



# ALTAIR

## Altair<sup>®</sup> FluxMotor<sup>®</sup> 2024

Synchronous Machines with wound field – Inner salient pole - Inner rotor

Motor Factory - Test - Characterization

General user information

## Contents

<b>1</b>	<b>Characterization – Model – Motor – Maps</b>	<b>4</b>
<b>1.1</b>	<b>Positioning and objective</b>	<b>4</b>
1.1.1	User inputs	5
1.1.1.1	Overview	5
1.1.2	Main outputs	5
<b>1.2</b>	<b>Settings</b>	<b>5</b>
<b>1.3</b>	<b>Inputs</b>	<b>6</b>
1.3.1	Introduction	6
1.3.2	Sharing data between tests	6
1.3.3	Standard inputs	7
1.3.3.1	Operating quadrants	7
1.3.3.2	Field Current and line current definition mode	7
1.3.3.3	Maximum field current, rms	7
1.3.3.4	Maximum field current density, rms	8
1.3.3.5	Maximum line current, rms	8
1.3.3.6	Maximum current density, rms	8
1.3.3.7	Maximum speed	8
1.3.3.8	Rotor position dependency	8
1.3.4	Advanced inputs	8
1.3.4.1	Number of computed electrical periods	8
1.3.4.2	Number of points per electrical period	8
1.3.4.3	Number of computations per quadrant for D-axis and Q-axis phase currents	8
1.3.4.4	Number of computations for $I_f$ - axis field current	9
1.3.4.5	Number of computations for speed	9
1.3.4.6	Skew model – Number of layers	9
1.3.4.7	Mesh order	9
1.3.4.8	Airgap mesh coefficient	9
1.3.4.9	Rotor initial position mode - Note	9
<b>1.4</b>	<b>Main principles of computation</b>	<b>10</b>
1.4.1	Flux linkage	10
1.4.2	Flux-linkage derivative respect to the rotor position	10
1.4.3	Dynamic inductances	11
1.4.4	Dynamic cross inductances	11
1.4.5	Static inductances	11
1.4.6	Saliency	11
1.4.7	Electromagnetic torque	12
1.4.7.1	Rotor position dependency set to “No”	12
1.4.7.2	Rotor position dependency set to “Yes”	12
1.4.8	Iron loss computation	12
1.4.8.1	Rotor position dependency set to “No”	12
1.4.8.2	Rotor position dependency set to “Yes”	12
1.4.8.3	Model used to compute iron losses.	13
1.4.9	Stator Joule losses	13
1.4.10	Rotor Joule losses	13
1.4.11	Mechanical losses	13
1.4.12	Total losses	13
<b>1.5</b>	<b>Test results</b>	<b>14</b>
1.5.1	Test conditions	14
1.5.1.1	Inputs	14

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1.5.1.2	Settings	14
1.5.1.3	Winding characteristics	14
1.5.2	Maps	14
1.5.3	Curves	17
1.5.3.1	Field current flux and cross effect flux curve	17
1.5.3.2	Rotor Joule losses	17
1.5.3.3	Mechanical losses	17

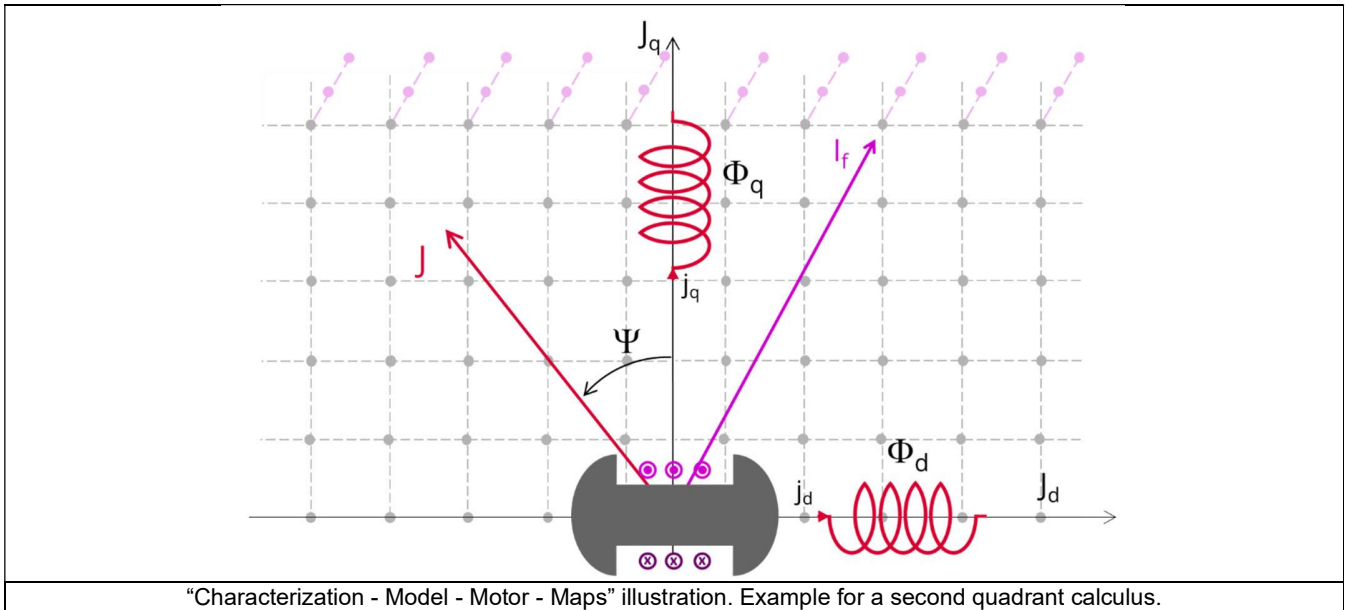
# 1 CHARACTERIZATION – MODEL – MOTOR – MAPS

## 1.1 Positioning and objective

The aim of the test “Characterization - Model - Motor - Maps” is to give maps along the three dimensions,  $I_f$ - $J_d$ - $J_q$ , for characterizing the 3-Phase synchronous machines with wound field.

These maps allow for predicting the behavior of the electrical rotating machine at a system level.

In this test, engineers will find a system integrator and / or control-command tool adapted to their needs and able to provide accurate maps ready to be used in system simulation software like Activate.



The performance of the machine in steady state can be deduced from the results obtained in this test in association with the drive and control mode to be considered.

The following table helps to classify the test:

Family	Characterization
Package	Model
Convention	Motor
Test	Maps

Positioning of the test “Characterization - Model - Motor - Maps”

## 1.1.1 User inputs

### 1.1.1.1 Overview

Maps are mainly function of the following user inputs: the maximum value of the field current, the maximum value of the line current, the speed, the number of quadrants to be considered, and the rotor position dependency.

## 1.1.2 Main outputs

Test results are illustrated with data, graphs, and tables.

