Altair® FluxMotor® 2022.2

Induction machines – Squirrel cage - Inner & Outer rotor

Motor Factory – Test – Performance mapping

General user information

Altairhyperworks.com

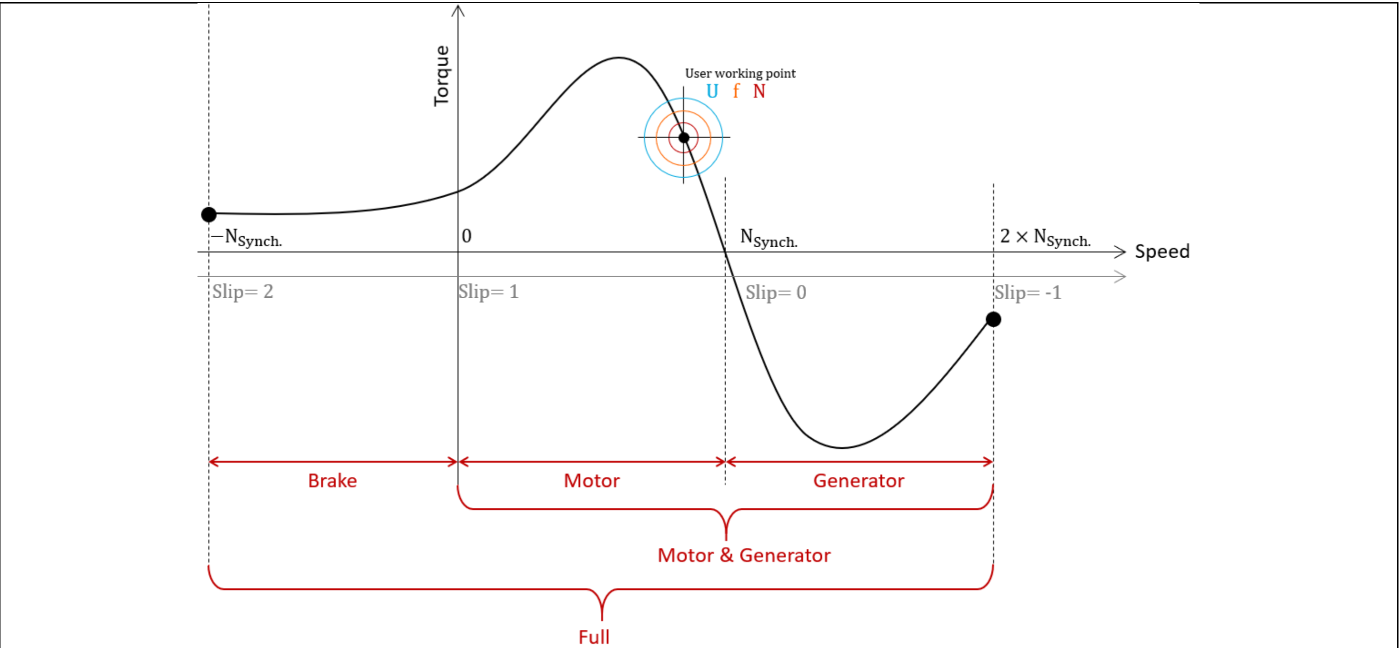
Contents

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)"

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_2022.2_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

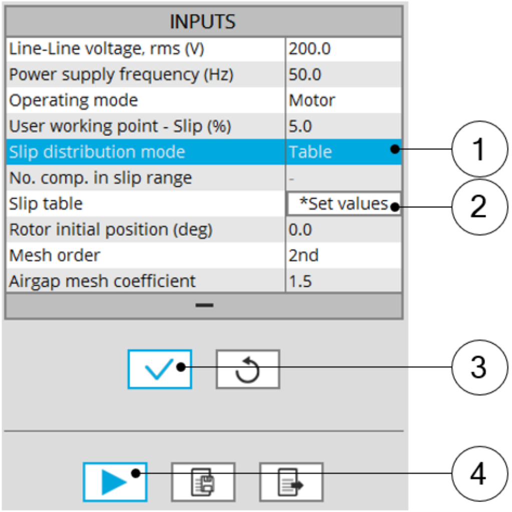
When "Logarithmic" is selected, the distribution of the computed points is automatically done. The number of computations to be done in the slip range must be set in the next field: "No. comp. in slip range".

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

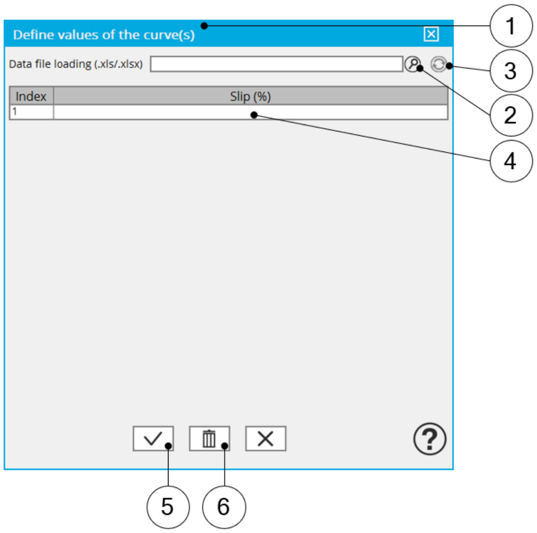
When "Table" is selected, the list of slips to be considered must be defined by using the next field: "Slip table" and by clicking on the button "Set values".
Two ways are possible to fill the table: either filling the table line by line or by importing an excel file where all the slips to be considered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

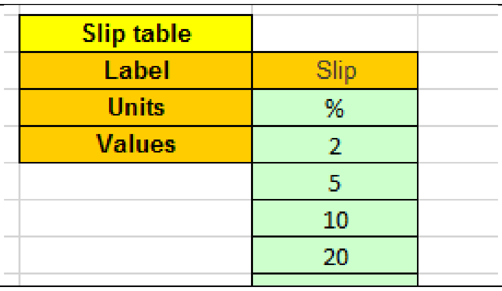
1	Select the "Table" option.
2	Click the button "Set values" of the field "Slip table" to open a dialog box to define the list of slips to be considered. Refer to the next illustration which shows how to fill the Slip table.
3	Button to validate and consider the user inputs
4	Button to run the computation



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.



