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Altair® FluxMotor® 2024.1

Reluctance Synchronous Machines - Inner rotor

Motor Factory – Test – Performance mapping

General user information

Contents

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1   PERFORMANCE MAPPING – SINE WAVE – MOTOR – EFFICIENCY MAP

1.1   Overview

1.1.1   Positioning and objective

The aim of the test "**Performance mapping – Sine wave – Motor – Efficiency map**" 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 desired "Maximum speed" of the machine are considered.

Two types of command modes are available: The Maximum Torque Per Volt command mode (MTPV) and the Maximum Torque Per Amps command mode (MTPA).

Input parameters define torque-speed area in which the evaluation of the machine behavior is performed.

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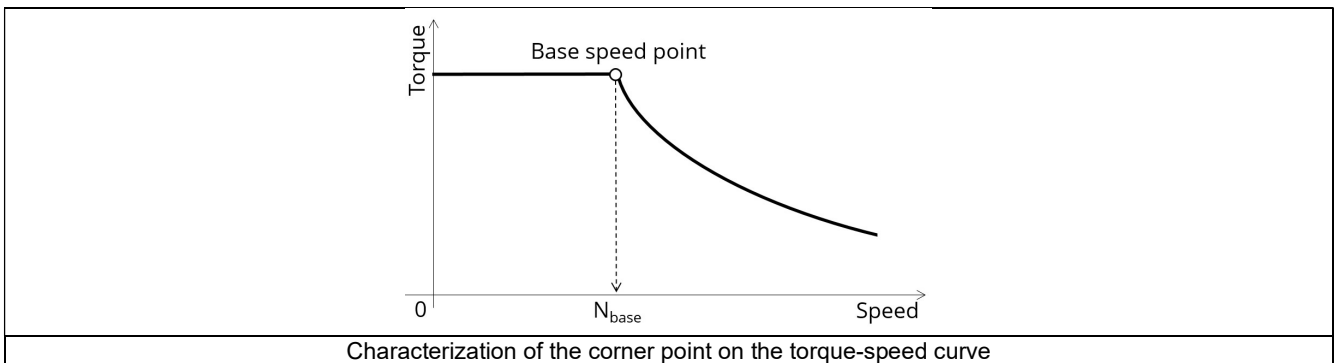
In the results, the performance of the machine at the base point (base speed point) and for the maximum speed set by the user are presented.
A set of curves (like Torque-Speed curve) and maps (like Efficiency map) are computed and displayed.

Mechanical torque versus speed - Example

Efficiency in torque-speed area - Example

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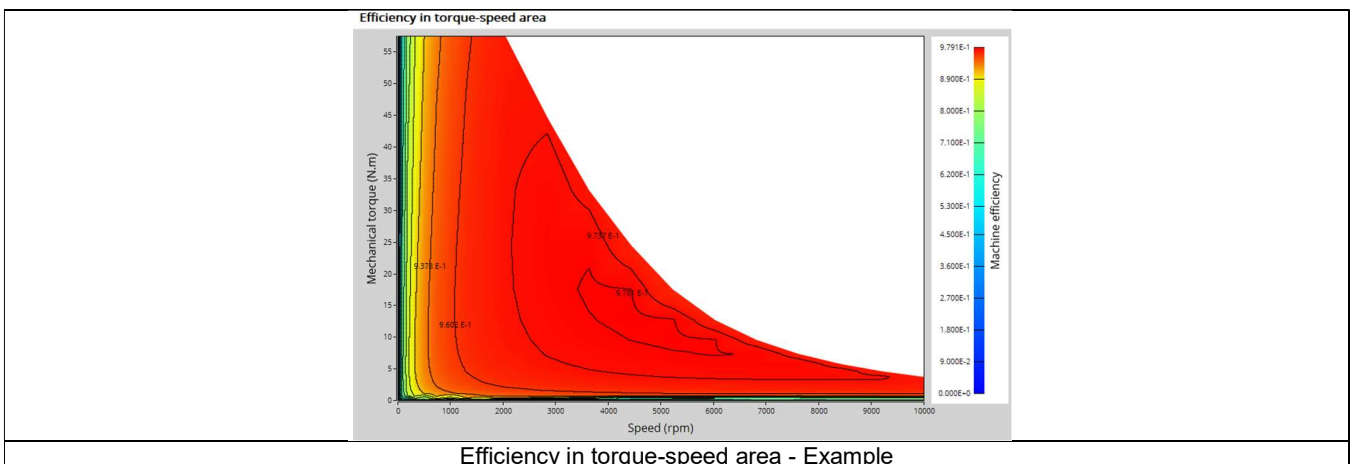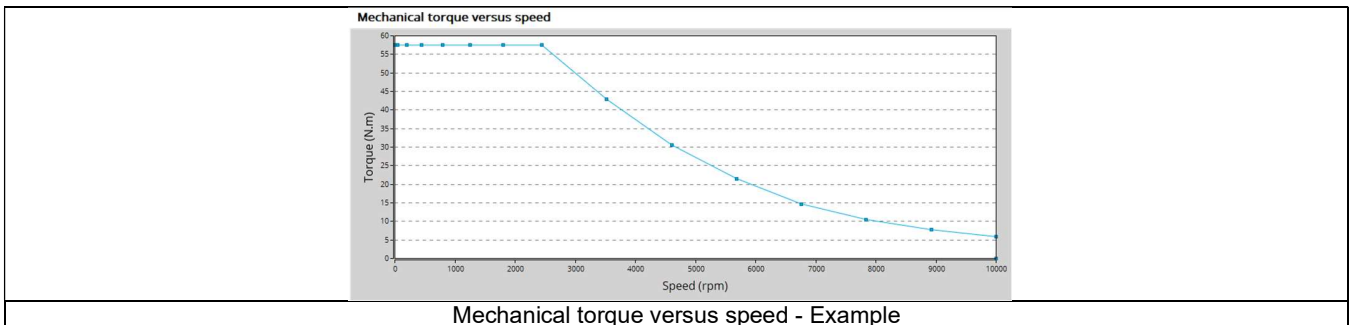
Note: In addition, in J_d-J_q plane, a graph shows the computed working points for the torque speed curve. The iso-electromagnetic torque, the iso-current and the iso-voltage are also displayed in J_d-J_q plane.
These results help the user to understand the possible performance of the machine in its electric environment.