### Maps in the three dimensions $I_f - J_d - J_q$

- 1) Flux linkage
  - D-axis flux-linkage  $\Phi_d$
  - Q-axis flux-linkage  $\Phi_q$
- 2) Flux linkage derivative (only when the rotor position dependency is considered)
  - D-axis flux-linkage derivative with respect to the rotor position  $\Phi_d/d\theta_r$
  - Q-axis flux-linkage derivative with respect to the rotor position  $\Phi_q/d\theta_r$
- 3) Inductance
  - D-axis inductance (dynamic, cross dynamic and static)
  - Q-axis inductance (dynamic, cross dynamic and static)
- 4) Saliency
- 5) Torque
  - Electromagnetic torque  $T_{em}$
- 6) Losses
  - Stator iron losses  $W_{ironStator}$  versus speed
  - Rotor iron losses  $W_{ironRotor}$  versus speed (only when the rotor position dependency is considered)
  - Total losses  $W_{total}$  versus speed

### Maps in the two dimensions $J_d - J_q$

- 1) Losses
  - Joule losses  $W_{Cus}$  in stator winding
  - Power electronics losses

### Curves

- 1) Field current flux and cross effect flux curve versus  $J_q$
- 2) Joule losses  $W_{Cur}$  in rotor winding versus field current
- 3) Mechanical losses versus speed versus speed

## 1.2 Settings

Three buttons give access to the following setting definition:

- Thermal settings – Definition of the phase winding and field winding temperature.
- Power electronics settings - Definition of the power electronics parameters
- Mechanics settings - Definition of mechanical loss model parameters

For more details, please refer to the document: MotorFactory\_SMWF\_ISP\_IR\_3PH\_Test\_Introduction – sections dealing with settings.

## 1.3 Inputs

### 1.3.1 Introduction

The total number of user inputs is equal to 13.  
Among these inputs, 5 are standard inputs and 8 are advanced inputs.

### 1.3.2 Sharing data between tests

An import button is available for allowing sharing the data simulated in Flux between “Characterization / Model / Map” and “Performance mapping / Efficiency map” tests.

Indeed, by implementing the rotor position dependency option for the model map test and efficiency map test of synchronous machines, this update facilitates the seamless transfer of settings, inputs, and crucially, simulated data in Flux between the two tests. As they use the same Flux data in most cases and significant computation time is required to obtain it, users can now accelerate the test resolution and optimize their workflow.

To streamline this process, an import button has been introduced in both the “Characterization / Model / Map” and “Performance mapping / Efficiency map” tests of the following machines:

- Reluctance Synchronous Machines - Inner rotor
- Synchronous Machines with wound field – Inner Salient Pole - Inner rotor

Note: The import button will be added to the tests of Synchronous machines – Permanent magnets - Inner & Outer rotor in the next version.

Upon completing a model map test, users can activate the import button in the efficiency map test GUI. This enables them to effortlessly import the settings and corresponding Flux data from the previous test, eliminating the need to rerun Flux for identical data, a step that typically consumes a substantial portion of computation time during efficiency mapping.

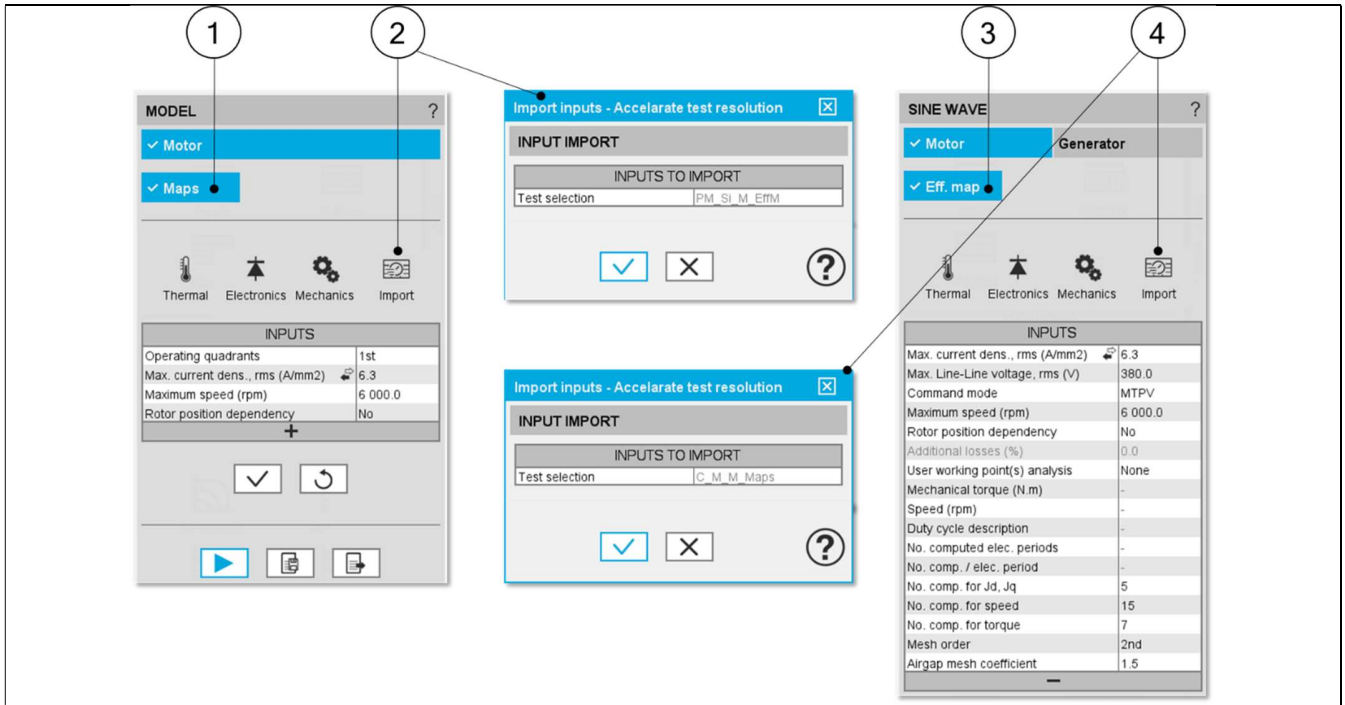
Conversely, upon concluding an efficiency map test, users can use the import button in the efficiency map test GUI to import settings and Flux data from the efficiency map test, further enhancing workflow efficiency.

Note: Only the most recent test results can be imported, saved test results are not yet able to be imported.

Note: While there are shared settings and inputs between the tests, each test may have its own unique settings and inputs. In such cases, the default settings, and inputs of the second test are automatically applied.

Note: When importing from the efficiency map test to the model map test, the quadrant setting defaults to the value specified in the model map test. For certain machine types (SMWF: 2nd quadrant, SM-RSM: 1st quadrant), specific quadrant selections are applied.

Note: In instances where quadrant inputs lead to incompatibility between the model map test and the efficiency map test, only settings and inputs are imported. A warning is issued, and Flux simulation is initiated to rectify the discrepancy.



Import function in Model Map test and Efficiency Map test to accelerate test resolution.  
Example for Wound field synchronous machines

1	Open model map test environment when an efficiency map test is available for import
2	Click the import button and import the settings, inputs, and Flux data of the latest efficiency map test
3	Open efficiency map test environment when a model map test is available for import
4	Click the import button and import the settings, inputs, and Flux data of the latest model map test

### 1.3.3 Standard inputs

#### 1.3.3.1 Operating quadrants

It defines the quadrants in the  $J_d - J_q$  plane where the test will be carried out. Options allow computing and displaying 1, 2 or 4 quadrants.

