Altair® FluxMotor® 2024

Induction machines – Squirrel cage - Inner & Outer rotor

Motor Factory – Test – Performance mapping

General user information

Contents

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1   PERFORMANCE MAPPING – SINE WAVE – MOTOR – T(Slip)

1.1   Overview

1.1.1   Positioning and objective

The aim of the test "**Performance Mapping – Sine wave – Motor – T(Slip)**" is to characterize the behavior of the machine when operating over a speed range corresponding to a targeted operating mode ("Motor", "Generator", "Brake", "Motor & Generator", "Motor & Brake" and "Full"). This also corresponds with the operating magnitude of line-line voltage (U) and power supply frequency input values (f). Hence, these inputs are enough to define a T(Slip) curve and to get additional curves defining all electromagnetic quantities.
Note: In addition, the input "user working point - slip" allows to target a specific working point to get all the corresponding electromagnetic quantities summarized in a table.

"Performance mapping – Sine wave – Motor – T(Slip)" Illustration
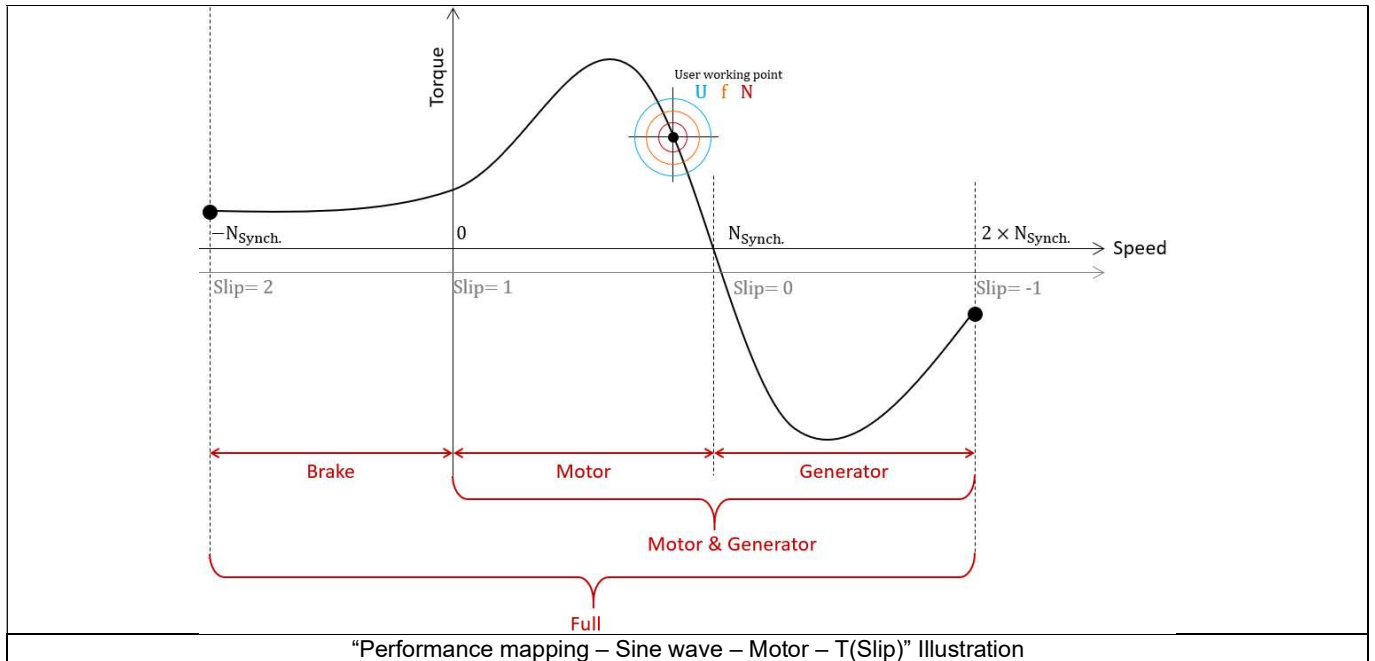
The results of this test give an overview of the electromagnetic behavior of the machine considering its topology.
For one or more operating modes, the general data of the machine, like mechanical torque, currents, power factor and power balance are computed and displayed as curves.

Note: The considered used convention is the motor one.

For the targeted user working point, in addition to the general data, machine constants, flux in airgap and the magnetic flux density in every regions of the machine's magnetic circuit are also computed for evaluating the design of the machine.
It also gives the capability to make comparisons between results got from the measurements and those got with the Altair® FluxMotor®.

The following table helps to classify the test "Performance mapping – Sine wave – Motor – T(Slip)".

Family	Performance mapping
Package	Sine wave
Convention	Motor
Test	T(Slip)

Positioning of the test "Performance mapping – Sine wave – Motor – T(Slip)"

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1.1.2   User inputs

The four main user input parameters are the supplied Line-Line voltage, the power supply frequency, the operating mode and the slip at the targeted working point. In addition, temperatures of winding and squirrel cage must be set.

1.1.3   Main outputs

Test results are illustrated with data, graphs, and tables

1.1.3.1   Tables of results

The number of sections where machine performance is displayed depends on the "Operating mode" which is selected. The following table summarize the different cases.

Operating mode	Starting torque	Break down torque, Motor mode	User working point	Break down torque, Generator mode	Minimum braking torque
Motor	X	X	X		
Generator			X	X	
Brake	X				X
Motor & Generator	X	X	X	X	
Full	X	X	X	X	X

In all these sections, the machine performances are illustrated with the same outputs:

- General data
- Machine constants
- Power balance
- Flux in airgap
- Flux density in iron

1.1.3.2   Curves

1) Mechanical torque versus slip
2) Stator current versus slip
   3) Efficiency versus slip
   4) Power factor versus slip
   5) Power balance versus slip
   6) Losses versus slip
   7) Iron losses versus slip
   8) Joule losses versus slip
   9) Current density versus slip

1.2   Settings

Three buttons give access to the following setting definition:

- Temperature of active components: winding and squirrel cage

- Definition of the power electronics parameters
      Inverter control strategy
      Inputs for evaluating the power electronics stage losses

- Definition of mechanical loss model parameters

For more details, please refer to the document: MotorFactory_IMSQ_IOR_3PH_Test_Introduction.

1.3 Inputs

1.3.1 Introduction

The total number of user inputs is equal to 10.
Among these inputs, 4 are standard inputs and 7 are advanced inputs.

1.3.2 Standard inputs

1.3.2.1 Line-Line voltage, rms

The rms value of the Line-Line voltage supplying the machine: "**Line-Line voltage, rms"** (*Line-Line voltage, rms value*) must be provided.
Note: The number of parallel paths and the winding connection are automatically considered in the results.

1.3.2.2 Power supply frequency

The value of the power supply frequency of the machine: "**Power supply frequency**" (*Power supply frequency*) must be provided.
The power supply frequency is the electrical frequency applied at the terminals of the machine.

1.3.2.3 Operating mode

The computation of the test « **Performance Mapping / Sine Wave / Motor / T(Slip)** » is performed by considering the machine operating mode. The selected operating mode can be "Motor", "Generator", "Brake", "Motor & Generator", "Motor & Brake" or "Full". According to the operating mode the resulting range of slip is automatically defined as illustrated in the following table.

Operating mode	Resulting range of Slip
Motor	[0,1]
Generator	[-1,0]
Brake	[1,2]
Motor & Generator	[-1,1]
Full	[-1,2]

Note: The considered used convention is the motor one.

1.3.2.4 User working point - Slip

The value of the targeted slip for the user working point "**User working point - Slip"** (*Slip at the targeted working point*) must be provided. This value must be in the range of slip corresponding to the selected operating mode.

1.3.3   Advanced inputs

1.3.3.1   Slip distribution mode

The computation of the test « **Performance Mapping / Sine Wave / Motor / T(s)** » is performed by considering a distribution of computed points. The user's input "**Slip distribution mode**" (*Select the method for the distribution of computed points*) gives three possibilities to the user:

1) Slip distribution mode = Logarithmic

When "Logarithmic" is selected, the distribution of the computed points is automatically done. The number of computations to be done in the slip range must be set in the next field: "No. comp. in slip range".

2) Slip distribution mode = Linear

When "Linear" is selected, the distribution of the computed points is automatically done. The number of computations to be done in the slip range must be set in the next field: "No. comp. in slip range".

3) Slip distribution mode = Table

When "Table" is selected, the list of slips to be considered must be defined by using the next field: "Slip table" and by clicking on the button "Set values".
Two ways are possible to fill the table: either filling the table line by line or by importing an excel file where all the slips to be considered are defined.
Note: The slips must be listed in ascending order.

INPUTS	
Line-Line voltage, rms (V)	200.0
Power supply frequency (Hz)	50.0
Operating mode	Motor
User working point - Slip (%)	5.0
Slip distribution mode	Table
No. comp. in slip range	-
Slip table	*Set values
Rotor initial position (deg)	0.0
Mesh order	2nd
Airgap mesh coefficient	1.5

Slip distribution mode = Table

1	Select the "Table" option.
2	Click the button "Set values" of the field "Slip table" to open a dialog box to define the list of slips to be considered. Refer to the next illustration which shows how to fill the Slip table.
3	Button to validate and consider the user inputs
4	Button to run the computation
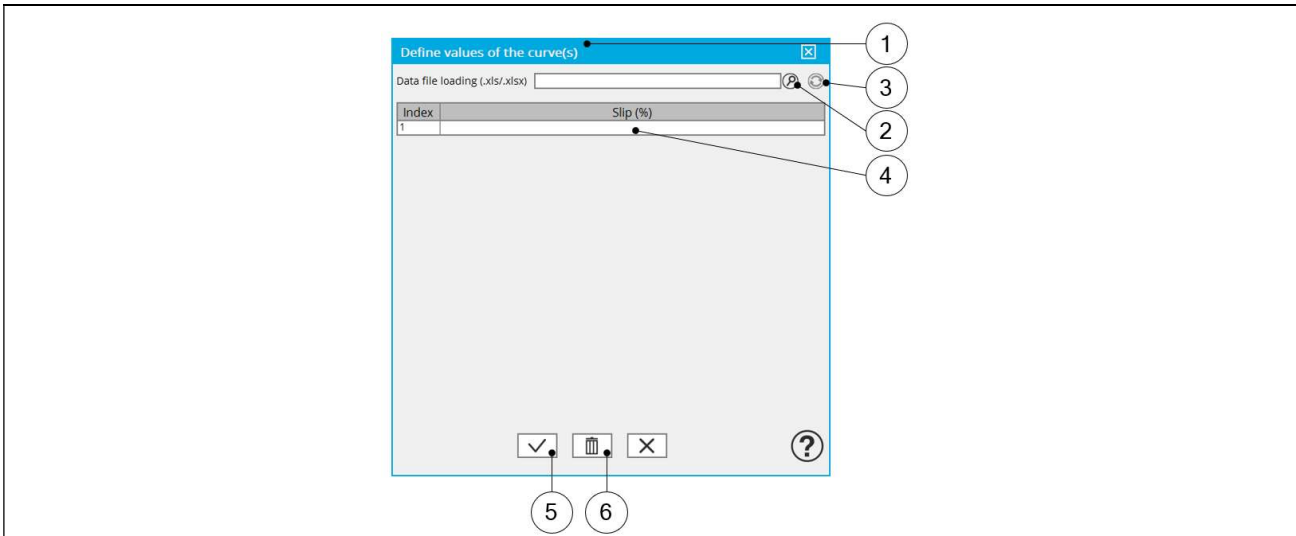
	Slip distribution mode = Table – Dialog box to define the list of slips
1	Dialog box opened after clicked on the button "Set values" in the field "Slip table"
2	Browse the folder to select an Excel file which is defined the list of slips
3	Button to refresh the table data when the considered Excel file has been modified
4	Fields to be filled with data to describe the considered slips
5	Button to apply the inputs
6	Button to erase the data table

Note: The Excel template used to import a list of slips is stored in the folder Resource/Template in the installation folder of FluxMotor®. An example of this template is displayed below.

Excel file template to define the list of slips

Note: The slips must be listed in ascending order.

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1.3.3.2   Number of computations in slip range

When the slip distribution mode is "Logarithmic" or "Linear", the "**No. comp. in slip range**" (*Number of computations for the whole domain corresponding to the slip range*) must be provided.
This parameter influences the accuracy of results and the computation time.

Note 1: The default value is equal to 15 when the selected operating mode is "**Motor**" or "**Generator**" or "**Brake**",
The default value is equal to 29 when the selected operating mode is "**Motor & Generator**" or "**Motor & Brake**"
The default value is equal to 44 when the selected operating mode is "**Full**".

Note 2: The minimum value allowed is 7.

Note 3: Default values are chosen to get a good compromise between the accuracy of results and computation time

1.3.3.3   Slip table

When the choice of point distribution mode is "**Table**", the list of slips to be considered "**Slip table**" (*Slip table*) must be provided. Refer to the above section 3) Slip distribution mode = Table

1.3.3.4   Skew model – No. of layers

When the rotor bars 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 modelling the skewing in Flux® Skew environment*).