Characteristics curves in J_d-J_q area - Example
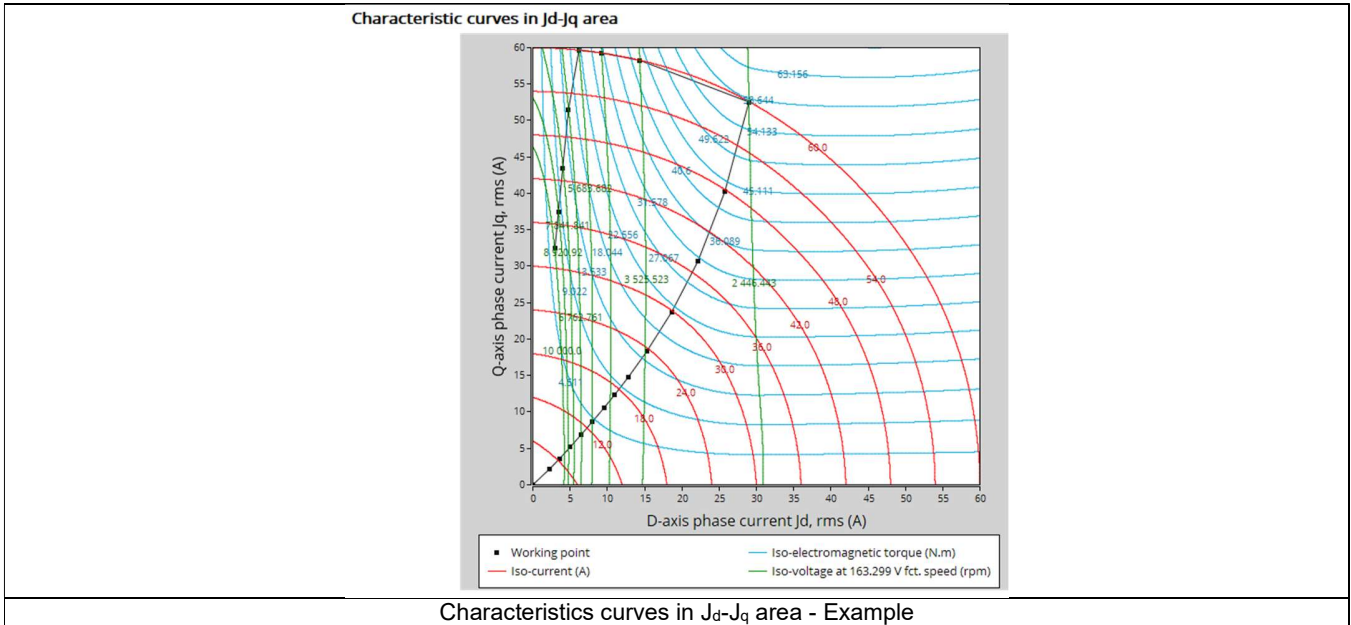
Moreover, two additional features are available in this test.
The first one allows extracting one torque-speed point from the efficiency map to get the machine performance, for this specific working point (general data + power balance).