By default, the considered quadrants are the “1st and 2nd” (i.e., the grid is defined for both negative and positive values of the current in the d axis and positive ones in the q axis). This option is chosen as default because the Synchronous Machine with wound field inherits the characteristic of both Synchronous Machine with Permanent Magnets and Reluctance Synchronous Machines which work respectively in the second and the first quadrant in the motor operating mode.

The other possible values for this input are “2nd”, “2nd and 3rd”, and “all”.

#### 1.3.3.2 Field Current and line current definition mode

There are two common ways to define electrical current.

Electrical current can be defined by the current density in electric conductors.

In this case, the current definition mode should be « **Density** ».

Electrical current can be defined directly by indicating the value of the line current (the RMS value is required) and field current (AC value).

In this case, the current definition mode should be « **Current** ».

#### 1.3.3.3 Maximum field current, rms

When the choice of current definition mode is “**Current**”, the maximum DC value of the field current supplied to the machine “**Max. field current, rms**” (*Maximum field current, rms value*) must be provided.

Note: The number of parallel paths is automatically considered in the results.

#### 1.3.3.4 Maximum field current density, rms

When the choice of current definition mode is “**Density**”, the maximum rms value of the current density in electric conductors “**Max. field current dens., rms**” (*Maximum current density in field conductors, DC value*) must be provided.

Note: The number of parallel paths is automatically considered in the results.

#### 1.3.3.5 Maximum line current, rms

When the choice of current definition mode is “**Current**”, the maximum rms value of the line current supplied to the machine “**Max. line current, rms**” (*Maximum line current, rms value*) must be provided.

Note: The number of parallel paths and the winding connections are automatically considered in the results.

#### 1.3.3.6 Maximum current density, rms

When the choice of current definition mode is “**Density**”, the maximum rms value of the current density in electric conductors “**Max. current dens., rms**” (*Maximum current density in line conductors, rms value*) must be provided.

Note: The number of parallel paths and the winding connection are automatically considered in the results.

#### 1.3.3.7 Maximum speed

The analysis of test results is performed over a given speed range to evaluate losses as a function of speed, like iron losses, mechanical losses, and total losses.

The speed range is fixed between 0 and the maximum speed to be considered « **Maximum speed** » (*Maximum speed*).

#### 1.3.3.8 Rotor position dependency

It defines the rotor position dependency, where the test will be carried out. By default, the rotor position dependency is set to “No”, but it can be set to “Yes”. In this case, the computation will be done along the three dimensions  $I_r - J_d - J_q$ , with an additional fourth axis corresponding to the rotor position  $\theta_r$ .

Note: In case the rotor dependency is set to “Yes”, whatever the operating quadrant choice, the finite element computation is done over all selected quadrants (in case the rotor dependency is set to “No”, symmetries are used).

### 1.3.4 Advanced inputs

#### 1.3.4.1 Number of computed electrical periods

The user input “**No. computed elec. periods**” (Number of computed electrical periods only required with rotor position dependency set to “Yes”) influences the computation time of the results.

The default value is equal to 0.5. The maximum allowed value is 1, according to the fact that computation is done to characterize steady state behavior based on magnetostatic finite element computation. The default value provides a good compromise between the accuracy of results and computation time.

Note: The outcomes obtained at 0.5 or 1 electrical period are identical across all presented outputs, except for slight variations in rotor iron losses arising from the symmetrical assumption regarding the magnetic flux waveform on the rotor.

#### 1.3.4.2 Number of points per electrical period

The user input “**No. points / electrical period**” (Number of computed electrical periods only required with rotor position dependency set to “Yes”) influences the accuracy of results (computation of the peak-peak ripple torque, iron losses...) and the computation time.

The default value is equal to 40. The minimum recommended value is 20, and the minimum allowed is 13. The default value provides a good balance between the accuracy of the results and the computation time.

#### 1.3.4.3 Number of computations per quadrant for D-axis and Q-axis phase currents

To get maps in the  $J_d - J_q$  plane, a grid is defined. The number of computation points per quadrant along the d-axis and q-axis can be defined with the user input « **No. comp. for current  $J_d, J_q$**  » (*Number of computations for D-axis and Q-axis phase currents*).

The default value is equal to 6. This default value provides a good compromise between the accuracy of results and computation time. The minimum allowed value is 5.



#### 1.3.4.4 Number of computations for $I_f$ - axis field current

To get maps along the  $I_f$  dimension, the field current is discretized from zero to its maximum value. The number of computation points along the  $I_f$  - axis can be defined with the user input « **No. comp. for  $I_f$**  » (*Number of computations for  $I_f$  - axis field currents*). The default value is equal to 6. This default value provides a good compromise between the accuracy of results and computation time. The minimum allowed value is 5.

Note: If one uses more than one quadrant, the total number of computations for  $J_d$  and  $J_q$  will be calculated based on the **No. comp. for current  $J_d$ ,  $J_q$**  input and the number of quadrants. For example, if **No. comp. for current  $J_d$ ,  $J_q$**  is set to 10 and the quadrant is set to "1st and 2nd", then the total number of computations for  $J_d$  is 10, but 19 for  $J_q$  considering  $J_d = 0$  is shared between both quadrants.

#### 1.3.4.5 Number of computations for speed

The number of computations for speed corresponds to the number of points to consider in the range of speed. It can be defined via the user input "**No. comp. for speed**" (*Number of computations for speed*). The default value is equal to 10. The minimum allowed value is 5.

#### 1.3.4.6 Skew model – Number of layers

When the rotor or the stator slots are skewed, the number of layers used in Flux® Skew environment to model the machine can be modified: "**Skew model - No. of layers**" (*Number of layers for modeling the skewing in Flux® Skew environment*).

#### 1.3.4.7 Mesh order

To get results, Finite Element Modeling computations are performed. The geometry of the machine is meshed. Two levels of meshing can be considered: First order and second order. This parameter influences the accuracy of results and the computation time. The default level is second order mesh.

#### 1.3.4.8 Airgap mesh coefficient

The advanced user input "**Airgap mesh coefficient**" is a coefficient that adjusts the size of mesh elements inside the airgap. When the value of "Airgap mesh coefficient" decreases, the mesh elements get smaller, leading to a higher mesh density inside the airgap and increasing the computation accuracy.

The imposed Mesh Point (size of mesh elements touching points of the geometry), inside the Flux® software, is described as:

$$\text{MeshPoint} = (\text{airgap}) \times (\text{airgap mesh coefficient})$$

Airgap mesh coefficient is set to 1.5 by default. The variation range of values for this parameter is [0.05; 2]. 0.05 giving a very high mesh density and 2 giving a very coarse mesh density.

#### Caution:

Be aware, a very high mesh density does not always mean a better result quality. However, this always leads to a huge number of nodes in the corresponding finite element model. So, it means a need of huge numerical memory and increases the computation time considerably.