1.3.3.5   Rotor initial position

The initial position of the rotor considered for computation can be set by the user in the field « **Rotor initial position** » (*Rotor initial position*). The default value is equal to 0.
The range of possible values is [-360, 360].

The rotor initial position has an impact only on the induction curve in the air gap.

1.3.3.6   Mesh order

To get the results, the original computation is performed by using a Finite Element Modeling. The geometry of the machine is automatically meshed.
Two levels of meshing can be considered for this finite element calculation: first order and second order.
This parameter influences the accuracy of results and the computation time.

By default, second order mesh is used.

1.3.3.7   Airgap mesh coefficient

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

1.4   Main principles of computation

1.4.1   Introduction

The aim of this test is to give a quick overview of the electromagnetic potential of the machine (in motor convention) by characterizing performance over a speed range corresponding to a targeted operating mode and according to the line-line voltage and the power supply frequency.

The computation process is based on finite element modelling (Flux® software - Steady state AC application).

1.4.2   General data

The computation process is based on finite element modelling Flux® software - Steady state AC application).
The general performances are computed over the considered slip range and by considering the line-line voltage and power supply frequency.
The computation process considers the complex values of current and voltage. Moreover, these quantities are computed by considering the symmetrical component transformation.
Then, the power balance which includes stator and rotor iron losses, are computed.

$$\begin{bmatrix} J_d \\ J_i \\ J_0 \end{bmatrix} = \frac{1}{3} \cdot \begin{bmatrix} 1 & a & a^2 \\ 1 & a^2 & a \\ 1 & 1 & 1 \end{bmatrix} \cdot \begin{bmatrix} J_a \\ J_b \\ J_c \end{bmatrix} \qquad a = e^{\frac{j.2.\pi}{3}}$$

Computation process with symmetrical component transformation
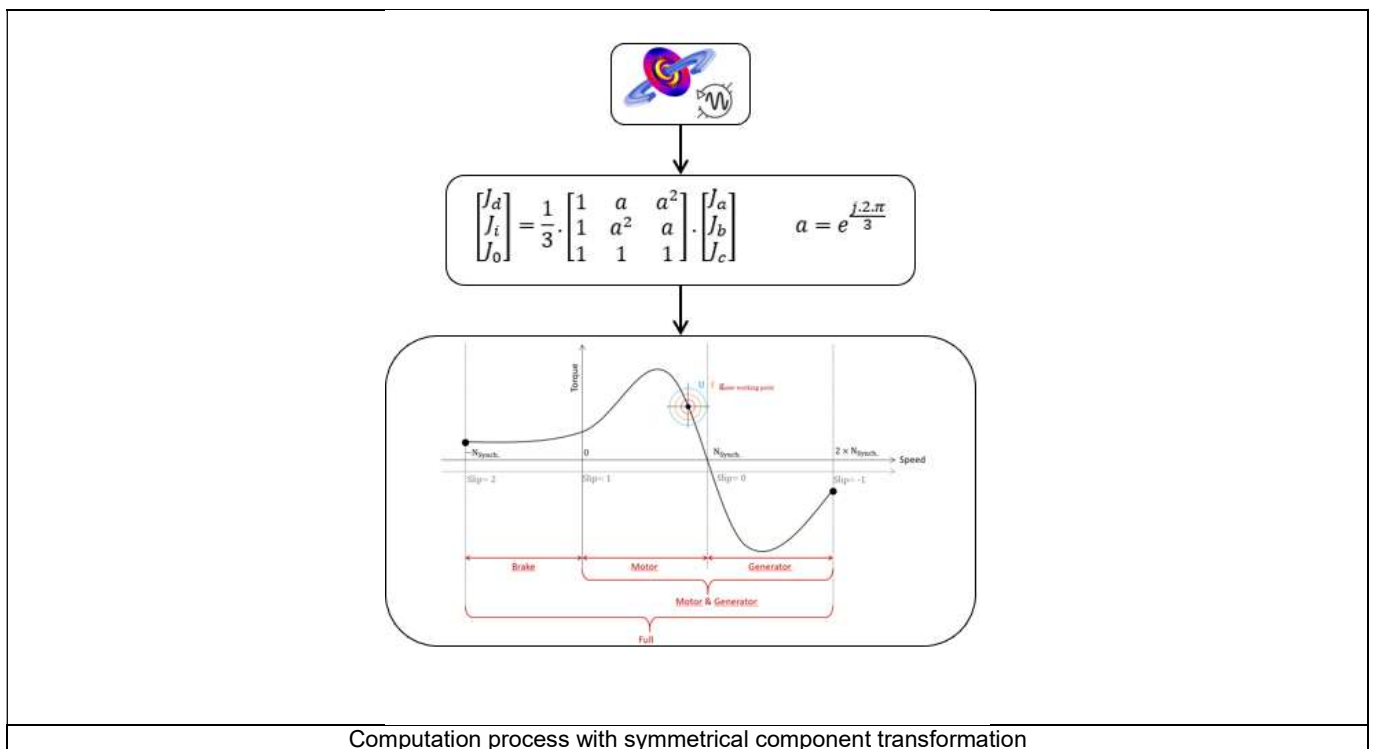
The use of the symmetrical component transformation is a key point.
Indeed, when using finite element modelling with Steady state AC application, each phase of the machine sees different airgap reluctance (due to the fixed rotor position) which generates indirect currents in the stator phases.
It is not a physical phenomenon because, over an electrical period, each phase sees the same air gap reluctance variation.
So, a correction must be done by using symmetrical component transformation which allows to get only the direct component of current and voltage.
Then, power balance and all electromagnetic quantities can be calculated accurately.

1.4.3   Operating modes

1.4.3.1   Overview

Different operating modes are addressed: "Motor, "Generator" and "Brake".
The following graph presents specifications of each mode:

"Performance mapping – Sine wave – Motor – T(Slip)" – Operating mode specifications
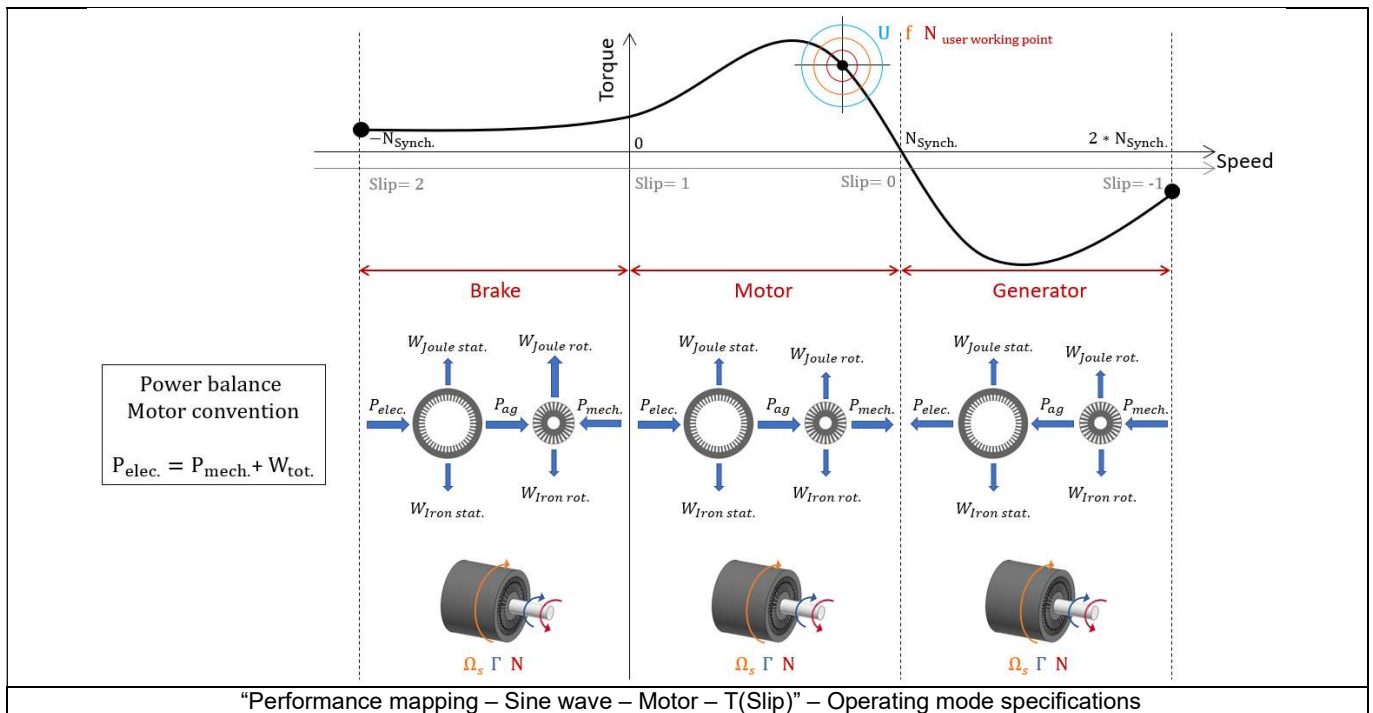
1.4.3.2   Motor mode

In motor mode, the torque is positive « $\Gamma > 0$ » and the speed is positive « $N > 0$ », so, the resulting mechanical power is also positive « $P_{mech.} > 0$ ». As the motor convention is used, the electrical power is regarded to be positive « $P_{elec.} > 0$ ». According to the power flow, the electrical power is greater than the mechanical power « $P_{elec.} > P_{mech.}$ ».

Note: The integration of iron losses into the power balance as well as the consideration of mechanical losses can lead to a negative mechanical power. In this case, there are too many losses to provide mechanical power. So, the operating points involved are assumed physically unreachable, therefore it is not displayed.

1.4.3.3   Generator mode

In generator mode, the torque is negative « $\Gamma < 0$ » and the speed is positive « $N > 0$ », so, the resulting mechanical power is also negative « $P_{mech.} < 0$ ». As the motor convention is used, the electrical power is regarded to be negative « $P_{elec.} < 0$ ». According to the power flow, if we look at the electrical and the mechanical power in absolute values, the mechanical is greater than the electrical $|P_{elec.}| < |P_{mech.}|$.

Note: The integration of iron losses into the power balance as well as the consideration of mechanical losses can lead to a positive electrical power. In this case, there are too many losses to provide electrical power, so, the operating points involved are assumed physically unreachable and are therefore not displayed.

1.4.3.4   Brake mode

In brake mode, the torque is positive « $\Gamma > 0$ » and the speed is negative « $N < 0$ », so, the resulting mechanical power is also negative « $P_{mech.} < 0$ ». As the motor convention is used, the electrical power is regarded to be positive « $P_{elec.} > 0$ ». According to the power flow, the electrical power is greater than the mechanical power « $P_{elec.} > P_{mech.}$ » and all of those are dissipated as losses "$W_{Joule\ stat.}, W_{Joule\ rot.}, W_{iron\ stat.}$ and $W_{iron\ rot.}$".

Note: The integration of iron losses into the power balance as well as the consideration of mechanical losses can lead to a positive mechanical power. In this case, there are not enough losses generated to dissipate an electrical and mechanical power. So, the operating points involved are assumed physically unreachable and therefore not displayed.

1.4.4   Electromagnetic behavior

1.4.4.1   Flux in airgap

The flux in the airgap is always computed using the dedicated magneto-harmonic computation at the working point.

The airgap flux density is computed along a path in the airgap in Flux® software. The resulting signal is obtained over an electric period. The average and the peak value of the flux density are also computed. A harmonic analysis of the flux density in airgap versus rotor position is done to compute the magnitude of the first harmonic flux density.

1.4.4.2   Flux density in iron

Mean and maximum values of flux density of each iron region are computed using sensors in Flux® software.

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 details, please refer to the document: MotorFactory_IMSQ_IOR_3PH_Test_Introduction.

1.5.1.2   Settings

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

- Thermal
- Electronics
- Mechanics

1.5.1.3   Winding and squirrel cage characteristics

All winding and squirrel cage characteristics are displayed in the following subsections:

- Winding characteristics
- Squirrel cage characteristics

1.5.2   Main results

1.5.2.1   Machine performance – Starting torque

For all the considered working point (Starting torque, Break down torque - Motor mode, Break down torque - Generator mode, Minimum breaking torque or User working point) the output data is displayed.

Here are the displayed subsections:

- General data
- Machine constants
- Power balance
- Flux in airgap
- Flux density in iron

1.5.2.2   Power electronics

- Inverter

When power electronics stage is selected by the user, the inverter control strategy and the DC bus voltage are reminded. For information, the corresponding maximum line-line voltage rms value is computed and displayed.

- Working point

The power balance and the corresponding efficiencies are computed and displayed for the machine, the power electronics stage and for the system (i.e. machine + power electronics stage).

For more details, please refer to the document: MotorFactory_IMSQ_IOR_3PH_Test_Introduction.

1.5.3   Curves

- Mechanical torque versus slip
- Stator current versus slip
- Efficiency versus slip
- Power factor versus slip
- Power balance versus slip
- Losses versus slip
- Iron losses versus slip
- Joule losses versus slip
- Current density versus slip

2   PERFORMANCE MAPPING – SINE WAVE – MOTOR – EFFICIENCY MAP SCALAR U-f

2.1   Overview

2.1.1   Positioning and objective

The aim of the test "**Performance mapping – Sine wave – Motor – Efficiency map scalar U-f**" is to characterize the behavior of the machine in the "Torque-Speed" area.
Input parameters like, "the maximum Line-Line voltage, the rated power supply frequency, the maximum line current and the maximum speed" of the machine are considered.