Note: The considered working point is then displayed on all the maps available. The working point can be selected to visualize the corresponding main information.
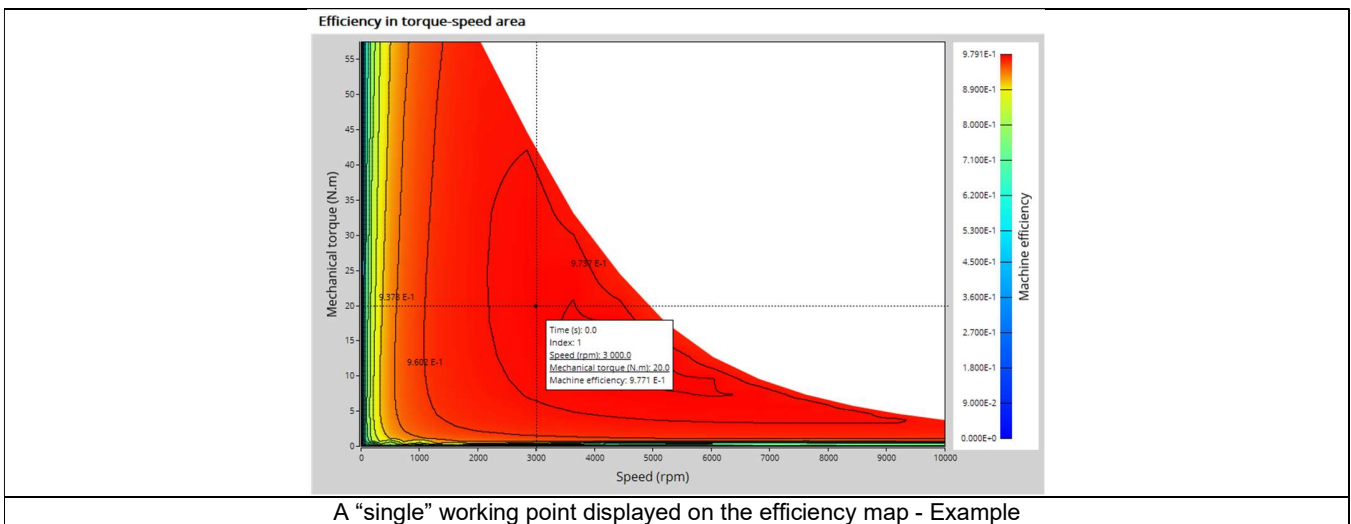
A "single" working point displayed on the efficiency map - Example

The second feature allows the user to define a duty cycle by giving a list of working points (speed, torque) versus the time. The displayed results illustrate the machine performance over the considered duty cycle (mean, min, and max values).

The time variation of the main quantities is also displayed (Mechanical torque, speed, control angle, current, voltage, power, efficiency, losses).

All the corresponding points are displayed on the different provided maps. Each working point can be selected to visualize the corresponding main information.
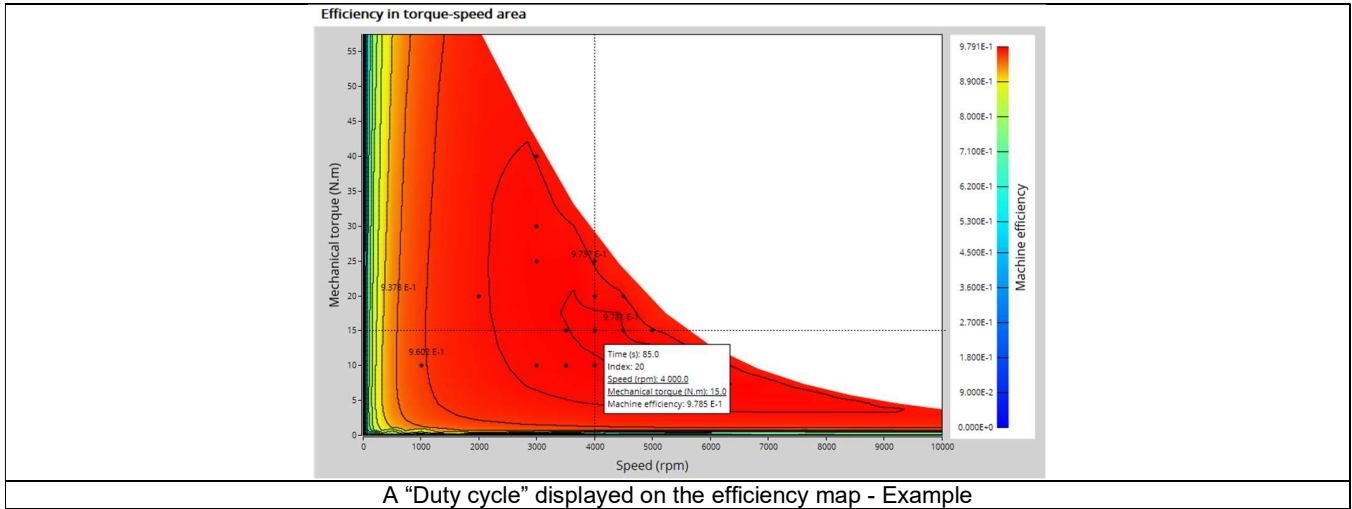
A "Duty cycle" displayed on the efficiency map - Example