#### 1.3.4.9 Rotor initial position mode - Note

The computations are performed by considering the relative angular position between the rotor and stator. This relative angular position corresponds to the angular distance between the direct axis of the rotor north pole and the axis of the stator phase 1 (reference phase). The value of the rotor d-axis location, which is automatically defined for each saliency part in Part Factory, can be visualized in the output parameters in the saliency area of the Motor Factory – Design environment.

## 1.4 Main principles of computation

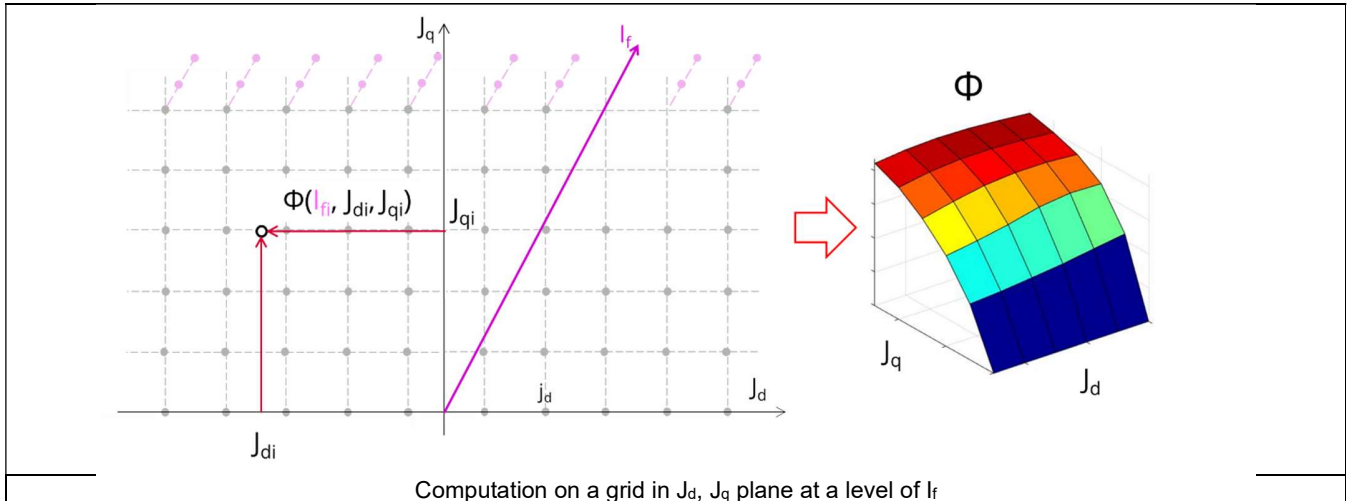
### 1.4.1 Flux linkage

One of the goals is to compute the D-axis and Q-axis flux linkage in the  $J_d$ ,  $J_q$  planes at different levels of  $I_f$  between zero and the maximum value of  $I_f$ .

To do that, a grid of values ( $J_d$ ,  $J_q$ ) is considered for all levels of  $I_f$ .

For each node of this grid, the corresponding flux linkage through each phase is extracted ( $\Phi_a$ ,  $\Phi_b$ ,  $\Phi_c$ ) through the corresponding phases (a, b, c). This is done using Finite Element modeling (Flux® software – Magnetostatic application).

**D-axis flux-linkage component -  $\Phi_d$  and Q-axis flux-linkage component -  $\Phi_q$**  are deduced according to Park's transformation.



Our modeling considers cross-saturation. However, winding harmonics and the variation of reluctance as a function of the angular position of the rotor are only considered if the “Rotor position dependency” input is “Yes”.

Note: The impact on accuracy will be more important for machines with high level of saturation.

*When the “Rotor position dependency” input is “No”, iron loss computations are based on both Finite Element modeling and an analytical method where leakage flux between stator teeth is neglected. In case of high level of saturation, this hypothesis leads to more errors, particularly in the area where the field is weakening.*

*When the “Rotor position dependency” input is “Yes”, iron loss computations are based on Finite Element modeling with all considerations for flux leakage.*

Note: In the examples shown in the images, negative value of  $J_d$  and positive value of  $J_q$  are considered as the 2nd quadrant is chosen as example. However, the considered quadrants can be chosen through dedicated input (e.g., user can choose all quadrants or only the 2nd, the 2nd and 3rd ones, etc.), allowing the characterization of the machine behavior for other control conditions.

Note: In case the “Rotor position dependency” is set to “Yes”, the computation is done in the three dimensions  $I_f - J_d - J_q$  with an additional fourth axis corresponding to the rotor position  $\theta_r$ .

### 1.4.2 Flux-linkage derivative respect to the rotor position

**D-axis flux-linkage derivative with respect to the rotor position -  $\Phi_d/d\theta_r$  and Q-axis flux-linkage derivative with respect to the rotor position -  $\Phi_q/d\theta_r$**  are computed from the flux linkage maps and using the following formula:

$$\frac{\Delta\Phi_d}{\Delta\theta_r}, \frac{\Delta\Phi_q}{\Delta\theta_r}$$

These maps are available only when the input Rotor position dependency is set to “Yes”. The computation is done in the three dimensions  $I_f - J_d - J_q$  with an additional fourth axis corresponding to the rotor position  $\theta_r$ .

Note 1: The rotor position derivative is always in radians per second to simplify the usage of this map while considering the Park's voltage equations.

### 1.4.3 Dynamic inductances

**D-axis synchronous inductance -  $L_{d-dynamic}$**  and **Q-axis synchronous inductance -  $L_{q-dynamic}$**  are computed from the flux linkage maps and using the following formulas:

$$L_{d-dynamic} = \frac{\Delta\Phi_d}{\Delta J_d} \quad L_{q-dynamic} = \frac{\Delta\Phi_q}{\Delta J_q}$$

Note 1: The end-winding leakage inductance  $L_{endw}$ , computed in the winding area, is included in the computation of D-axis and Q-axis flux-linkage. The values of the dynamic inductances  $L_{d-dynamic}$  and  $L_{q-dynamic}$  consider the value of the end-winding inductance.

Note 2: In the previous formula, one considers peak values for both flux and current.

Note 3: In case the Rotor position dependency is set to “Yes”, the computation is done in the three dimensions  $I_f - J_d - J_q$  with an additional fourth axis corresponding to the rotor position  $\theta_r$ .

### 1.4.4 Dynamic cross inductances

**D-axis synchronous cross inductance -  $L_{dq-dynamic}$**  and **Q-axis synchronous cross inductance -  $L_{qd-dynamic}$**  are computed from the flux linkage maps and using the following formula:

$$L_{dq-dynamic} = \frac{\Delta\Phi_d}{\Delta J_q} \quad L_{qd-dynamic} = \frac{\Delta\Phi_q}{\Delta J_d}$$

Note 1: The end-winding leakage inductance  $L_{endw}$ , computed in the winding area, is included in the computation of D-axis and Q-axis flux-linkage. However, the values of the dynamic cross inductances  $L_{dq-dynamic}$  and  $L_{qd-dynamic}$  are not impacted by the end-winding inductance value since they are obtained with the derivative of the D-axis and Q-axis flux-linkage with respect to current variation along the corresponding quadrature axis (Q-axis and D-axis, respectively).

Note 2: In the previous formula, one considers peak values for both flux and current.

