Electrical equations

Equivalent impedance of the load:

$$\underline{Z} = R_2 + \mathrm{j}\omega L_2 \quad \rightarrow \quad \begin{cases} |\underline{Z}| = 0.509\ \ \Omega \\ \arg(\underline{Z}) = 38.14° \end{cases}$$

Voltage sources:

$$\begin{cases} \underline{V_1} = Ve^{j0} = \underline{Z} \cdot \underline{I_{12}} \\ \underline{V_2} = Ve^{j\frac{-2\pi}{3}} = \underline{Z} \cdot \underline{I_{22}} \\ \underline{V_3} = Ve^{j\frac{2\pi}{3}} = \underline{Z} \cdot \underline{I_{32}} \end{cases}$$

Data

Resistors: R_2 = 0.4 Ω
Inductors: L_2 = 1 mH
Frequency: f = 50 Hz
Voltage sources: V = 230 V_{RMS}

Solving

Magnitude of currents: I_{i2} = 230/0.509 = 452.2 A_{RMS}

$$\begin{cases} \underline{I_{12}} = \underline{V_1} / \underline{Z} = 355.6 - \mathrm{j}\,279.3\ \ \mathrm{A} \\ \underline{I_{22}} = \underline{V_2} / \underline{Z} = -419.7 - \mathrm{j}168.3\ \ \mathrm{A} \\ \underline{I_{32}} = \underline{V_3} / \underline{Z} = 64.1 + \mathrm{j}\,447.6\ \ \mathrm{A} \end{cases} \rightarrow \begin{cases} \left|\underline{I_{12}}\right| = 452.2\ \ \mathrm{A} \\ \left|\underline{I_{22}}\right| = 452.2\ \ \mathrm{A} \\ \left|\underline{I_{32}}\right| = 452.2\ \ \mathrm{A} \end{cases} \text{and} \begin{cases} \arg(\underline{I_{12}}) = -38.14° \\ \arg(\underline{I_{22}}) = -158.14° \\ \arg(\underline{I_{32}}) = 81.86° \end{cases}$$

7.3. Ideal current inside load 3

Introduction

This section deals with computation of ideal currents inside **load 3** for case 1.

Electrical equations

$$\begin{cases} \underline{V_1} = R_3 \cdot \underline{I_{13}} \\ \underline{V_2} = R_3 \cdot \underline{I_{23}} \\ \underline{V_3} = R_3 \cdot \underline{I_{33}} \end{cases}$$

Data

Resistors: $R_3 = 0.5\ \Omega$
Voltage sources: $V = 230\ V_{RMS}$

Solving

Magnitude of currents: $I_{i3} = 230/0.5 = 460\ A_{RMS}$

$$\begin{cases} \underline{I_{13}} = \underline{V_1} / R_3 = 460\ \text{A} \\ \underline{I_{23}} = \underline{V_2} / R_3 = -230 - \text{j}\,398.4\ \text{A} \\ \underline{I_{33}} = \underline{V_3} / R_3 = -230 + \text{j}\,398.4\ \text{A} \end{cases} \rightarrow \begin{cases} \left|\underline{I_{13}}\right| = 460\ \text{A} \\ \left|\underline{I_{23}}\right| = 460\ \text{A} \\ \left|\underline{I_{33}}\right| = 460\ \text{A} \end{cases} \quad \text{and} \quad \begin{cases} \arg(\underline{I_{13}}) = 0° \\ \arg(\underline{I_{23}}) = -120° \\ \arg(\underline{I_{33}}) = 120° \end{cases}$$

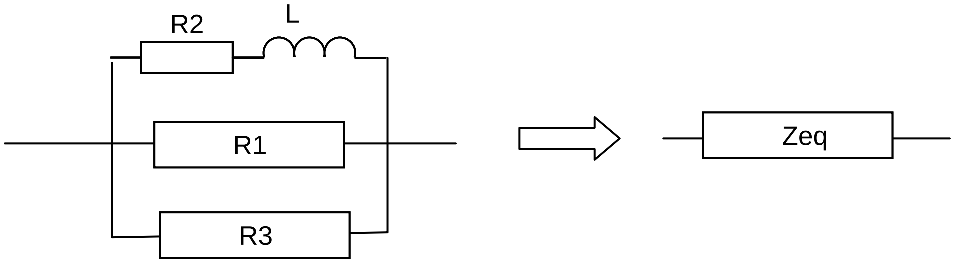
7.4. Ideal current inside voltage source

Introduction

This section deals with computation of ideal currents flowing inside elements of three-phase voltage source for case 1.

Equivalent load

For each phase, the three loads are connected in parallel; the equivalent impedance for each is presented in the figure below.



$$\underline{Zeq} = \frac{R_1 \cdot R_3 \cdot (R_2 + \mathrm{j}\omega L_2)}{R_1 \cdot R_2 + R_2 \cdot R_3 + R_3 \cdot R_1 + (R_1 + R_3) \cdot \mathrm{j}\omega L_2}$$

$$\rightarrow \begin{cases} \left|\underline{Zeq}\right| = \dfrac{R_1 \cdot R_3 \cdot \sqrt{R_2^{\,2} + (\omega L_2)^2}}{\sqrt{(R_1 \cdot R_2 + R_2 \cdot R_3 + R_3 \cdot R_1)^2 + ((R_1 + R_3) \cdot \omega L_2)^2}} \\ \arg(\underline{Zeq}) = arctg\left(\dfrac{\omega L_2}{R_2}\right) - arctg\left(\dfrac{(R_1 + R_3) \cdot \omega L_2}{R_1 \cdot R_2 + R_2 \cdot R_3 + R_3 \cdot R_1}\right) \end{cases}$$

$$\rightarrow \begin{cases} \left|\underline{Zeq}\right| = 0.176 \ \Omega \\ \arg(\underline{Zeq}) = 12.35° \end{cases}$$

Solving

$$\begin{cases} \underline{V_1} = \underline{Zeq} \cdot \underline{I_1} \\ \underline{V_2} = \underline{Zeq} \cdot \underline{I_2} \\ \underline{V_3} = \underline{Zeq} \cdot \underline{I_3} \end{cases}$$

Magnitude of currents: $I_i = 230/0.176 = 1305.85\ A_{RMS}$

$$\begin{cases} \underline{I_1} = \underline{V_1} / \underline{Zeq} = 1275.6 - \mathrm{j}\,279.3 \ \text{A} \\ \underline{I_2} = \underline{V_2} / \underline{Zeq} = -879.7 - \mathrm{j}\,965.1 \ \text{A} \\ \underline{I_3} = \underline{V_3} / \underline{Zeq} = -395.9 + \mathrm{j}\,1244.4 \ \text{A} \end{cases} \rightarrow \begin{cases} \left|\underline{I_1}\right| = 1305.85 \ \text{A} \\ \left|\underline{I_2}\right| = 1305.85 \ \text{A} \\ \left|\underline{I_3}\right| = 1305.85 \ \text{A} \end{cases} \text{and} \begin{cases} \arg(\underline{I_1}) = -12.35° \\ \arg(\underline{I_2}) = -132.35° \\ \arg(\underline{I_3}) = 107.65° \end{cases}$$

The reader can check that each current of the voltage source is equal to the sum of the three corresponding currents flowing in the loads, since the three-phase system is star connected:

$$\underline{I_i} = \underline{I_{i1}} + \underline{I_{i2}} + \underline{I_{i3}}$$