The following table helps to classify the test "**Performance mapping – Sine wave – Motor – Efficiency map**".

Family	Performance mapping
Package	Sine wave
Convention	Motor
Test	Efficiency map

Positioning of the test "Performance mapping – Sine wave – Motor – Efficiency map"

1.1.2   User inputs

The main user input parameters needed to perform this test are the maximum allowed supplied, line-line voltage, the line current, the targeted maximum speed and the command mode. Winding temperatures must also be set.
When required, the location of the working points (single point or duty cycle) to be evaluated must be defined as inputs.

Warning! Default values of advanced inputs have been set to get the best compromise between accuracy and computation time.
Three advanced user input parameters allow adjusting the compromise between accuracy and computation time: the number of computations for J_d-J_q , for speed and for torque.

1.1.3   Main outputs

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

1.1.3.1   Main test results

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

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

3) Machine performance - User working point (when requested)
   - General data like torque, speed, electrical powers, control angle, efficiency etc.
   - Power balance

4) Machine performance - Duty cycle analysis (when requested)
   - General data like torque, speed, electrical powers, control angle, efficiency etc. (min., mean and max. values)
   - Power balance
   - Energy balance

5) Power electronics (when requested by the user)
   - Inverter
   - Base speed point - Power balance
   - Maximum speed point - Power balance
   - User working point – Power balance (when requested)
   - Duty cycle - Power balance (when requested)

6) Torque-speed curves
   - Mechanical torque versus speed
   - Current (J, J_d, J_q) versus speed
   - Voltage (V, V_d, V_q) versus speed
   - Control angle versus speed
   - Power (Mechanical power, machine electrical power, system electrical power) versus speed
   - Power factor versus speed
   - Losses versus speed (total machine and system, Joule, iron, mechanical, additional, power electronics)

7) Characteristic curves
   - Electromagnetic torque versus current and control angle (Ψ) according to base speed point
   - Characteristic curves in Jd-Jq area - Evolution of the working points in Jd-Jq plane, with iso-torque, iso-current and iso-voltage.

8) Torque-Speed maps
   - Efficiency in torque-speed area
   - Current (J, J_d, J_q) in torque-speed area
   - Voltage (V, V_d, V_q) in torque-speed area
   - Control angle in torque-speed area
   - Power in torque-speed area (Mechanical power and electrical power) in the torque-speed plane
   - Power factor in torque-speed area
   - Losses in torque-speed area (Total, Joule, Iron, Mechanical and additional) in the torque-speed plane

9)   Duty cycle curves (when requested)
- Speed versus time
- Mechanical torque versus time
- Control angle versus time
- Current (J, J_d, J_q) versus time
- Voltage (V, V_d, V_q) versus time
- Power factor versus time
- Power versus time (Mechanical power and machine and system electrical power)
- Efficiency versus time
- Losses versus time (Total, Joule, Iron, Mechanical and additional)

Note: When a user working point has been targeted or if a duty cycle is considered, the corresponding working points are displayed on all the maps described above.

1.2   Settings

Three buttons give access to the following setting definition:

- Thermal settings – Definition of the temperature of active components.
  For the considered test this concerns the winding temperatures.
- Power electronics settings - Definition of the power electronics parameters
- Mechanics settings - Definition of mechanical loss model parameters

  For more details, please refer to the document: MotorFactory_SMRSM_IR_3PH_Test_Introduction – section "settings"