Note 3: In case the Rotor position dependency is set to “Yes”, the computation is done in the three dimensions  $I_f - J_d - J_q$  with an additional fourth axis corresponding to the rotor position  $\theta_r$ .

### 1.4.5 Static inductances

**D-axis synchronous inductance -  $L_{d-static}$**  and **Q-axis synchronous inductance -  $L_{q-static}$**  are computed from the flux linkage maps and using the following formula:

$$L_{d-static} = \frac{(\Phi_d - \phi_0)}{\sqrt{2} \times J_d} \quad L_{q-static} = \frac{\Phi_q}{\sqrt{2} \times J_q}$$

$\phi_0$  is the D-axis magnetic flux linkage component when  $J_d$  equals zero. This term corresponds to the magnetic flux linkage created by the field current  $I_f$  added to the flux created by the cross effect of  $J_q$  along the q-axis. Its value is a function of  $J_q$  and  $I_f$ .

Note 1: The end-winding leakage inductance  $L_{endw}$ , computed in the winding area, is included in the computation of D-axis and Q-axis flux-linkage. The values of the static inductances  $L_{d-static}$  and  $L_{q-static}$  consider the value of the end-winding inductance.

Note 2: In the previous formula, one considers peak values for both flux and current.

Note 3: In case the Rotor position dependency is set to “Yes”, the computation is done in the three dimensions  $I_f - J_d - J_q$  with an additional fourth axis corresponding to the rotor position  $\theta_r$ .

### 1.4.6 Saliency

The saliency in the  $J_d$ - $J_q$  area is computed and displayed as a map in  $J_d$ - $J_q$  plane for all levels of  $I_f$ . This value corresponds to the ratio between q-axis and d-axis static inductances.

$$\text{Saliency} = \frac{L_{q-static}}{L_{d-static}}$$

Note: In case the Rotor position dependency is set to “Yes”, the computation is done in the three dimensions  $I_f - J_d - J_q$  with an additional fourth axis corresponding to the rotor position  $\theta_r$ .

### 1.4.7 Electromagnetic torque

The **Electromagnetic torque**  $T_{em}$  is computed in different ways as a function of the input Rotor position dependency value.

#### 1.4.7.1 Rotor position dependency set to “No”

The flux linkage maps, and the following formula are used:

$$T_{em} = \frac{m}{2} \times p \times (\Phi_d \times J_q - \Phi_q \times J_d)$$

Where  $m$  is the number of phases (3) and  $p$  is the number of pole pairs.  $J_d$  and  $J_q$  are the d and q axis peak currents.

#### 1.4.7.2 Rotor position dependency set to “Yes”

The **Electromagnetic torque**  $T_{em}$  is computed thanks to finite element computation and the virtual work method to get the best evaluation of the ripple torque.

Note: In case the Rotor position dependency is set to “Yes”, **Electromagnetic torque**  $T_{em}$  average value computed with the Park’s equation or with virtual works is equal.

### 1.4.8 Iron loss computation

The **iron losses** are computed in a different way as a function of the value of the “Rotor position dependency” input.

#### 1.4.8.1 Rotor position dependency set to “No”

A dedicated process has been developed to compute the **stator iron losses** (rotor iron losses are not computed).

Stator iron losses are computed only for the stator magnetic circuit built with lamination material (computation is not applicable for solid materials).

Our method of computation doesn’t allow for computing iron losses on the rotor side. However, iron loss level is generally not very important on the rotor side in comparison with iron losses on the stator side.

For each node of the grid, in the three dimensions  $J_d$ - $J_q$ - $I_r$  defined and illustrated above, magnetic flux densities in stator teeth are obtained from a dedicated semi-numerical method based on the integration of the flux density in the airgap.

For each considered region (foot teeth, teeth, and yoke), we get the magnetic flux density as a function of the angular position. Then, the derivative of each magnetic flux density is computed as a function of the angular position.

At last, for each considered speed, a mathematical transformation is applied to get the derivative of magnetic flux density as a function of time.

$$\frac{dB}{dt}(t) = \frac{dB}{d\theta}(\theta) \times \frac{d\theta}{dt}$$

Total iron losses are computed considering the magnetic circuit volume, the density of materials used, and the stacking coefficient considered for the stator lamination.

#### 1.4.8.2 Rotor position dependency set to “Yes”

The **iron losses, stator, and rotor** are computed thanks to the magnetostatic application of Flux (Finite Element modeling - MS FE) based on the magnetic flux derivative obtained over the finite element meshing.

The accuracy obtained is the same as the one with a magnetic transient finite element computation (MT FE) and for a given scenario, the MS FE computation time is approximately reduced by a factor 2 times lower than MT FE.

### 1.4.8.3 Model used to compute iron losses.

The model used to compute iron losses ( $W_{\text{iron}}$ ) is:

$$W_{\text{iron}} = \left[ \left( K_h \cdot \left( \frac{B_{\text{max}}}{K_f} \right)^{\alpha_h} \cdot f^{\beta_h} \right) + \left( K_c \cdot \frac{1}{T_{\text{elec}}} \cdot \int_0^{T_{\text{elec}}} \left[ \frac{\left( \frac{dB}{dt} \right)}{K_f} \right]^{\alpha_c} dt \right) + \left( K_e \cdot \frac{1}{T_{\text{elec}}} \cdot \int_0^{T_{\text{elec}}} \left[ \frac{\left( \frac{dB}{dt} \right)}{K_f} \right]^{\alpha_e} dt \right) \right] \cdot V_{\text{iron}} \cdot K_f$$

With:

$B_{\text{max}}$ : Peak value of the magnetic flux density (T)  
 $f$ : Electrical frequency (Hz)  
 $V_{\text{iron}}$ : Stator core lamination volume  
 $K_f$ : Stacking factor.

The other parameters of this model are defined in the application dedicated to materials in FluxMotor®, i.e., “Materials”.

Note: In case the “Rotor position dependency” input is set to “No”, the impact on accuracy will be more important for a machine with a high level of saturation. In fact, the semi-numerical method used to compute the magnetic flux density of the stator teeth neglects flux leakage between teeth. This hypothesis will lead to more errors, particularly in areas where there is field weakening (generally applicable at high speeds).

### 1.4.9 Stator Joule losses

Joule losses in stator winding  $W_{\text{Cus}}$  are computed using the following formula:

$$W_{\text{Cus}} = m \times R_{\text{ph}} \times (J)^2$$

$$\underline{J} = J_d + jJ_q$$

$$|\underline{J}| = J = \sqrt{J_d^2 + J_q^2}$$

Where  $m$  is the number of phases (3 in the first version of FluxMotor®),  
 $J$  is the rms value of the phase current ( $I$  is the line current.  $I = J$  with a Wye winding connection),  
 $R_{\text{ph}}$  is the phase resistance computed according to the temperatures defined by user in the test settings.

Note 1:  $R_{\text{ph}}$  considers the resistance factor defined in the winding settings (DESIGN area of Motor Factory).

### 1.4.10 Rotor Joule losses

Joule losses in rotor winding  $W_{\text{Cur}}$  are computed using the following formula:

$$W_{\text{Cur}} = R_r \times I_f^2$$

$I_f$  is the DC value of the field current,  
 $R_r$  is the field resistance computed according to the temperatures defined by user in the test settings.