One type of command mode is available: scalar command.
Input parameters define the torque-speed area in which the evaluation of the machine behavior is performed.

Characterization of the corner point on the torque-speed curve
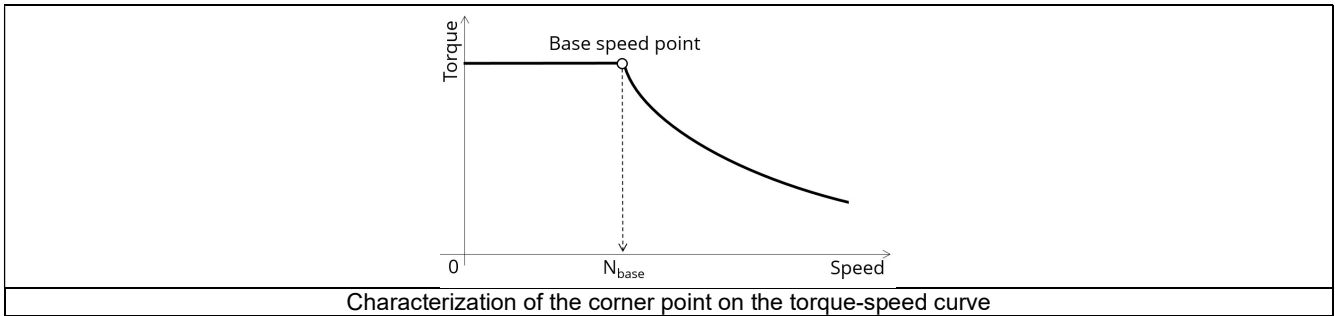
In the results, the performance of the machine at the base point (base speed point) and at the maximum speed (maximum speed point), set by the user are presented.
A set of curves (like Torque-Speed curve) and maps (like Efficiency map) are computed and displayed.

Mechanical torque versus speed - Example

Efficiency in torque-speed area - Example

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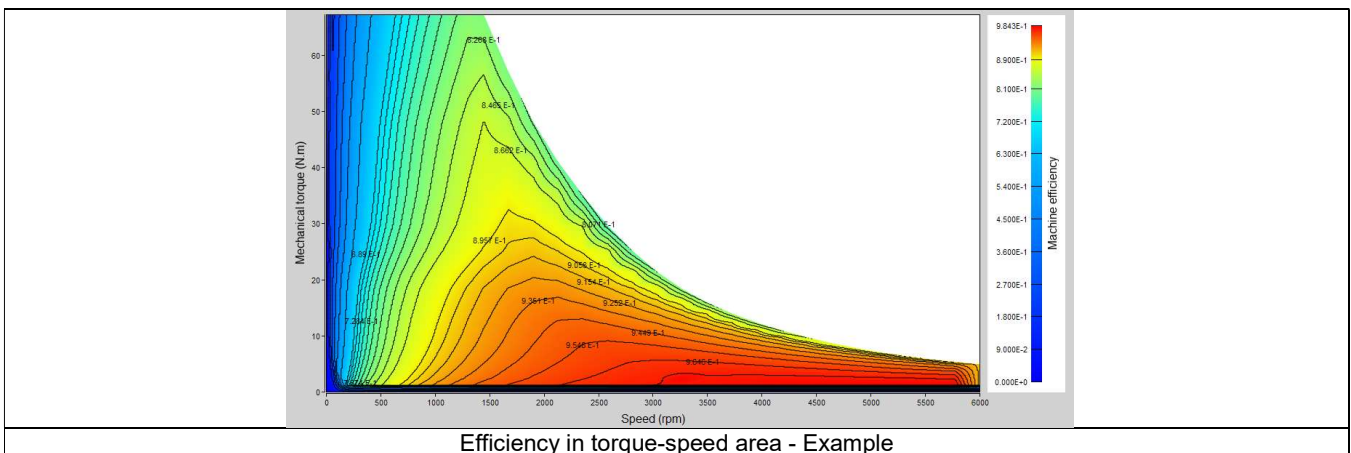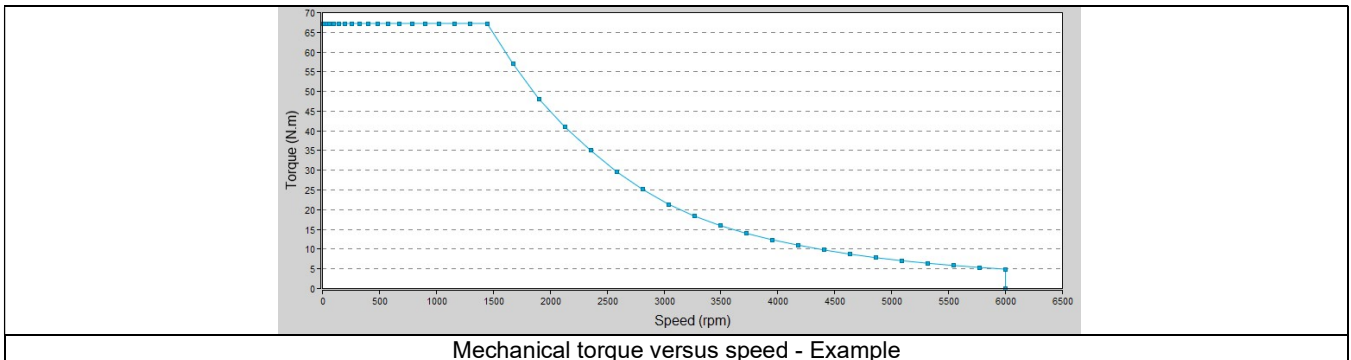
Note: Additional graphs provide an interesting overview on some topics such as, "Normalized base point curves", "Normalized torque-speed curves" and "Voltage boost at low speed". These results help the user to understand the possible performance of the machine in its electric environment.
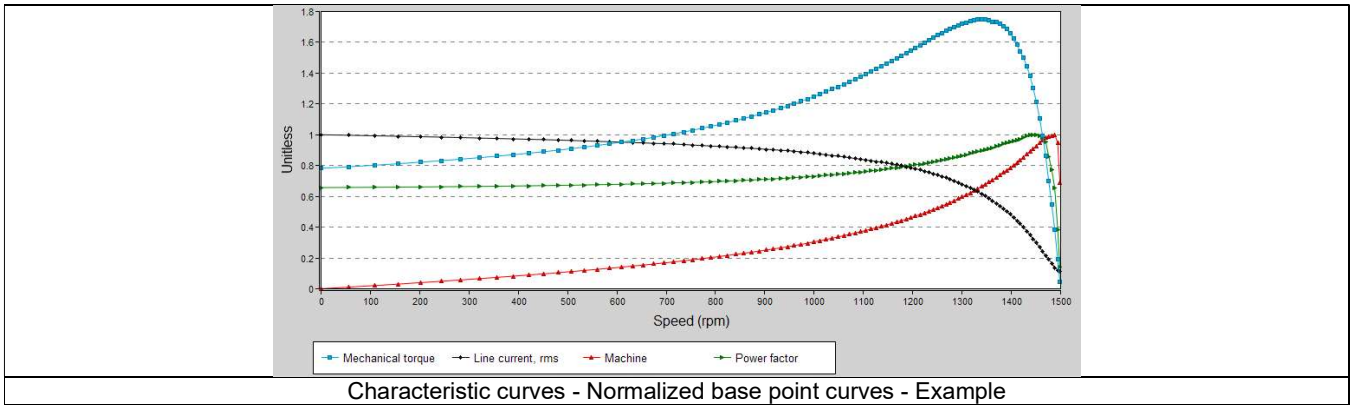
Characteristic curves - Normalized base point curves - Example
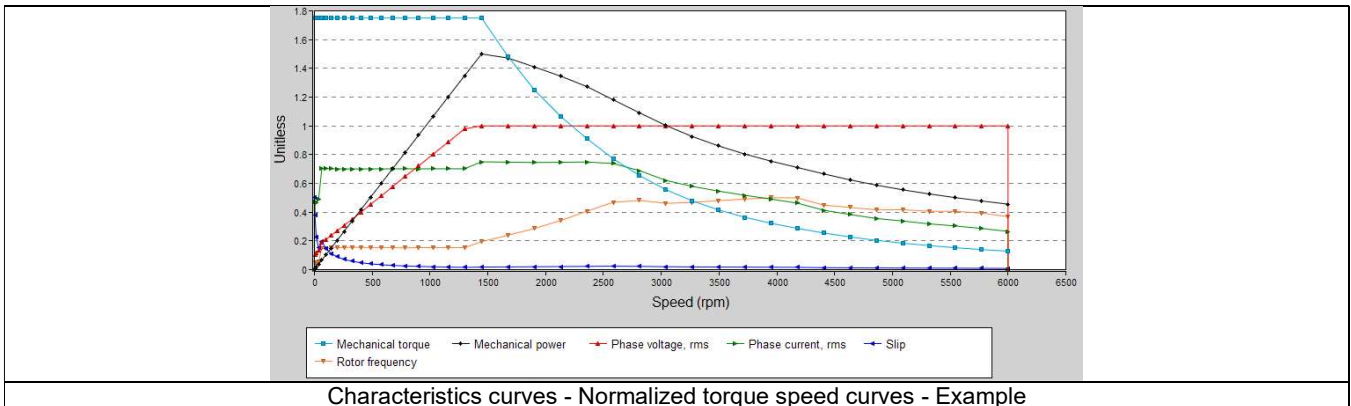
Characteristics curves - Normalized torque speed curves - Example
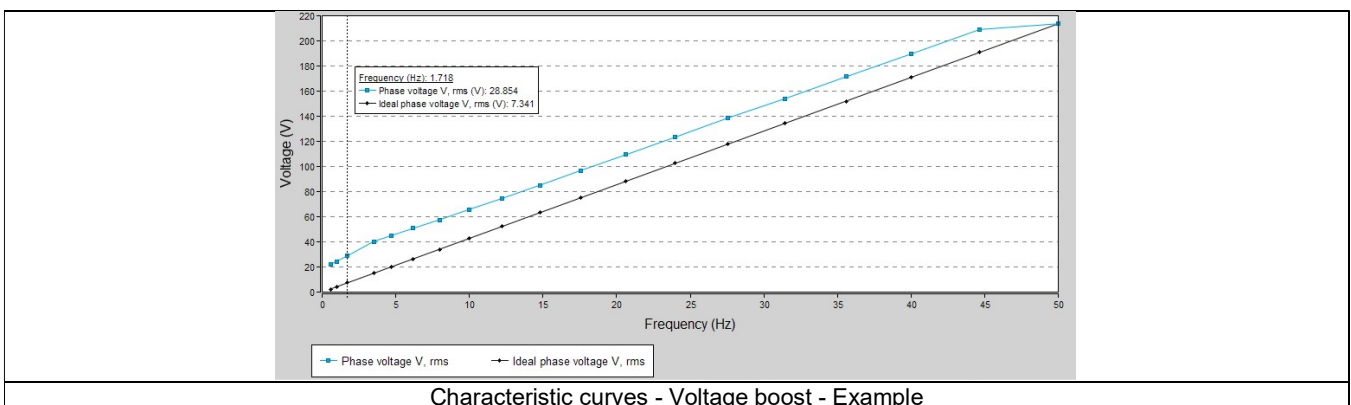
Characteristic curves - Voltage boost - Example

The following table helps in classifying the test "**Performance mapping – Sine wave – Motor – Efficiency map scalar U-f**".

Family	Performance mapping
Package	Sine wave
Convention	Motor
Test	Efficiency map scalar U-f

Positioning of the test "Performance mapping - Sine wave - Motor - Efficiency map scalar U-f"

2.1.2   User inputs

The four main user input parameters are "the maximum Line-Line voltage, the rated power supply frequency, the maximum line current and the maximum speed". In addition, temperatures of winding, and squirrel cage must be set, and the power electronics data if needed.

Warning! Default values of advanced inputs have been set to obtain the best compromise between accuracy and computation time.

2.1.3   Main outputs

Different kinds of output are displayed like data, curves, maps, and tables.

2.1.3.1   Main test results

1) Machine performance - Base speed point
   - General data like torque, speed, electrical powers, power factor, efficiency etc.
   - Power balance

2) Machine performance - Maximum speed
   - General data like torque, speed, electrical powers, power factor, efficiency etc.
   - Power balance

3) Torque-speed curves
   - Mechanical torque versus speed
   - Efficiency torque versus speed
   - Current versus speed
   - Voltage versus speed
   - Slip versus speed
   - Frequency versus speed
   - Power (Mechanical power, machine electrical power, system electrical power) versus speed
   - Power factor versus speed
   - Losses versus speed (total machine and system, Stator Joule, Rotor Joule, mechanical, power electronics) (iron losses are neglected for the first version of this test)

4) Characteristic curves
   - "Normalized base point curves" versus speed
   - "Normalized torque-speed curves" versus speed
   - "Voltage boost" versus speed (low speed between zero speed and base speed)

5) Torque-Speed maps
   - Efficiency in torque-speed area
   - Current in torque-speed area
   - Voltage in torque-speed area
   - Slip in torque-speed area
   - Frequency in torque-speed area
   - Power (Mechanical power, machine electrical power, system electrical power) in torque-speed area
   - Power factor in torque-speed area
   - Losses in torque-speed area (total machine and system, total Joule, mechanical, power electronics) (iron losses are neglected for the first version of this test)
   - Joule losses in torque-speed area (Total, Stator and Rotor)

2.2   Settings

Four buttons give access to the following setting definition:

- Temperature of active components: winding and squirrel cage

- Definition of the power electronics parameters
        Inverter control strategy
        Inputs for evaluating the power electronics stage losses

- Definition of mechanical loss model parameters

For more details, please refer to the document: MotorFactory_IMSQ_IOR_3PH_Test_Introduction.