1.3   Inputs

1.3.1   Introduction

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

1.3.2   Sharing data between tests

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

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

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

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

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

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

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

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

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

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

Note: In instances where quadrant inputs lead to incompatibility between the model map test and the efficiency map test, only settings and inputs are imported. A warning is issued, and Flux simulation is initiated to rectify the discrepancy.
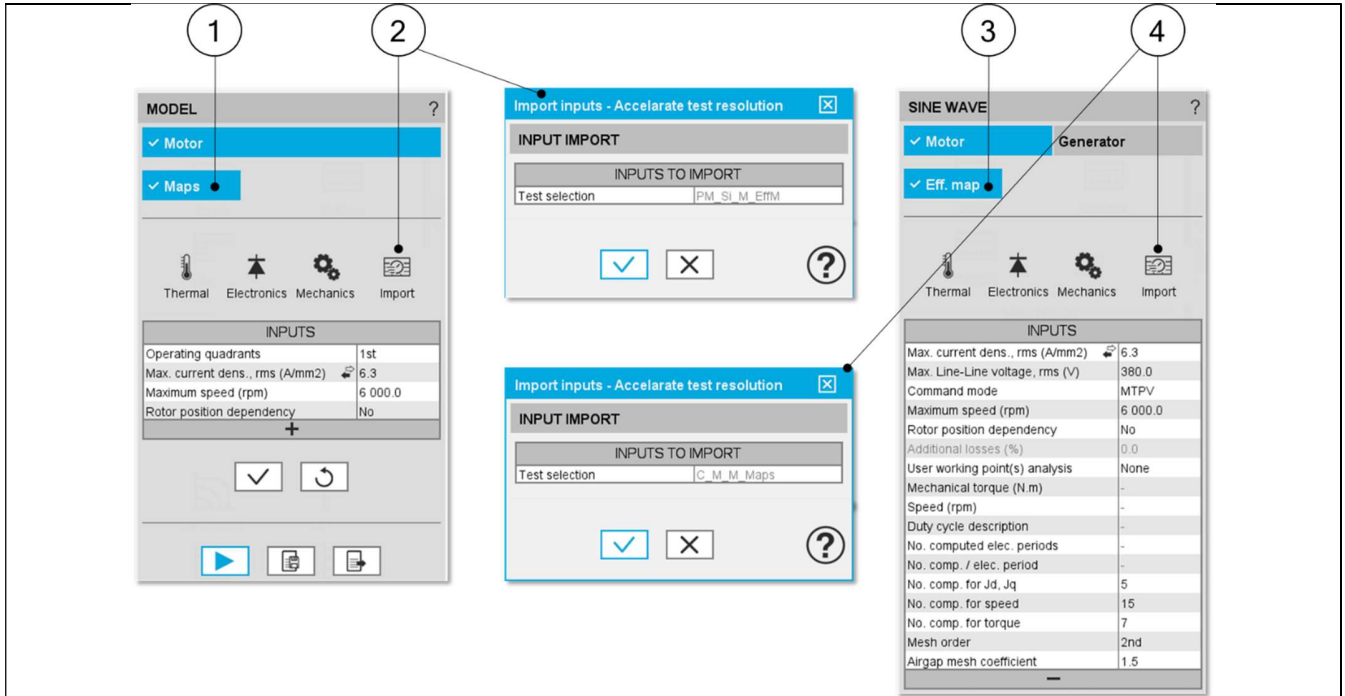
	Import function in Model Map test and Efficiency Map test to accelerate test resolution. Example for Wound field synchronous machines
1	Open model map test environment when an efficiency map test is available for import
2	Click the import button and import the settings, inputs, and Flux data of the latest efficiency map test
3	Open efficiency map test environment when a model map test is available for import
4	Click the import button and import the settings, inputs, and Flux data of the latest model map test

1.3.3   Standard inputs

1.3.3.1   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.
In this case, the current definition mode should be « **Density** »

Electric current can be defined directly by indicating the value of the maximum line current (the rms value is required).
In this case, the current definition mode should be « **Current** »

1.3.3.2   Maximum line current, rms

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

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

1.3.3.3   Maximum current density, rms

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

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

1.3.3.4   Maximum Line-Line voltage, rms

The rms value of the maximum line-line voltage supplying to the machine: "**Max. 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.

1.3.3.5   Command modes – Introduction

For any applied command mode, the first step of the process consists of computing the torque-speed curve and the second step is to compute the efficiency map bounded by the torque-speed curve.
In function of the command mode, the applied process of computation is different to obtain curves and maps.
For additional information on this topic see the section 1.5 (Command modes)

1.3.3.6   Maximum speed

The computation and analysis of the torque-speed curves are performed over a given speed range.
The maximum allowed value for the « **Maximum speed** » corresponds to 53000 rad/s - about 506000 rpm.
Notes: As a function of the maximum speed value, following different cases must be considered:

   1)   Case 1: The maximum speed is lower than the base speed N_{base} (corner point speed of the torque-speed curve) $N_{max} < N_{base}$.