Note 1:  $R_r$  considers the resistance factor defined in the winding settings (DESIGN area of Motor Factory).

### 1.4.11 Mechanical losses

The mechanical losses are computed as a function of the speed.

For more details, please refer to the document: MotorFactory\_SMPM\_IOR\_3PH\_Test\_Introduction – section “Mechanical loss model settings.”

### 1.4.12 Total losses

For each considered value of speed and currents  $J_d$ ,  $J_q$ ,  $I_f$  the amount of losses described above (Stator iron loss, Joule loss, and mechanical losses) are computed and displayed.

Note: In case the Rotor position dependency is set to “Yes”, the computation is done in the three dimensions  $I_f - J_d - J_q$  with an additional fourth axis corresponding to the rotor position  $\theta_r$ .

## 1.5 Test results

Once a test is finished, the corresponding results are automatically displayed in the central window.

### 1.5.1 Test conditions

#### 1.5.1.1 Inputs

All the parameter values belonging to standard inputs or advanced inputs are described in this section. It shows the initial conditions considered for the test.

Here are the displayed subsections:

- Context
- Standard parameters
- Advanced parameters

For more information refer to the section 1.3 (Inputs).

#### 1.5.1.2 Settings

All the settings dedicated to the test and dealing with the thermal are displayed in this section.

Here are the displayed subsections:

- Thermal
- Electronics
- Mechanics

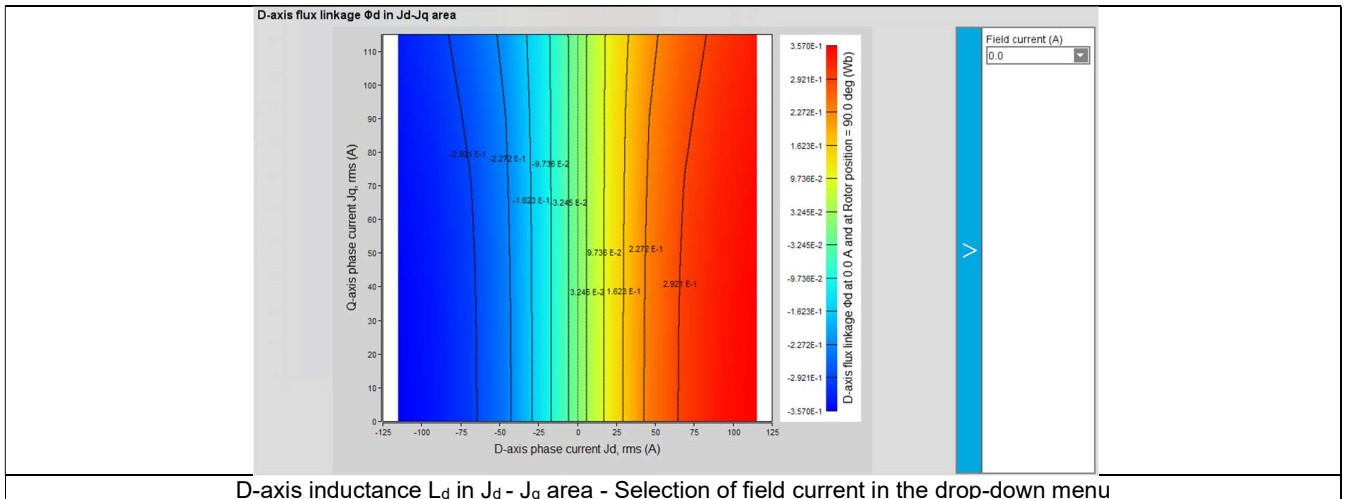
#### 1.5.1.3 Winding characteristics

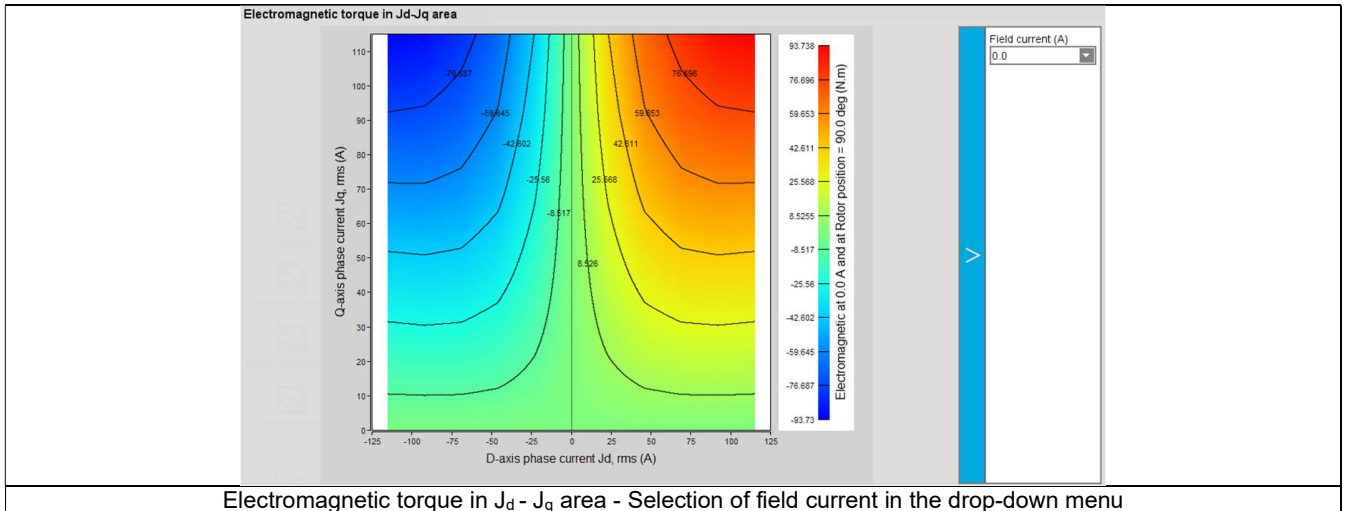
All the winding characteristics are displayed (for all the winding, end-windings, and straight parts).

For more details, please refer to the document: MotorFactory\_SMPM\_IOR\_3PH\_Test\_Introduction – sections dealing with settings.