- Import

Provides the ability to import the current inputs and results from the test "**Characterization – Model – Motor – Scalar**". This will save the computation time related to the identification of the non-linear model, in other words, saves the computation time related to the finite element solving, which generally represent the main part of the computation time of the test.

1	Import inputs – Accelerate test resolution
2	Current results from test "Characterization – Model – Motor – Scalar"
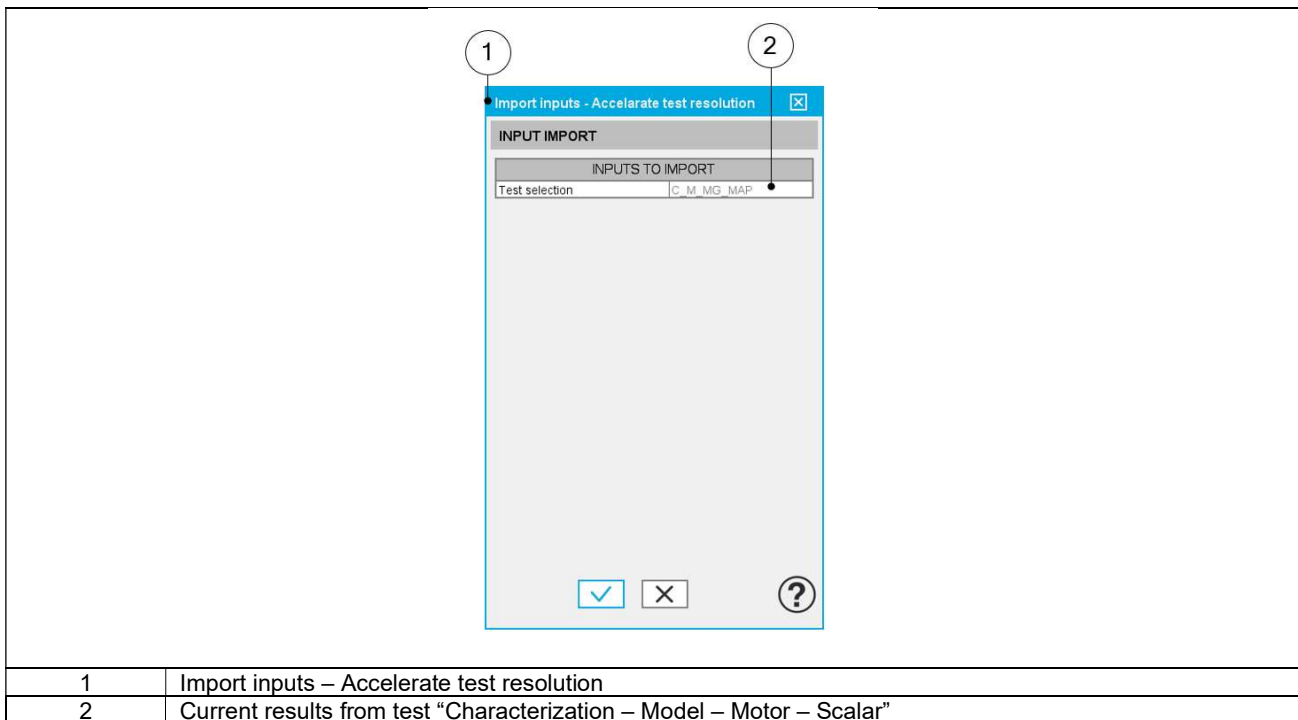
2.3   Inputs

2.3.1   Introduction

The total number of user inputs is equal to 14.
Among these inputs, 4 are standard inputs and 10 are advanced inputs.

The maximum line current, the maximum Line-Line voltage and the rated power supply frequency allows to define the base speed point and in addition, the maximum speed allows to define the maximum speed point.

2.3.2   Standard inputs

2.3.2.1   Maximum Line-Line voltage, rms

The rms value of the maximum Line-Line voltage supplying the machine: "Maximum **Line-Line voltage, rms"** (*Maximum Line-Line voltage, rms value*) must be provided.
Note: The number of parallel paths and the winding connection are automatically considered in the results.

2.3.2.2   Rated power supply frequency

The value of the rated power supply frequency of the machine: "**Rated power supply frequency**" (rated p*ower supply frequency*) must be provided.
The rated power supply frequency is the electrical frequency applied at the terminals of the machine for the base speed point.

2.3.2.3   Current definition mode

There are three common ways to define the electrical current:

-    Electrical current can be defined by the current density in electric conductors.
-    Electric current can be defined directly by indicating the value of the maximum line current (the rms value is required).
-    Electric current can be defined by a rated slip ratio which leads to impose a value of current (between the break down torque and zero torque).

The electrical current addition to the maximum Line-Line voltage and the rated power supply frequency allows to define the base speed point.

2.3.2.4   Maximum line current, rms

The value of the maximum line current supplied to the machine "**Maximum line current, rms**" (*Maximum line current, rms*) must be provided. The maximum line current value corresponds to the line current targeted at the base speed point.

If you don't know the value of "**Maximum line current, rms**", the following identification process of the "Maximum line current, rms" at the "Base speed point" is recommended:

1)   Solve the test "Characterization – Model – Motor – Scalar" (with the same inputs and settings are those to be applied for the test "Performance mapping – Sine wave – Motor – Efficiency map scalar U-f).

2)   From the "Mechanical torque versus speed" curve, select the "Rated power supply frequency value" (Yellow box on the following picture), and the "Max. Line-Line voltage value" (Red box on the following picture)

From the "Mechanical torque versus speed" curve, selection of the "Rated power supply frequency value"

3)   Identify the speed at the break down torque (Green box on the previous picture)

4)   Following the previous steps, select the maximum current value you want to target at the base speed point.
     The value of current selected must be between the speed at break down torque and the maximum speed (green box on the next picture)

From the "Stator line current versus speed" curve, selection of the maximum current value

Note:

- The number of parallel paths and the winding connections are automatically considered in the results.
- The base speed point is also defined by the maximum line-line voltage and the rated power supply frequency.
- In case the "**Maximum line current, rms**" set in input is higher or lower than those in the range defined by the break down torque and the zero torque, an automatic correction is done to target a realistic value (inside the range).

- If the current targeted is higher than the maximum value of the current range, the following formula is applied:

$$J_{Ph,rms\ corrected} = \max(J_{Ph,rms\ range}) - 10\% * \left(\frac{\max(J_{Ph,rms\ range}) - \min(J_{Ph,rms\ range})}{2}\right)$$

Where:

$J_{Ph,rms\ corrected}$: "**Maximum line current, rms**" value corrected by the internal process applied to compute the efficiency map,

$J_{Ph,rms\ range}$: Range of current between the break down torque and the zero torque at the Maximum Line-Line voltage and the rated power supply frequency.

- If the current targeted is lower than the minimum value of the current range, the following formula is applied:

$$J_{Ph,rms\ corrected} = min(J_{Ph,rms\ range}) + 10\% * \left(\frac{\max(J_{Ph,rms\ range}) - \min(J_{Ph,rms\ range})}{2}\right)$$

$J_{Ph,rms\ corrected}$: "**Maximum line current, rms**" value corrected by the internal process applied to compute the efficiency map,

$J_{Ph,rms\ range}$: Range of current between the break down torque and the zero torque at the Maximum Line-Line voltage and the rated power supply frequency.

2.3.2.5   Maximum current density, rms

The value of the rated current density in electric conductors "**Max. current density, rms**" (*Maximum current density in conductors, rms*) must be provided. The rated current density value corresponds to the current density targeted at the base speed point.

If the value of "**Maximum current density, rms**" is unknown, the following identification process of the "Maximum current density, rms" at the "Base speed point" is recommended:

1)   Solve the test "Characterization – Model – Motor – Scalar" (with the same inputs and settings are those to be applied for the test "Performance mapping – Sine wave – Motor – Efficiency map scalar U-f".

2)   From the "Mechanical torque versus speed" curve, select the "Rated power supply frequency value" (Yellow box on the following picture) and the "Max. Line-Line voltage value" (Red box on the following picture)

From the "Mechanical torque versus speed" curve, selection of the rated power supply frequency value

3)   Identify the speed at the break down torque (Green box on the previous picture)

4)   Following the previous steps, select the maximum current value you want to target at the base speed point.
      The value of current selected must be between the speed at break down torque and the maximum speed (green box on the next picture).

From the "Stator line current versus speed" curve, selection of the maximum current value

5)   By using the "**Line current, rms**" deduced, and finally the corresponding "**Current density, rms**" can be computed using the following formula:

$$J = \frac{\left(\dfrac{J_{Ph,rms}}{P_{paths}}\right)}{A_{Cond}}$$

A_{Cond} = Conductor conductive area

$$A_{Cond} = Nwires \times A_{wire}$$

A_{wire} = Wire area (without insulation); $Nwires$ = No. wires in hand; P_{paths} = Number of parallel paths

Note:
- The number of parallel paths and the winding connections are automatically considered in the results.
- The base speed point is also defined by the maximum line-line voltage and the rated power supply frequency.
- In case the "**Maximum current density, rms**" set in input is higher or lower than those in the range defined by the break down torque and the zero torque, an automatic correction is done to target a realistic value (inside the range).

- If the current density targeted is higher than the value of the current density range, the following formulas is applied:

$$J_{Ph,rms\ corrected} = \max(J_{Ph,rms\ range}) - 10\% * \left(\frac{\max(J_{Ph,rms\ range}) - \min(J_{Ph,rms\ range})}{2}\right)$$

$$J_{\text{corrected}} = \frac{\left(\frac{J_{\text{Ph,rms corrected}}}{P_{\text{paths}}}\right)}{A_{\text{Cond}}}$$

Where:

$J_{Ph,rms\ corrected}$: "**Maximum line current, rms**" value corrected by the internal process applied to compute the efficiency map,
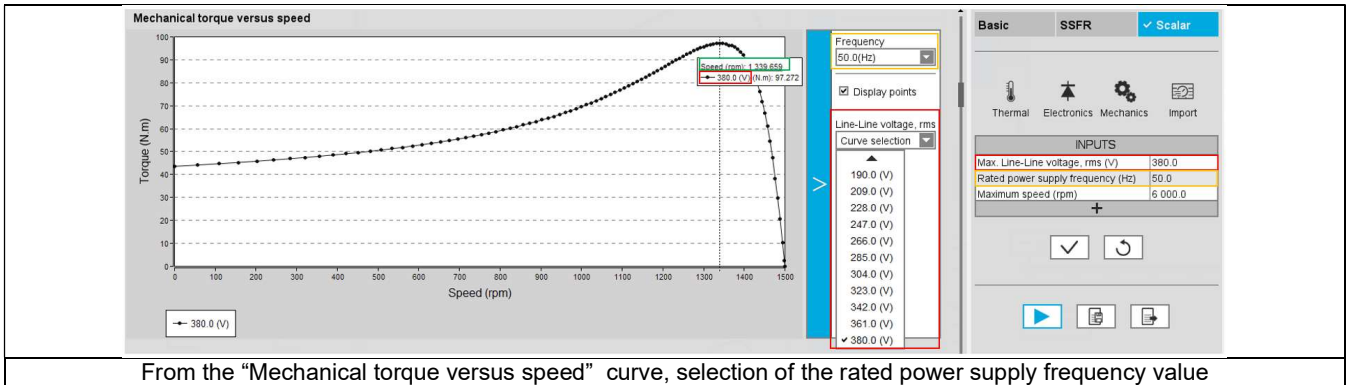
$J_{Ph,rms\ range}$: Range of current between the break down torque and the zero torque at the Maximum Line-Line voltage and the rated power supply frequency,
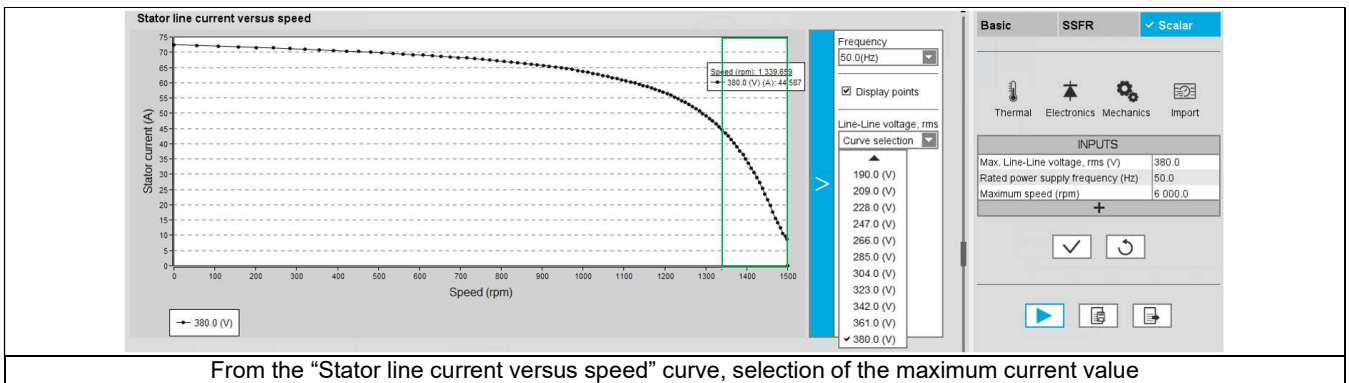
$J_{corrected}$: "**Maximum current density, rms**" value corrected by the internal process applied to compute the efficiency map