In that case, for any command mode (MTPA or MTPV), the behavior of the machine will be studied over the speed range $[0, N_{max}]$.
That allows the user to choose precisely the range of speed to be considered for computing and displaying the torque-speed curve and especially maps like efficiency map.

   2)   Case 2: The maximum speed is greater than the base speed (corner point speed) $N_{max} > N_{base}$.

The relevance of the maximum speed given by the user is analyzed to evaluate if it is reachable by the machine.
If the user maximum speed is unreachable by the machine, the correction of this value is automatically performed.
The resulting new maximum speed is linked to a limit torque. This limit torque is obtained by applying a reduction coefficient to the base point torque.

1.3.3.7   Rotor position dependency

It defines the rotor position dependency of electromagnetic data used for the optimization of the efficiency map such as D-axis magnetic flux, Q-axis magnetic flux, electromagnetic torque, iron losses. By default, the rotor position dependency is set to "No" but it can be set to "Yes". In this case the computation will be done along the two dimensions J_d - J_q, with an additional fourth axis corresponding to the rotor position θ_r.

Note: This option allows to have a better accuracy in the evaluation of magnetic flux, electromagnetic torque as well as iron losses. It is worth noting that only with rotor position dependency that the rotor iron losses can be evaluated.

1.3.3.8   Additional losses

Note: "Additional losses" input is not available in the current version (The input label is written in grey).

1.3.3.9   User working point(s) analysis
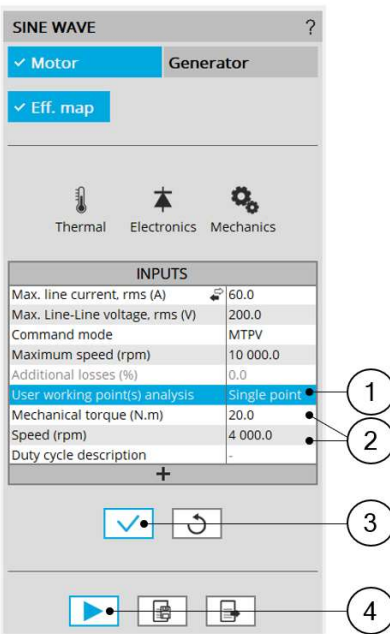
It is possible to perform additional analysis on working point(s) located under the torque-speed curve. The user's input "**User working point(s) analysis**" *(additional analysis on working point(s))* gives three possibilities to the user:

1)   User working point(s) analysis = None (=default mode)

This corresponds to the basic configuration of the test, with no additional working point analysis.

2)   User working point(s) analysis = Single point

This allows computing the machine performance on a working point specified by the user with the targeted speed and torque. In that case the next two fields must be filled with the targeted speed and mechanical torque.

	User working point analysis = Single point	
1	Select the "Single point" option to perform a computation on one working point.	
2	Define the targeted working point mechanical torque and speed.	
3	Button to validate and consider the user inputs	
4	Button to run the computation	

3)   User working point(s) analysis = Duty cycle

This allows computing the machine performance all over a considered duty cycle.
This duty cycle must be defined by using the next field: "Duty cycle description" and by clicking on the button "Set values".
Two ways are possible to fill in the table: either filling in the table line by line or by importing an excel file which all the working points of the duty cycle are defined.

Note: A working point is defined by a time, a speed and a mechanical torque.

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	User working point analysis = Duty cycle
1	Select the "Duty cycle" option
2	Click in the button "Set values" of the field "Duty cycle" to open a dialog box to define the duty cycle. Refer to the next illustration which shows how to fill the Duty cycle table.
3	Button to validate the user input data
4	Button to run the computations