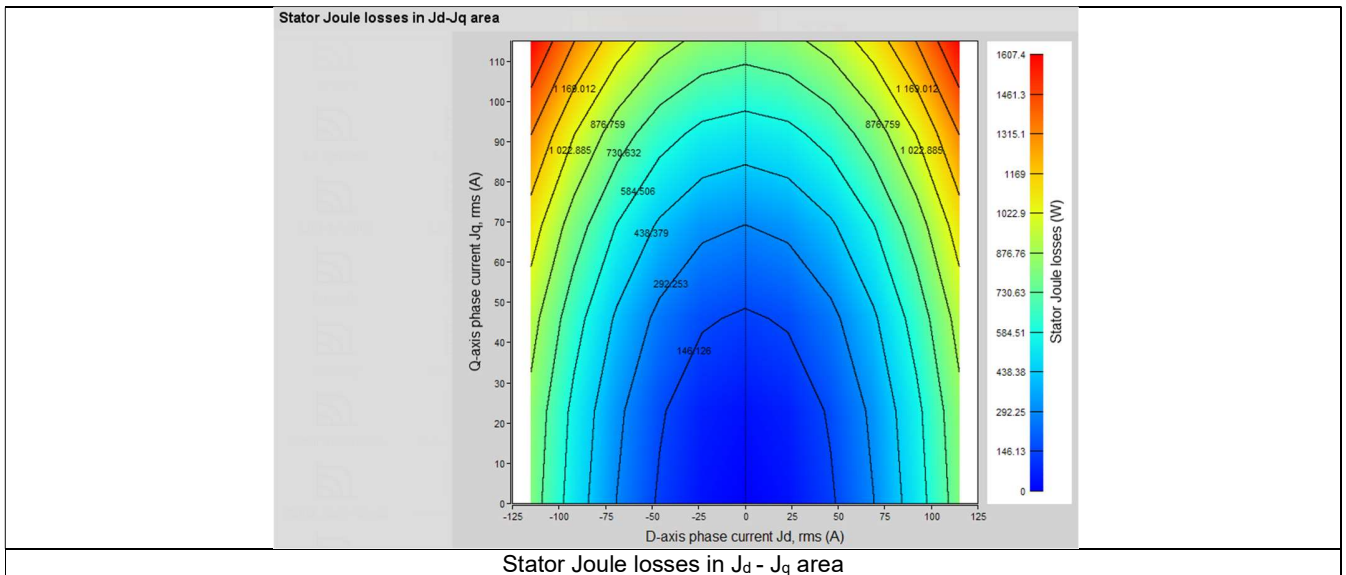
### 1.5.2 Maps

Maps illustrating the following quantities ( $\Phi_d$ ,  $\Phi_q$ ,  $\Phi_d/d\theta_r$ ,  $\Phi_q/d\theta_r$ ,  $L_d$ -dynamic,  $L_q$  dynamic,  $L_d$ -dynamic,  $L_q$  dynamic,  $L_d$ -static,  $L_q$  static, saliency, torque) are displayed in the  $J_d$ - $J_q$  plane with a drop-down menu allowing to pick the desired value of  $I_r$  field current.

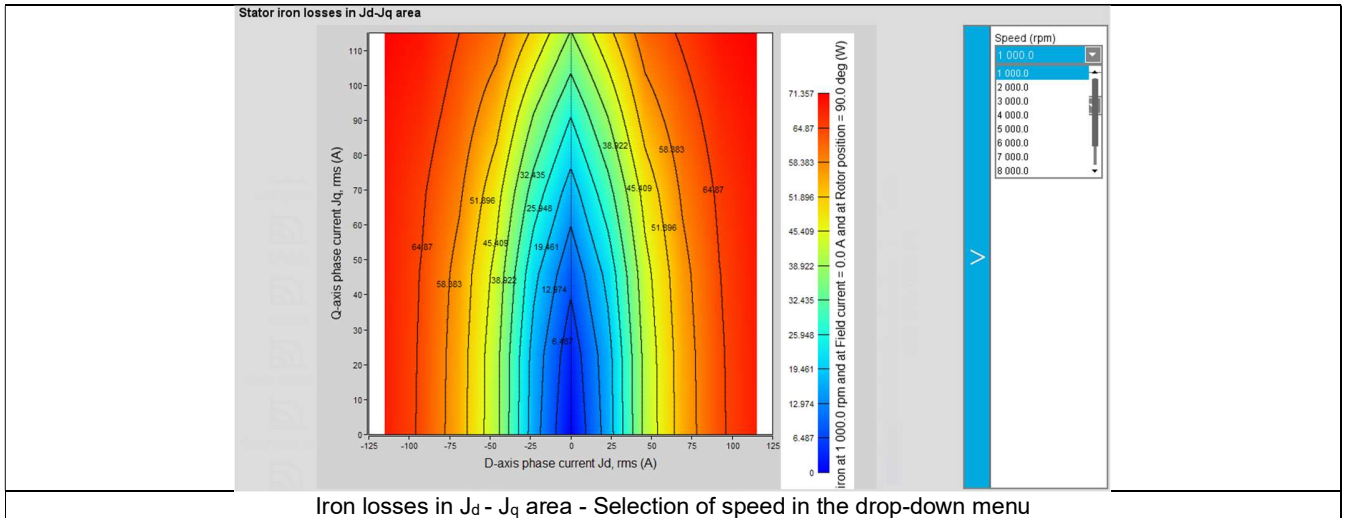




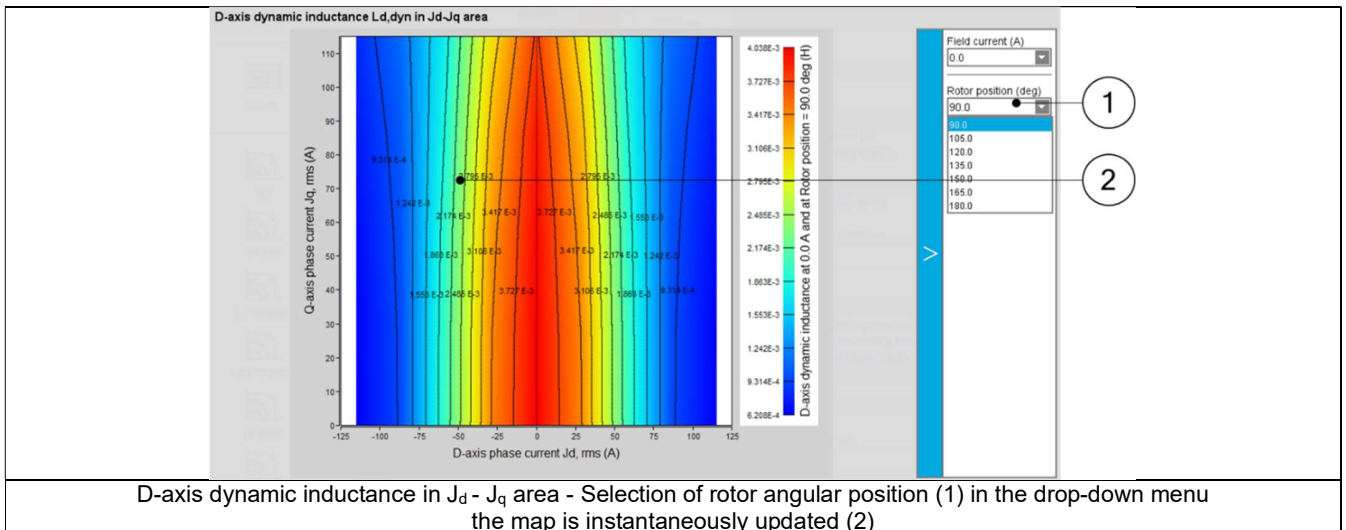
Joule loss maps and power electronic loss maps are displayed in the J<sub>d</sub>-J<sub>q</sub> plane without the selection of field current because they are independent of field current.