- If the current targeted is lower than the minimum value of the current density range, the following formulas is applied:

$$J_{Ph,rms\ corrected} = \min(J_{Ph,rms\ range}) + 10\% * \left(\frac{\max(J_{Ph,rms\ range}) - \min(J_{Ph,rms\ range})}{2}\right)$$

$$J_{\text{corrected}} = \frac{\left(\frac{J_{\text{Ph,rms corrected}}}{P_{\text{paths}}}\right)}{A_{\text{Cond}}}$$

Where:

$J_{Ph,rms\ corrected}$: "**Maximum line current, rms**" value corrected by the internal process applied to compute the efficiency map,

$J_{Ph,rms\ range}$: Range of current between the break down torque and the zero torque at the Maximum Line-Line voltage and the rated power supply frequency,

$J_{corrected}$: "**Maximum current density, rms**" value corrected by the internal process applied to compute the efficiency map

2.3.2.6   Rated slip ratio

The value of the rated slip ratio of the machine "**Rated slip ratio**" (*Rated slip ratio*) must be provided.
The rated slip ratio corresponds to the ratio between the "slip (or speed) obtained from the targeted rated torque" and the "slip (or speed) range" (Slip range is defined between the break down torque and the zero torque).
The following picture describes the principle of computation.
This input allows the automatic computation of the related maximum line current at the base speed point.

Torque vs speed curve - Rated slip ratio – Base speed point
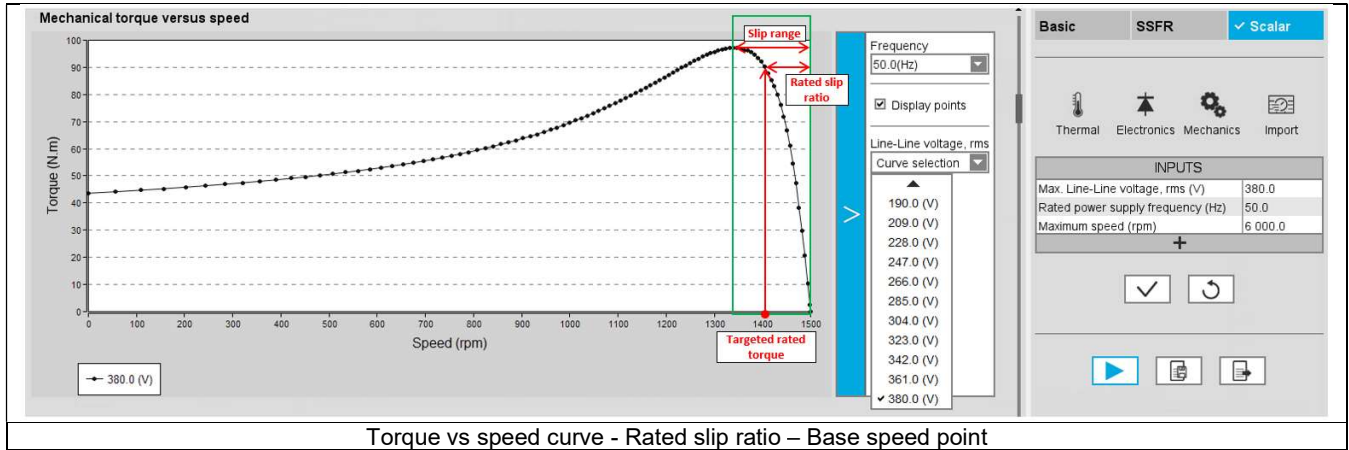
Note:

- This way to target a maximum line current is the only one that is not subject to potential correction in function of the user value.
- The number of parallel paths and the winding connections are automatically considered in the results.
- The base speed point is also defined by the maximum line-line voltage and the rated power supply frequency.

2.3.2.7   Maximum speed

The value of the « **Maximum speed** » (*Maximum speed*).) must be provided.
The analysis of test results is performed over a given speed range defined between 0 and the maximum speed. This allows the user to evaluate the behavior of the machine as a function of speed (like rotor Joule losses, total losses, power factor...) in this range.

2.3.3   Advanced inputs

2.3.3.1   Electrical equivalent scheme identification

In the first step of the internal process of computation, it is needed to identify the model (non-linear electrical equivalent scheme – see "**Characterization – Model – Motor – Scalar**" for more details). That means computation for each component of the electrical scheme (resistance and inductances) maps in function of the Line-Line voltage and the power supply frequency.
The following inputs allow to fix the discretization required to identify the non-linear model.

2.3.3.2   Model maps identification - Number of computations for Line-Line voltage

The number of computations for the voltage must be defined with the user input « **ID - No. Comp. for voltage** » *(Electrical equivalent scheme identification - Number of computations for Line-Line voltage)*.
The default value is equal to 10. This default value provides a good compromise between the accuracy and the computation time. The minimum allowed value is 10.

Note: We recommend increasing « ID - No. Comp. for voltage » to at least 15 in case of fractional slot per pole and per phase.

2.3.3.3   Model maps identification - Number of computations for power supply frequency

The number of computations for the frequency must be defined with the user input « ID - **No. Comp. for freq.** » *(Electrical equivalent scheme identification - Number of computations for power supply frequency)*.
The default value is equal to 10. This default value provides a good compromise between the accuracy and the computation time. The minimum allowed value is 10.

Note: We recommend increasing « ID - No. Comp. for freq. » to at least 15 in case of fractional slot per pole and per phase.

2.3.3.4   Operation of the non-linear model to generate T(U,f,s)

In the second step of the internal process of computation, it is needed to operate (solve) the model (non-linear electrical equivalent scheme) to generate sets of curves in function of the Line-Line voltage, the power supply frequency, and the slip to get the performances of the machine as in the T(Slip) test.
Forth following inputs allow to fix the discretization required to operate the non-linear model in order to get the data set of T(U,f,s) curves representing the behavior of the machine in function of the Line-Line voltage, the power supply frequency and the slip (or speed).

2.3.3.5   Operation of model to generate T(U,f,s) - Number of computations for Line-Line voltage

The number of computations for the voltage must be defined with the user input « **OP. - No. comp. for voltage** » (Operation of model to generate T(U,f,s) - Number of computations for Line-Line voltage).
The default value is equal to 500. This default value provides a good overview of the machine behavior. The minimum allowed value is 10.

Notes: Values higher than the default value can be used, particularly in the case where, at low speed, some points of the torque-speed curve are fixed at "0" while the torque at zero speed is different from "0". There is a lack of robustness in the first version of this test, but increasing the number of calculations is usually the solution.

2.3.3.6   Operation of model to generate T(U,f,s) - Number of computations for power supply frequency

The number of computations for the frequency must be defined with the user input « **Op. - No. comp. for freq.** » *(Operation of model to generate T(U,f,s) - Number of computations for power supply frequency)*.
The default value is equal to 500. This default value provides a good overview of the machine behavior. The minimum allowed value is 10.

Note: Values higher than the default value can be used, particularly in the case where, at low speed, some points of the torque-speed curve are fixed at "0" while the torque at zero speed is different from "0". There is a lack of robustness of the first version of this test, but increasing the number of calculations is usually the solution.

2.3.3.7   Operation of model to generate T(U,f,s) – Slip distribution mode

The computation of the test « **Characterization – Model – Motor – Scalar** » is performed by considering a distribution of computed points. The user's input "**Slip distribution mode**" (*Select the method for the distribution of computed points*) gives three possibilities to the user:

1)   Slip distribution mode = Logarithmic
When "Logarithmic" is selected, the distribution of the computed points is automatically done. The number of computations to be done in the slip range must be set in the next field: "No. comp. in slip range".

2)   Slip distribution mode = Linear

When "Linear" is selected, the distribution of the computed points is automatically done. The number of computations to be done in the slip range must be set in the next field: "No. comp. in slip range".

3)   Slip distribution mode = Table

When "Table" is selected, the list of slips to be considered must be defined by using the field: "Slip table" and then clicking on the button "Set values".
Two ways are possible to fill the table: either filling the table line by line or by importing an excel file, where all the slips to be considered are defined.

Note: The slips must be listed in ascending order.

	Slip distribution mode = Table
1	Select the "Table" option.
2	Click the button "Set values" of the field "Slip table" to open a dialog box defining the list of slips to be considered. Refer to the next illustration which shows how to fill the Slip table.
3	Button to validate and consider the user inputs
4	Button to run the computation

	Slip distribution mode = Table – Dialog box to define the list of slips
1	Dialog box opened when clicking on the button "Set values" in the field "Slip table"
2	Browse the folder to select an Excel file which defines the list of slips
3	Button to refresh the table data when the considered Excel file has been modified
4	Fields to be filled with data to describe the considered slips
5	Button to apply the inputs
6	Button to erase the data table

Note: The Excel template used to import the list of slips is stored in the folder Resource/Template in the installation folder of FluxMotor®. An example of this template is displayed below.

Slip table	
Label	Slip
Units	%
Values	2
	5
	10
	20

Excel file template to define the list of slips

Note:
- The slips must be listed in ascending order.
- We recommend to define at least 100 values to get an accuracy high enough, (especially since going below 100 does not lead to a significant reduction in computation time).

2.3.3.8   Operation of model to generate T(U,f,s) - Number of computations for slip

The number of computations for the slip must be defined with the user input « **Op. - No. comp. for slip** » *(Operation of model to generate T(U,f,s) - Number of computations for slip)*.
The default value is equal to 100. This default value provides a good overview of the machine behavior.
The minimum allowed value is 10 it is recommended not to go below 100 to get a high enough accuracy (especially since going below 100 does not lead to a significant reduction in computation time).

Note:
- The machine operating mode is "Motor", so the slip range is [0,1].
- The slip distribution mode used is logarithmic or linear.
- The computation time of the test is not highly impacted by this input and huge values such as 200 can be used.

2.3.3.9   Operation of model to generate T(U,f,s) – Slip table

When the choice of point distribution mode is "**Table**", the list of slips to be considered "Op. - **Slip table**" (Operation of model to generate T(U,f,s) - *Slip table*) must be provided. Refer to the above section 2) Slip distribution mode = Table

Note: The machine operating mode is fixed to "Motor", so the slip range is]0,1].

2.3.3.10 Efficiency map computation parameters

As a final step of the internal process of computation, it is needed to apply the scalar command.
The command is applied to the data set generated in the previous step (Operation of model to generate T(U,f,s)) through an automatic post-processing.
With this post-processing the behavior of the machine in the torque speed plane is obtained in consistency with the scalar command.
The following inputs allow to fix the discretization required to compute the efficiency map and associated results in the torque-speed plane.
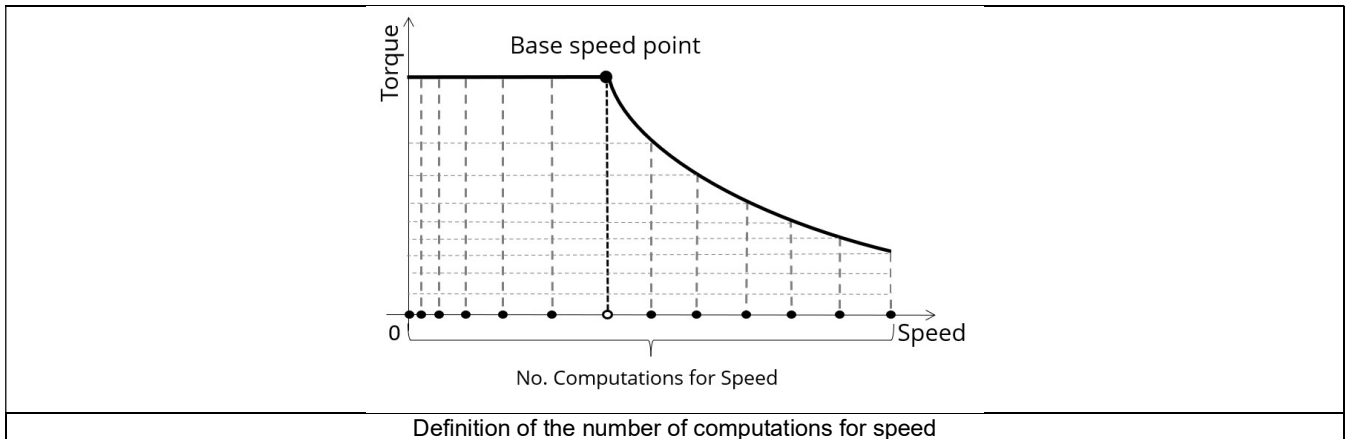
2.3.3.11 EM - Number of computations for speed

The "**EM - No. comp. for speed**" (*Efficiency map - Number of computations for speed*) corresponds to the number of points to be considered in the speed range from 0 to the maximum speed.
Half of these points are distributed from 0 to the base speed. The remaining points are distributed from the base speed to the maximum speed.
In both cases, base speed is considered as an additional point.
Note: If the user input parameter "**No. comp. for speed**" is an odd number, one discretization point is automatically removed.