Note: Once the test results have been computed, new user working point and duty cycle values can be set, and results will appear instantaneously when relaunching the test.
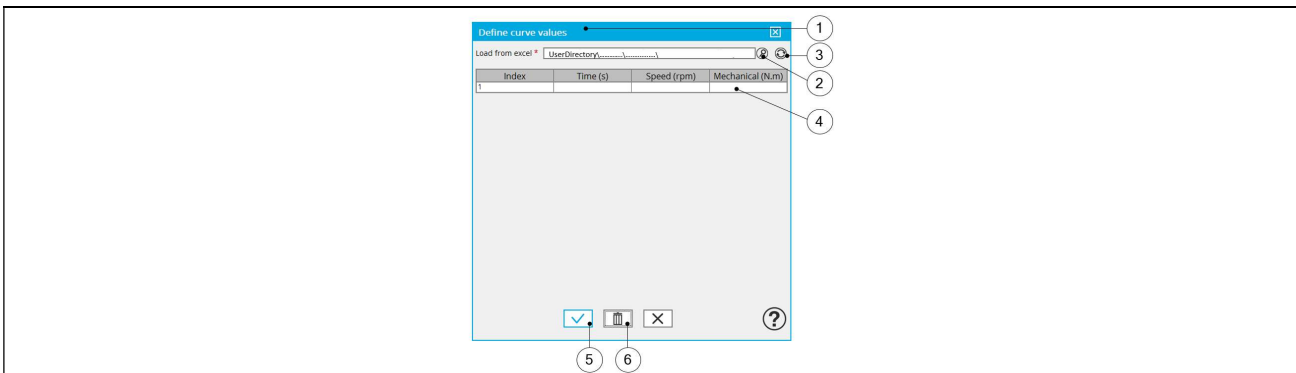
	User working point analysis = Duty cycle – Dialog box to define the duty cycle
1	Dialog box opened after having clicking the button "Set values" in the field "Cycle description"
2	Browse the folder to select an Excel file which is described the duty cycle
3	Button to refresh the table data when the considered Excel file has been modified
4	Fields to be filled with data to describe the duty cycle to be considered

Note: The Excel template used to import a duty cycle 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 duty cycle

1.3.4   Advanced inputs

1.3.4.1   Number of computed electrical periods

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

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

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

1.3.4.2   Number of computations for J_d, J_q

First, it is needed to compute the D-axis and Q-axis flux linkage in the J_d - J_q plane.

To get maps in the J_d - J_q plane, a grid is defined. The number of computation points along the d-axis and q-axis can be defined with the user input « **No. Comp. for J_d, J_q** » *(Number of computations for D-axis and Q-axis currents)*.
The default value is equal to 5. This default value provides a good compromise between accuracy and computation time. The minimum allowed value is 5.

1.3.4.3   Number of computations for speed

The "**No. comp. for speed**" (*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 15, the minimum allowed value is 5. 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.

1.3.4.4   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 speed in the speed range [N_{base}; $N_{max.}$] (Red points in the image shown below).
The advanced user input parameter "**No. comp. for torque**" allows finalizing 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 7. The minimum allowed value is 3. The maximum recommended value is 20.

Definition of the number of computations for torque – MTPV command mode
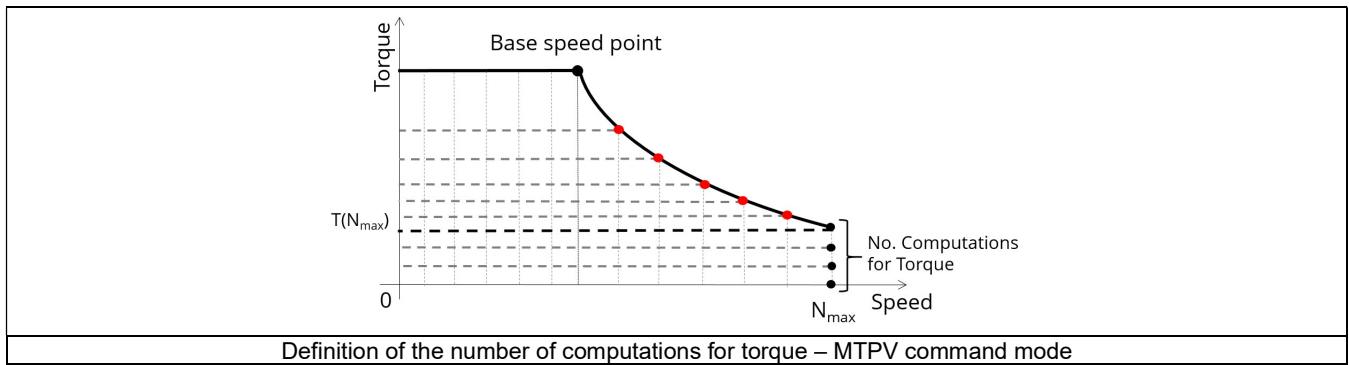
1.3.4.5 Skew model – Number of layers

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

1.3.4.6 Mesh order

To get the results, the original computation is performed using a Finite Element Modeling.
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.

1.3.4.7 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 to a higher mesh density inside the airgap and increasing the computation accuracy.

The imposed Mesh Point (size of mesh elements touching points of the geometry), inside the Flux®, 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.

1.3.4.8 Rotor d-axis location

In most cases, the computations are performed by considering a relative angular position between rotor and stator.

For the reluctance synchronous machines, the rotor d-axis location is defined and automatically used to perform computations.
This value is characterized by the saliency topology. This is important to keep in mind this information it.