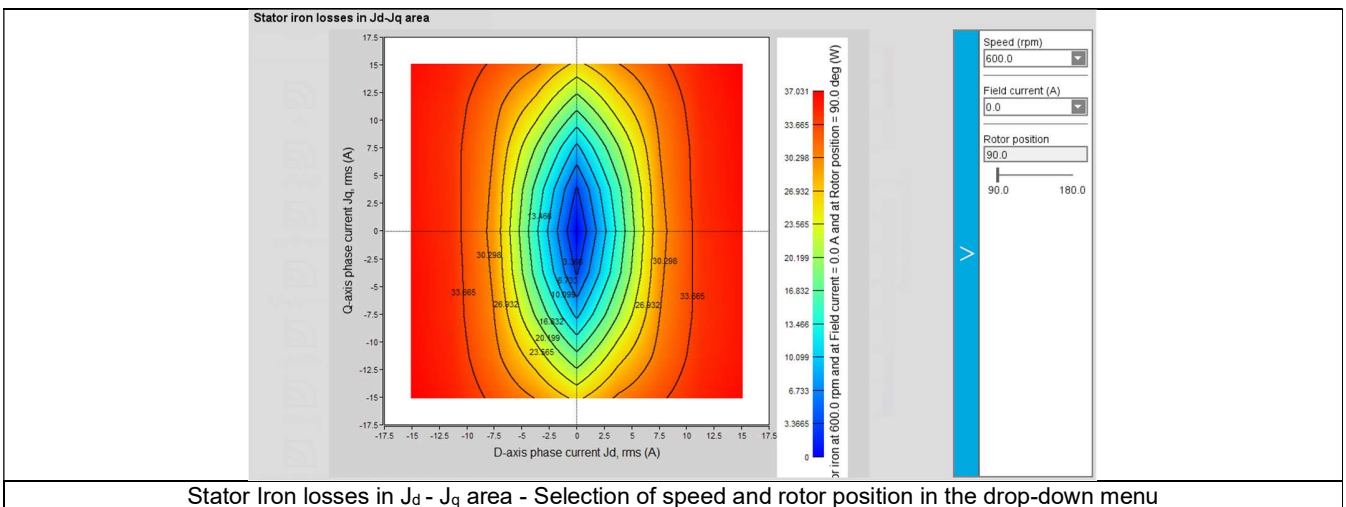
Iron loss maps, total loss maps, and power electronics loss maps are displayed in the J<sub>d</sub>-J<sub>q</sub> plane, and they are also parameterized as a function of field current and speed. The desired field current and speed can be chosen in the drop-down menu on the right of the graph (close to the legend).



Illustrations of results depending on the user's inputs dealing with the Rotor position dependency ("Yes" or "No"). In case the Rotor position dependency is set to "Yes", computations are done in the three dimensions  $J_d - J_q - I_f$  with an additional fourth axis corresponding to the rotor position  $\theta$ .



The results depend on the selected operating quadrants ("2nd and 3rd", "1st and 2nd" or "all"). An example is presented below.





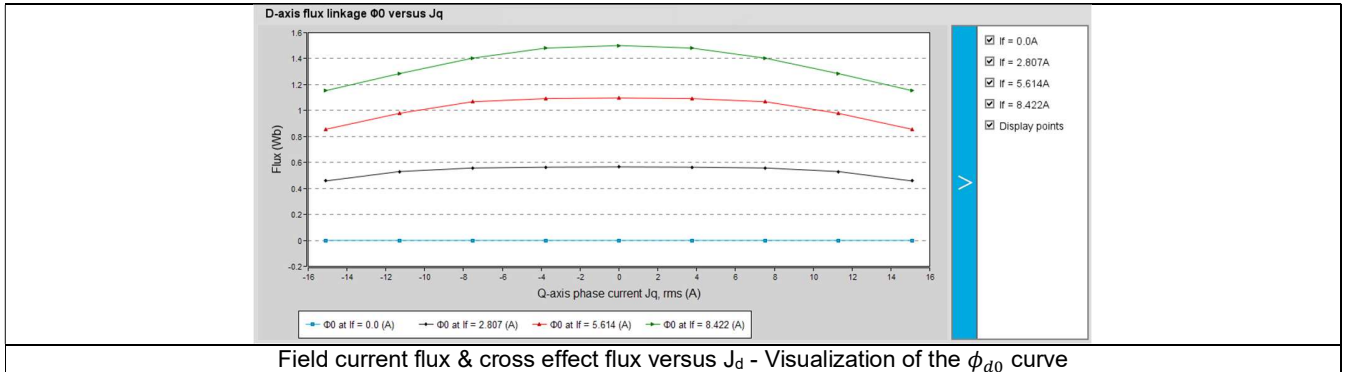
### 1.5.3 Curves

#### 1.5.3.1 Field current flux and cross effect flux curve

Curves showing the evolution of field current flux added by magnetic flux provided by  $J_d$  along the q-axis at different levels of field current  $I_f$  are displayed.

The maximum line current and field current considered are the ones defined in the test input parameters.

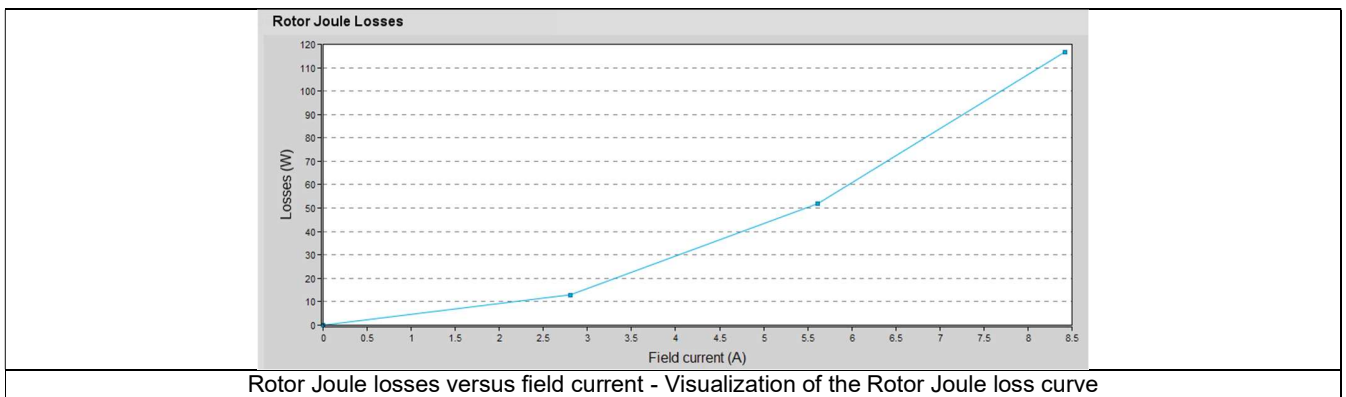
One can choose to display curves corresponding to the levels of field current  $I_f$  by checking the desired value of  $I_f$ .



#### 1.5.3.2 Rotor Joule losses

A curve showing the evolution of rotor Joule losses versus field current is displayed.

The maximum field current considered is the one defined in the test input parameters.



#### 1.5.3.3 Mechanical losses

A curve showing the evolution of mechanical losses versus speed is displayed.

The maximum speed considered is the one defined in the test input parameters.