Definition of the number of computations for speed

The default value is equal to 20. The minimum allowed value is 10 while the maximum recommended value is 40.

Note: Increasing the number of computations can improve the convergence of the optimization used to define the torque-speed curve and the efficiency map. However, that also means longer computation time.

2.3.3.12 EM - Number of computations for torque

For the speed range [N_{base}; $N_{max.}$], the number of computations for torque is imposed by the number of computations for the defined speed range [N_{base}; $N_{max.}$] (Red points in the image shown below).
The advanced user input parameter "**EM - No. comp. for torque**" (*Efficiency map - Number of computations for torque*) allows to finalize the grid within the torque range [0, T ($N_{max.}$)] at the maximum speed (Black points in the image shown below).

The default value is equal to 4. The minimum allowed value is 4 while the maximum recommended value is 10.

Definition of the number of computations for torque
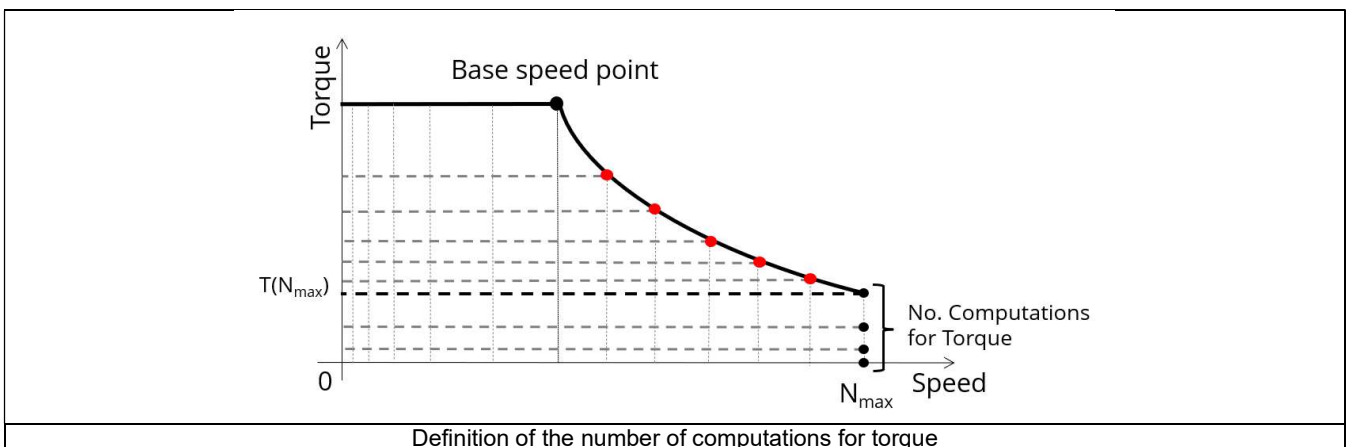
2.3.3.13 Skew model – No. of layers

When the rotor bars 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 modelling the skewing in Flux® Skew environment*).

2.3.3.14 Rotor initial position

The initial position of the rotor considered for computation can be set by the user in the field « **Rotor initial position** » (*Rotor initial position*). The default value is equal to 0.
The range of possible values is [-360, 360].

The rotor initial position has an impact only on the induction curve in the air gap.

2.3.3.15 Airgap mesh coefficient

The advanced user input "**Airgap mesh coefficient**" is a coefficient which 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, thereby increasing the computation accuracy.

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

$$MeshPoint = (airgap) \times (airgap\ mesh\ coefficient)$$

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

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2.4   Main principles of computation

Will be completed soon.

2.5   Test results

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

2.5.1   Test conditions

2.5.1.1   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 **Erreur ! Source du renvoi introuvable.** (**Erreur ! Source du renvoi introuvable.**).

2.5.1.2   Settings

All the settings dedicated to the test and dealing with the thermal conditions are displayed in this section.
Here is the displayed subsection:

- Thermal
- Electronics
- Mechanics
- Import

For more details, please refer to the document: MotorFactory_IMSQ_IOR_3PH_Test_Introduction – section "Settings" and section 2.2 (Settings).

2.5.1.3   Winding and squirrel cage characteristics

All winding and squirrel cage characteristics are displayed in the following subsections:

- Winding characteristics
- Squirrel cage characteristics

For more details, please refer to the document: MotorFactory_IMSQ_IOR_3PH_Test_Introduction – section "Test generic information".

2.5.1.4   Inter bar resistance versus rotor frequency over the operating range

Curve which allows to see the evolution of the inter bar resistance in function of the rotor frequency.
Note: These values are those considered for the identification of the non-linear model.

2.5.1.5   Inter bar inductance versus rotor frequency over the operating range

Curve which allows to see the evolution of the inter bar inductance in function of the rotor frequency.
Note: These values are those considered for the identification of the non-linear model.

2.5.2 Main results

2.5.2.1 Machine performance – Base speed point

All the machine main electromagnetic data computed for the base speed point are presented in this table with the following subsections:

- General data
- Power balance

For more details, please refer to the document: MotorFactory_IMSQ_IOR_3PH_Test_Introduction – section "Test generic information".

2.5.2.2 Machine performance – Maximum Speed point

All the machine main electromagnetic data computed for the maximum speed point are presented in this table with the following subsections:

- General data
- Power balance

For more details, please refer to the document: MotorFactory_IMSQ_IOR_3PH_Test_Introduction – section "Test generic information".

2.5.3 Curves

2.5.3.1 Torque-speed curves

List of torque-speed curves computed and displayed:
- Mechanical torque versus speed
- Efficiency torque versus speed
- Current versus speed (Line and phase)
- Voltage versus speed (Line-Line and phase)
- Slip versus speed
- Frequency versus speed (Stator and rotor)
- Power (Mechanical power, machine electrical power, system electrical power) versus speed
- Power factor versus speed
- Losses versus speed (total machine and system, Stator Joule, Rotor Joule, mechanical, power electronics) (iron losses are neglected for the first version of this test)

2.5.3.2 Characteristic curves

Additional graphs provide an interesting overview on some topics with:

- "Normalized base point curves" versus speed
- "Normalized torque-speed curves" versus speed
- "Voltage boost" versus speed (low speed between zero speed and base speed)

These results help the user to understand the possible performance of the machine in its electric environment.

Characteristics curves - Normalized base point curves - Example

Characteristics curves - Normalized torque speed curves - Example

Characteristics curves - Voltage boost - Example
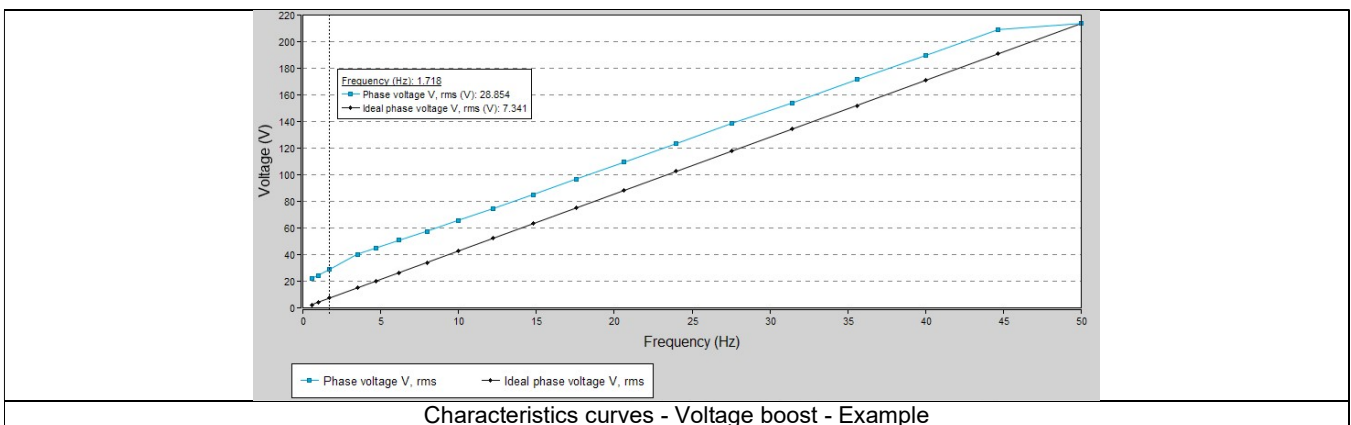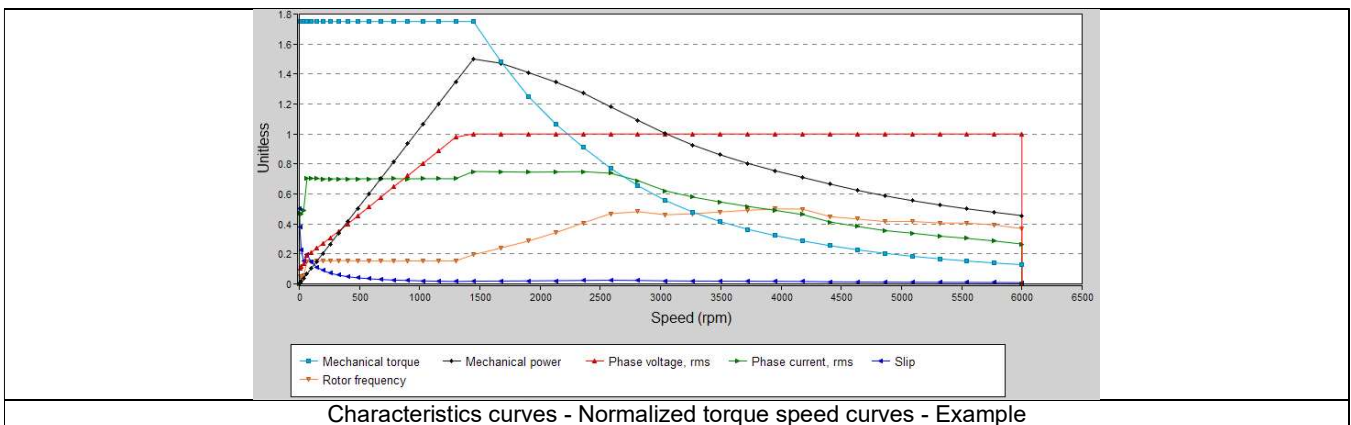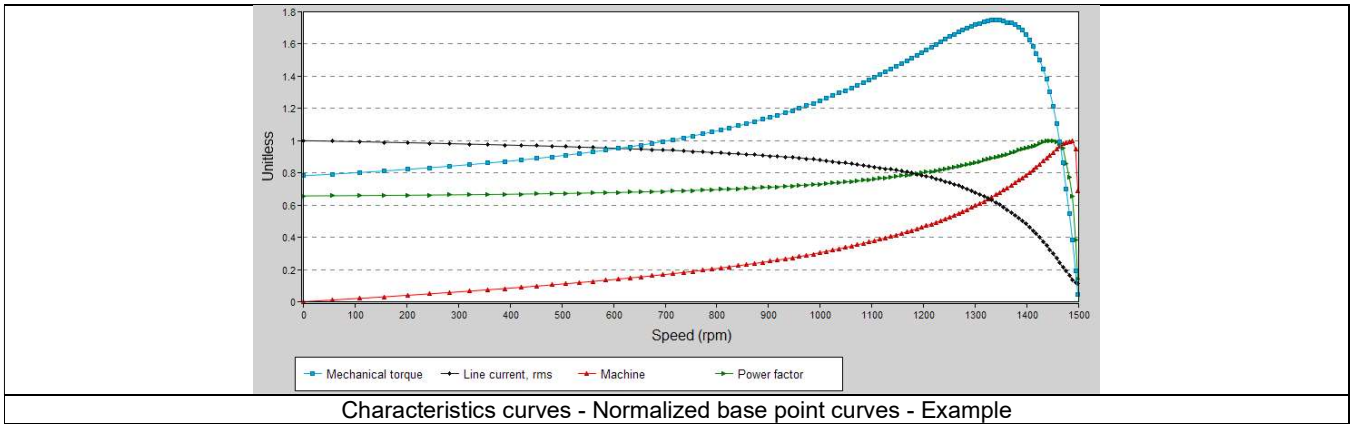
2.5.4   Torque-speed Maps

List of torque-speed maps computed and displayed:

- Efficiency in torque-speed area
- Current in torque-speed area (Line and phase)
- Voltage in torque-speed area (Line-Line and phase)
- Slip in torque-speed area
- Frequency in torque-speed area (Stator and rotor)
- Power (Mechanical power, machine electrical power, system electrical power) in torque-speed area
- Power factor in torque-speed area
- Losses in torque-speed area (Total machine and system, total Joule, mechanical, power electronics) (iron losses are neglected for the first version of this test)
- Joule losses in torque-speed area (Total, Stator and Rotor)

3   PERFORMANCE MAPPING – SINE WAVE – MOTOR – EFFICIENCY MAP SCALAR U-I

3.1   Overview

3.1.1   Positioning and objective

The aim of the test "**Performance mapping – Sine wave – Motor – Efficiency map scalar U-I**" is to characterize the behavior of the machine in the "Torque-Speed" area.
Input parameters like, "the maximum Line-Line voltage, the maximum line current and the maximum speed" of the machine are considered.
The main difference with the test "**Performance mapping – Sine wave – Motor – Efficiency map scalar U-f**" is that the speed of the base speed point is not fix by a user input (Rated power supply frequency) but deduced by the internal process of computation to maximize mechanical power.