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.

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

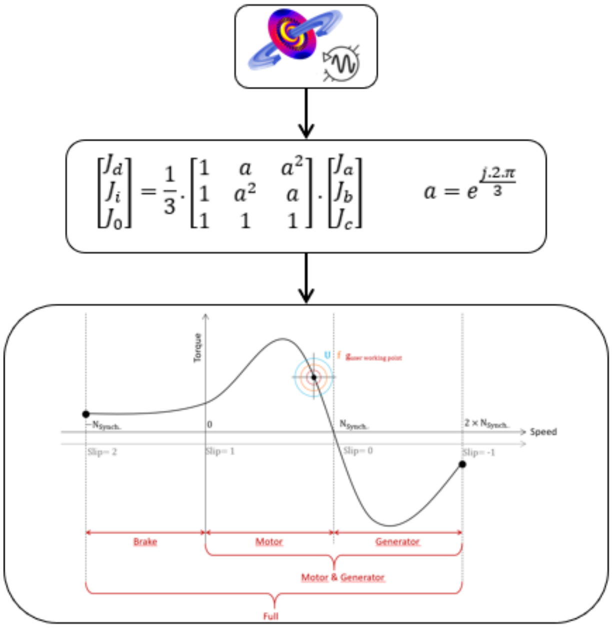
1.4.1 Introduction

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.



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

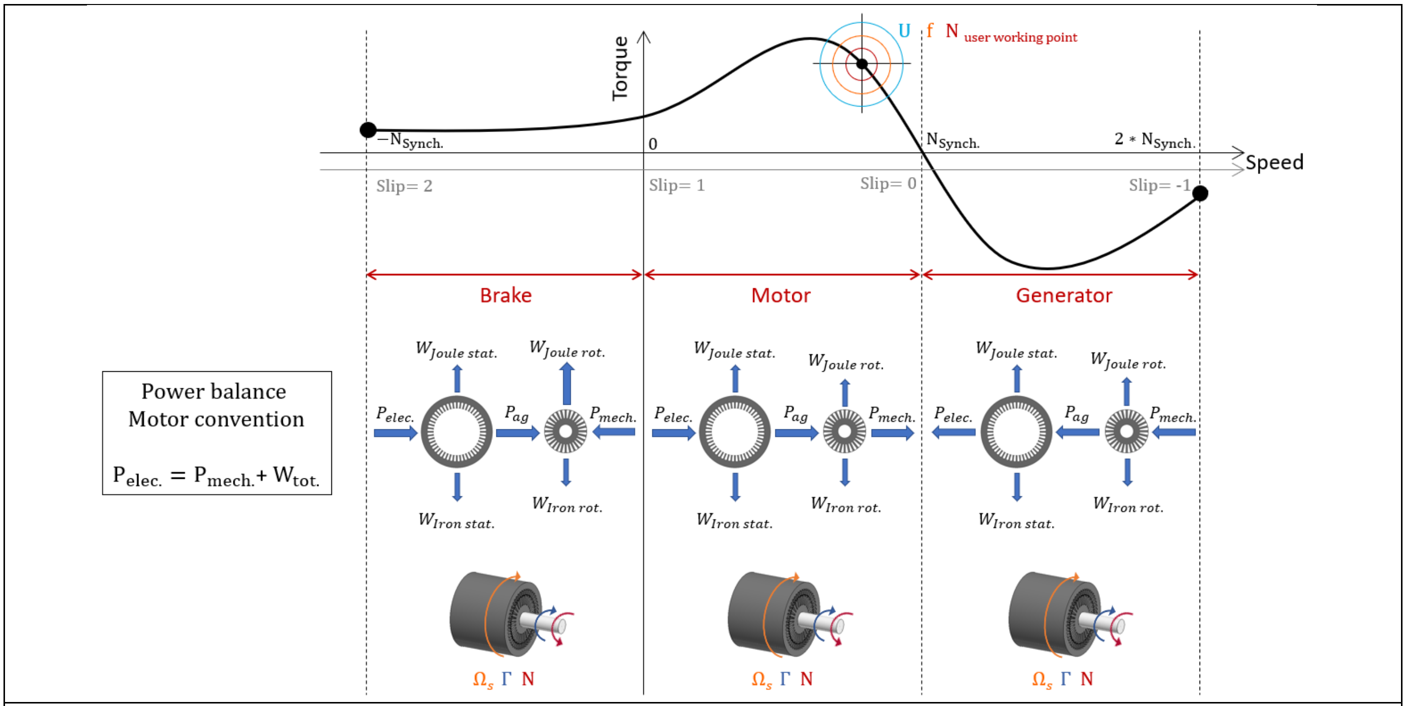
Computation process with symmetrical component transformation

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_2022.2_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_2022.2_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