One type of command mode is available: scalar command.
Input parameters define the torque-speed area in which the evaluation of the machine behavior is performed.

Characterization of the corner point on the torque-speed curve
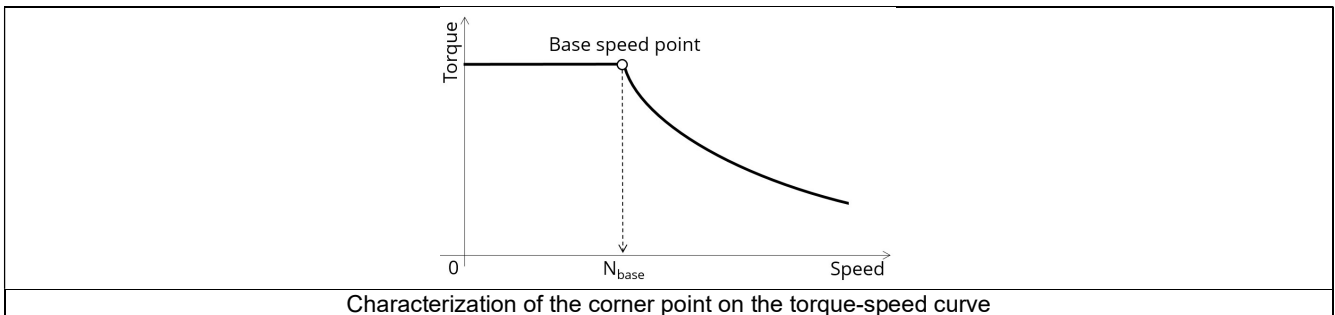
In the results, the performance of the machine at the base point (base speed point) and the maximum speed (maximum speed point), set by the user are presented.
A set of curves (like a Torque-Speed curve) and maps (like an Efficiency map) are computed and displayed.

Mechanical torque versus speed - Example

Efficiency in torque-speed area - Example
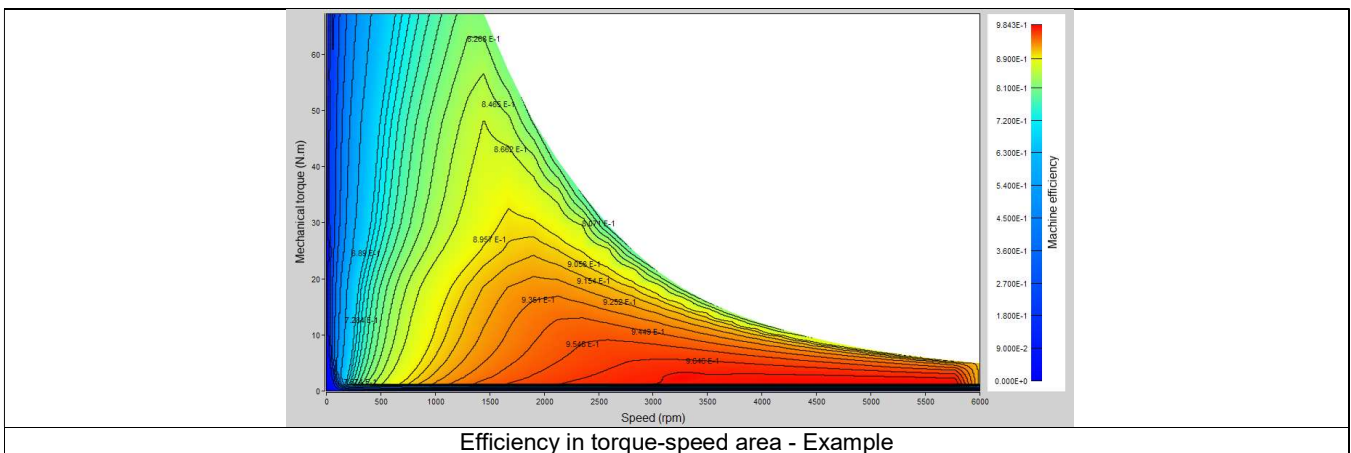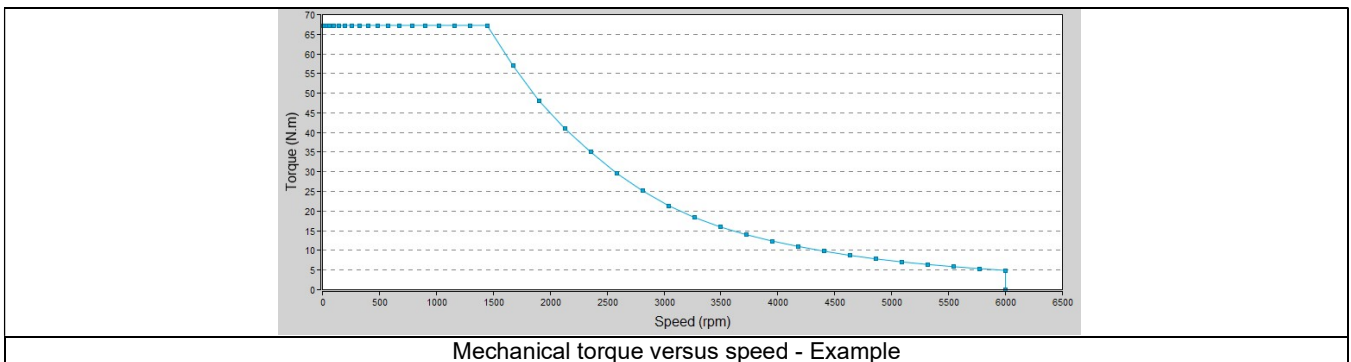
Note: Curves are calculated and displayed identical to those presented in the test "**Performance mapping – Sine wave – Motor – Efficiency map scalar U-f**".
Please refer to the section dedicated to this test to see the corresponding illustrations.

The following table helps in classifying the test: "**Performance mapping – Sine wave – Motor – Efficiency map scalar U-I**".

Family	Performance mapping
Package	Sine wave
Convention	Motor
Test	Efficiency map scalar U-I

Positioning of the test "Performance mapping - Sine wave - Motor - Efficiency map scalar U-I"

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3.1.2   User inputs

The three main user input parameters are "the maximum Line-Line voltage, the maximum line current and the maximum speed". In addition, the temperatures of the winding, and squirrel cage must be set, as well as the power electronics data if needed.

Warning! Default values of advanced inputs have been set to obtain the best compromise between accuracy and computation time.

3.1.3   Main outputs

Different kinds of output are displayed, like data, curves, maps, and tables.

3.1.3.1   Main test results

1)   Machine performance - Base speed point
   - General data like torque, speed, electrical powers, power factor, efficiency etc.
   - Power balance

2)   Machine performance - Maximum speed
   - General data like torque, speed, electrical powers, power factor, efficiency etc.
   - Power balance

3)   Torque-speed curves
   - Mechanical torque versus speed
   - Efficiency torque versus speed
   - Current versus speed
   - Voltage versus speed
   - Slip versus speed
   - Frequency versus speed
   - Power (Mechanical power, machine electrical power, system electrical power) versus speed
   - Power factor versus speed
   - Losses versus speed (total machine and system, Stator Joule, Rotor Joule, mechanical, power electronics) (iron losses are neglected for the first version of this test)

4)   Characteristic curves
   - "Normalized base point curves" versus speed
   - "Normalized envelope curves" versus speed
   - "Voltage boost" versus speed (low speed between zero speed and base speed)

5)   Torque-Speed maps
   - Efficiency in torque-speed area
   - Current in torque-speed area
   - Voltage in torque-speed area
   - Slip in torque-speed area
   - Frequency in torque-speed area
   - Power (Mechanical power, machine electrical power, system electrical power) in torque-speed area
   - Power factor in torque-speed area
   - Losses in torque-speed area (total machine and system, total Joule, mechanical, power electronics) (iron losses are neglected for the first version of this test)
   - Joule losses in torque-speed area (Total, Stator and Rotor)

3.2   Settings

Four buttons give access to the following setting definition:

- Temperature of active components: winding and squirrel cage

- Definition of the power electronics parameters
    - Inverter control strategy
    - Inputs for evaluating the power electronics stage losses

- Definition of mechanical loss model parameters

For more details, please refer to the document: MotorFactory_IMSQ_IOR_3PH_Test_Introduction.

3.3   Inputs

3.3.1   Introduction

The total number of user inputs is equal to 13.
Among these inputs, 3 are standard inputs and 10 are advanced inputs.

The maximum line current and the maximum Line-Line voltage allow to define the base speed point and in addition, the maximum speed allows to define the maximum speed point.

3.3.2   Standard inputs

3.3.2.1   Maximum Line-Line voltage, rms

The rms value of the maximum Line-Line voltage supplying the machine: "**Maximum Line-Line voltage, rms"** (*Maximum Line-Line voltage, rms value*) must be provided.
Note: The number of parallel paths and the winding connection are automatically considered in the results.

3.3.2.2   Current definition mode

There are two common ways to define the electrical current:

- Electrical current can be defined by the current density in electric conductors.
- Electric current can be defined directly by indicating the value of the maximum line current (the rms value is required).

The electrical current, in addition to the maximum Line-Line voltage and the rated power supply frequency allows to define the base speed point.

3.3.2.3   Maximum line current, rms

The value of the maximum line current supplied to the machine "**Maximum line current, rms**" (*Maximum line current, rms*) must be provided. The maximum line current value corresponds to the line current targeted at the base speed point.

Note:
- The number of parallel paths and the winding connections are automatically considered in the results.
- The base speed point is also defined by the maximum line-line voltage and the rated power supply frequency.
- In case the "**Maximum line current, rms**" set in input is higher or lower than those in the range defined by the break down torque and the zero torque, an automatic correction is done to target a realistic value (inside the range).

3.3.2.4   Maximum current density, rms

The value of the rated current density in electric conductors "**Max. current density, rms**" (*Maximum current density in conductors, rms*) must be provided. The rated current density value corresponds to the current density targeted at the base speed point.

3.3.2.5   Maximum speed

The value of the « **Maximum speed** » (*Maximum speed*) must be provided.
The analysis of test results is performed over a given speed range defined between 0 and the maximum speed. This allows the user to evaluate the behavior of the machine as a function of speed (like rotor Joule losses, total losses, power factor...) in this range.

3.3.3   Advanced inputs

3.3.3.1   Electrical equivalent scheme identification

In the first step of the internal process of computation, it is needed to identify the model (non-linear electrical equivalent scheme – see "**Characterization – Model – Motor – Scalar**" for more details). That means computation for each component of the electrical scheme (resistance and inductances) maps in function of the Line-Line voltage and the power supply frequency.
The following inputs allow to fix the discretization required to identify the non-linear model.

3.3.3.2   Model maps identification - Number of computations for Line-Line voltage

The number of computations for the voltage must be defined with the user input « **ID - No. Comp. for voltage** » *(Electrical equivalent scheme identification - Number of computations for Line-Line voltage)*.
The default value is equal to 10. This default value provides a good compromise between the accuracy and the computation time. The minimum allowed value is 10.

Note: We recommend increasing « ID - No. Comp. for voltage » to at least 15 in case of fractional slot per pole and per phase.

3.3.3.3   Model maps identification - Number of computations for power supply frequency

The number of computations for the frequency must be defined with the user input « ID - **No. Comp. for freq.** » *(Electrical equivalent scheme identification - Number of computations for power supply frequency)*.
The default value is equal to 10. This default value provides a good compromise between the accuracy and the computation time. The minimum allowed value is 10.

Note: We recommend increasing « ID - No. Comp. for freq. » to at least 15 in case of fractional slot per pole and per phase.

3.3.3.4   Operation of the non-linear model to generate T(U,f,s)

In the second step of the internal process of computation, it is needed to operate (solve) the model (non-linear electrical equivalent scheme) to generate sets of curves in function of the Line-Line voltage, the power supply frequency, and the slip to get the performances of the machine as in the T(Slip) test.
Forth following inputs allow to fix the discretization required to operate the non-linear model in order to get the data set of T(U,f,s) curves representing the behavior of the machine in function of the Line-Line voltage, the power supply frequency and the slip (or speed).

3.3.3.5   Operation of model to generate T(U,f,s) - Number of computations for Line-Line voltage

The number of computations for the voltage must be defined with the user input « **OP. - No. comp. for voltage** » (Operation of model to generate T(U,f,s) - Number of computations for Line-Line voltage).
The default value is equal to 500. This default value provides a good overview of the machine behavior. The minimum allowed value is 10.

Notes: Values higher than the default value can be used, particularly in the case where, at low speed, some points of the torque-speed curve are fixed at "0" while the torque at zero speed is different from "0". There is a lack of robustness in the first version of this test, but increasing the number of calculations is usually the solution.

3.3.3.6   Operation of model to generate T(U,f,s) - Number of computations for power supply frequency

The number of computations for the frequency must be defined with the user input « **Op. - No. comp. for freq.** » *(Operation of model to generate T(U,f,s) - Number of computations for power supply frequency)*.
The default value is equal to 500. This default value provides a good overview of the machine behavior. The minimum allowed value is 10.

Note: Values higher than the default value can be used, particularly in the case where, at low speed, some points of the torque-speed curve are fixed at "0" while the torque at zero speed is different from "0". There is a lack of robustness of the first version of this test, but increasing the number of calculations is usually the solution.

3.3.3.7   Operation of model to generate T(U,f,s) – Slip distribution mode

The computation of the test « **Characterization – Model – Motor – Scalar** » is performed by considering a distribution of computed points. The user's input "**Slip distribution mode**" (*Select the method for the distribution of computed points*) gives three possibilities to the user:

1)   Slip distribution mode = Logarithmic

When "Logarithmic" is selected, the distribution of the computed points is automatically done. The number of computations to be done in the slip range must be set in the next field: "No. comp. in slip range".
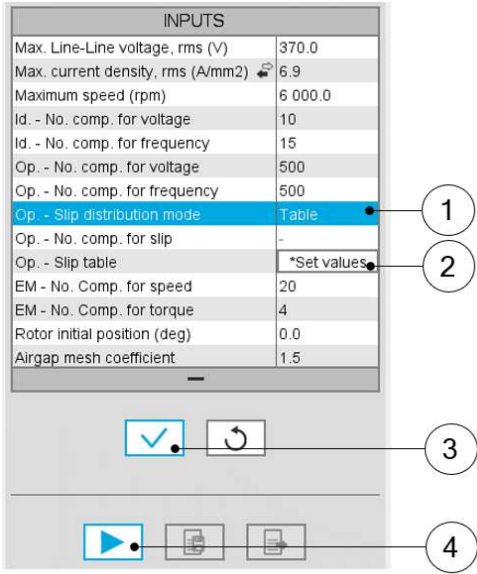
2) Slip distribution mode = Linear

When "Linear" is selected, the distribution of the computed points is automatically done. The number of computations to be done in the slip range must be set in the next field: "No. comp. in slip range".

3) Slip distribution mode = Table

When "Table" is selected, the list of slips to be considered must be defined by using the field: "Slip table" and then clicking on the button "Set values".
Two ways are possible to fill the table: either filling the table line by line or by importing an excel file, where all the slips to be considered are defined.
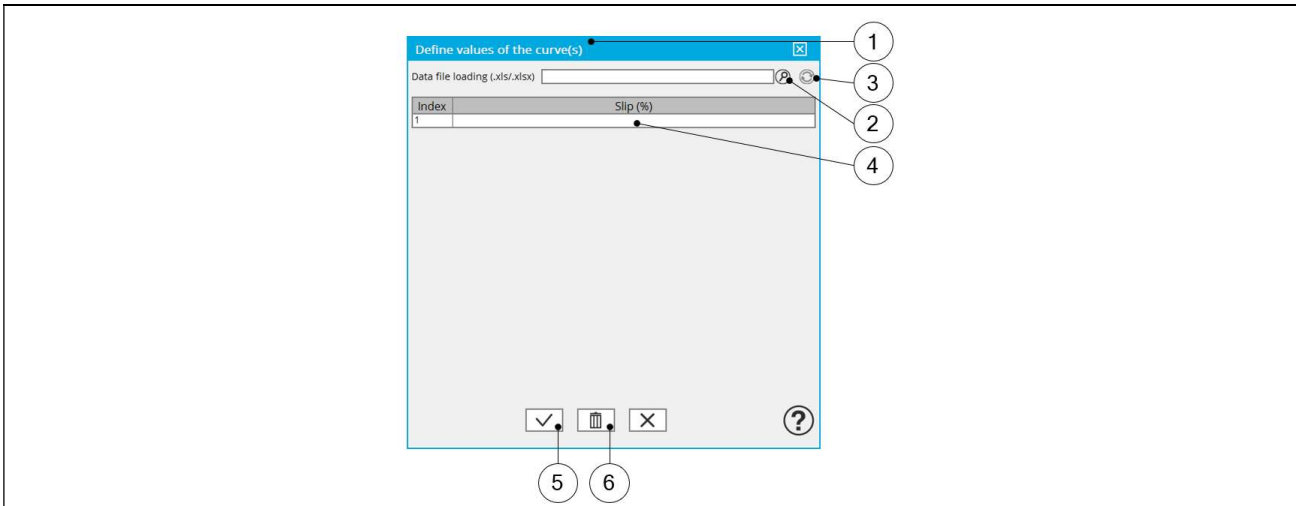
Note: The slips must be listed in ascending order.

Slip distribution mode = Table	
1	Select the "Table" option.
2	Click the button "Set values" of the field "Slip table" to open a dialog box defining the list of slips to be considered. Refer to the next illustration which shows how to fill the Slip table.
3	Button to validate and consider the user inputs
4	Button to run the computation

	Slip distribution mode = Table – Dialog box to define the list of slips
1	Dialog box opened when clicking on the button "Set values" in the field "Slip table"
2	Browse the folder to select an Excel file which defines the list of slips
3	Button to refresh the table data when the considered Excel file has been modified
4	Fields to be filled with data to describe the considered slips
5	Button to apply the inputs
6	Button to erase the data table

Note: The Excel template used to import the list of slips is stored in the folder Resource/Template in the installation folder of FluxMotor®. An example of this template is displayed below.

Excel file template to define the list of slips

Note:
- The slips must be listed in ascending order.
- We recommend defining at least 100 values to get an accuracy high enough, (especially since going below 100 does not lead to a significant reduction in computation time).

3.3.3.8   Operation of model to generate T(U,f,s) - Number of computations for slip

The number of computations for the slip must be defined with the user input « **Op. - No. comp. for slip** » *(Operation of model to generate T(U,f,s) - Number of computations for slip)*.
The default value is equal to 100. This default value provides a good overview of the machine behavior.
The minimum allowed value is 10 it is recommended not to go below 100 to get a high enough accuracy (especially since going below 100 does not lead to a significant reduction in computation time).

Note:
- The machine operating mode is "Motor", so the slip range is [0,1].
- The slip distribution mode used is logarithmic or linear.
- The computation time of the test is not highly impacted by this input and huge values such as 200 can be used.

3.3.3.9   Operation of model to generate T(U,f,s) – Slip table

When the choice of point distribution mode is "**Table**", the list of slips to be considered "Op. - **Slip table**" (Operation of model to generate T(U,f,s) - *Slip table*) must be provided. Refer to the above section 2) Slip distribution mode = Table

Note: The machine operating mode is fixed to "Motor", so the slip range is]0,1].

3.3.3.10 Efficiency map computation parameters

As a final step of the internal process of computation, it is needed to apply the scalar command.
The command is applied to the data set generated in the previous step (Operation of model to generate T(U,f,s)) through an automatic post-processing.
With this post-processing the behavior of the machine in the torque speed plane is obtained in consistency with the scalar command.
The following inputs allow to fix the discretization required to compute the efficiency map and associated results in the torque-speed plane.
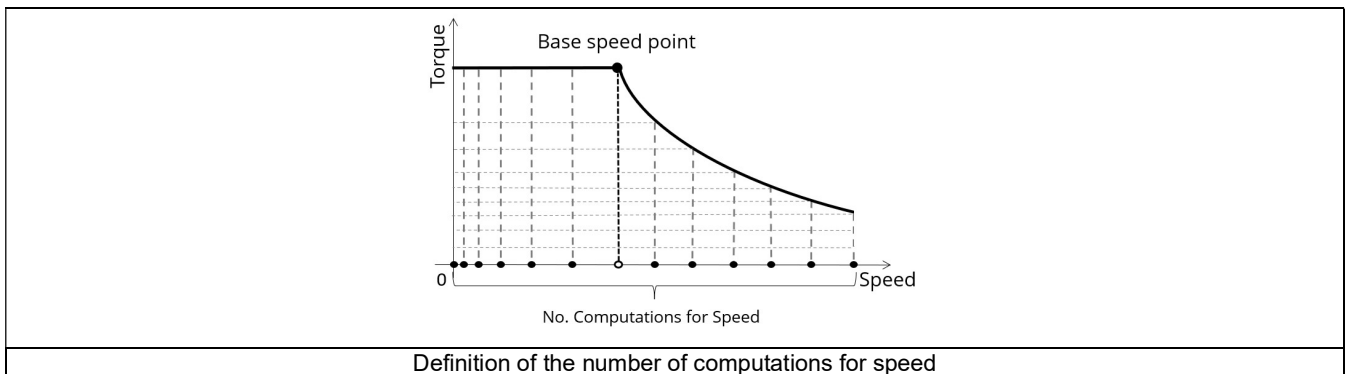
3.3.3.11 EM - Number of computations for speed

The "**EM - No. comp. for speed"** (*Efficiency map - Number of computations for speed*) corresponds to the number of points to be considered in the speed range from 0 to the maximum speed.
Half of these points are distributed from 0 to the base speed. The remaining points are distributed from the base speed to the maximum speed.
In both cases, base speed is considered as an additional point.
Note: If the user input parameter "**No. comp. for speed**" is an odd number, one discretization point is automatically removed.

Definition of the number of computations for speed

The default value is equal to 20. The minimum allowed value is 10 while the maximum recommended value is 40.

Note: Increasing the number of computations can improve the convergence of the optimization used to define the torque-speed curve and the efficiency map. However, that also means a longer computation time.

3.3.3.12 EM - Number of computations for torque

For the speed range [N_{base}; $N_{max.}$], the number of computations for torque is imposed by the number of computations for the defined speed range [N_{base}; $N_{max.}$] (Red points in the image shown below).
The advanced user input parameter "**EM - No. comp. for torque**" (*Efficiency map - Number of computations for torque*) allows to finalize the grid within the torque range [0, T ($N_{max.}$)] at the maximum speed (Black points in the image shown below).

The default value is equal to 4. The minimum allowed value is 4 while the maximum recommended value is 10.

Definition of the number of computations for torque
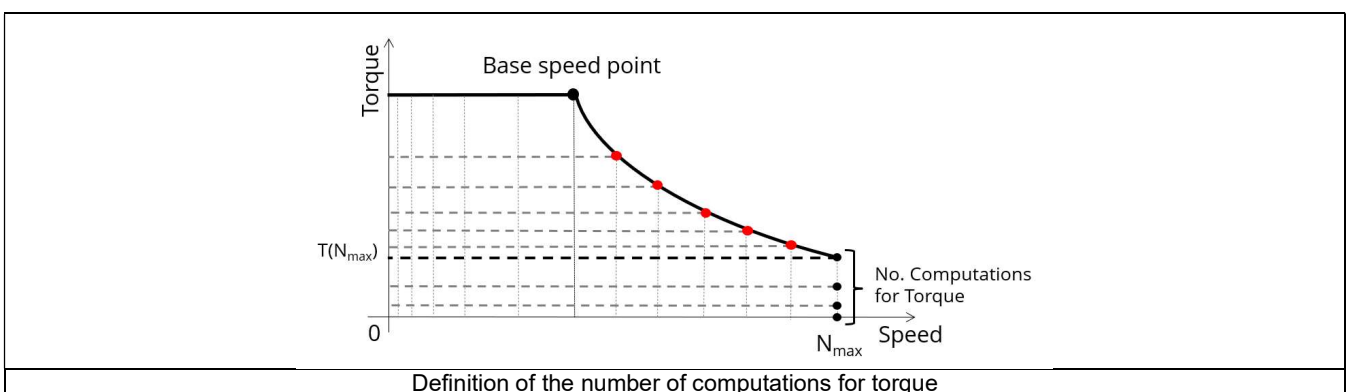
3.3.3.13 Skew model – No. of layers

When the rotor bars 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 modelling the skewing in Flux® Skew environment*).

3.3.3.14 Rotor initial position

The initial position of the rotor considered for computation can be set by the user in the field « **Rotor initial position** » (*Rotor initial position*). The default value is equal to 0.
The range of possible values is [-360, 360].

The rotor initial position has an impact only on the induction curve in the air gap.

3.3.3.15 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, thereby increasing the computation accuracy.

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

$$MeshPoint = (airgap) \times (airgap\ mesh\ coefficient)$$

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

3.4   Main principles of computation

Will be completed soon.

3.5   Test results

Once a test is finished, the corresponding results are automatically displayed in the central window.
The test results are calculated and displayed identical to those presented in the test "**Performance mapping – Sine wave – Motor – Efficiency map scalar U-f**".
Please refer to the section dedicated to this test to see the corresponding illustrations.