For more details, please refer to the document: MotorFactory_SMRSM_IR_3PH_Test_Introduction – section "Rotor and stator relative position".

1.4   Main principles of computation

1.4.1   Introduction

This paragraph deals with the process to get the torque-speed curves and maps (For example - efficiency map).

The process is separated into the two following parts:
- Raw data and Park model
- Identification of the torque-speed curves and maps – Overview

1.4.2   Raw data and Park's model

The first step consists of computing the raw data which characterize the machine in the J_d-J_q plane. This is done using Finite Element modelling (Flux® – Magnetostatic application).
To do that, a grid of (J_d, J_q) values is considered.
Flux linkage through each phase (Φ_a, Φ_b, Φ_c) and flux density in regions (teeth and yoke of the machine) are computed and extracted as a function of (J_d, J_q).

Raw data – Test "Performance mapping – Sine Wave – Motor – Efficiency map"

The second step consists of using the raw data with the Park's model.
D-axis flux-linkage component (Φ_d) and Q-axis flux-linkage component (Φ_q) is computed according to the Park's transformation.

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

1) If rotor position dependency is set to "No", the flux linkage maps, and the following formula are used:

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

Park's model - Motor convention - Torque equation

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

2) If rotor position dependency is set to "Yes", the Electromagnetic torque T_{em} is computed thanks to finite element computation and virtual work method to get the best evaluation of the ripple torque.

Note: In case the Rotor position dependency is set to "Yes", **Electromagnetic torque T_{em}** average value computed with the Park's equation or with virtual works are equal.
Note: The computations are the same as those performed in the test "Characterization - Model – Motor - Maps" with or without rotor position dependency. Here are the obtained results which are used to build the next step, that is, curves and maps in the torque-speed area:

- D-axis flux-linkage component - Φ_d
- Q-axis flux-linkage component - Φ_q
- Electromagnetic torque T_{em}
- Stator iron losses W_{iron} versus speed
- Joule losses in stator winding W_{Cus}
- Mechanical losses versus speed
- Amount of total losses W_{total} versus speed

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1.4.3 Identification process for the torque-speed curves and maps – Overview

Below presented are the three main steps involved in building the efficiency map and other associated results. These steps are similar for all the command modes with only some specifications.

These steps are performed by using the computed raw data (see previous section) with optimization processes associated with the considered command mode functions like MTPA curves.

- Building of the torque-speed curve and other associated results
- Define the grid in the area under torque-speed curve
- Building of the efficiency map and other associated results

Main steps of the computation algorithm
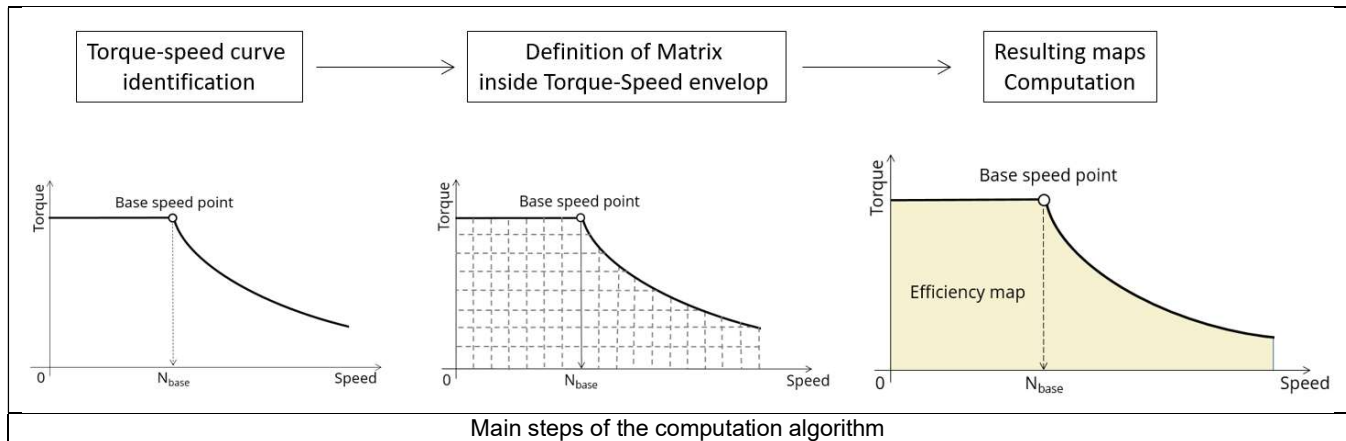
For more information, please refer to the section 1.5 (Command modes) dealing with the command modes

1.5   Command modes

1.5.1   Introduction

The user can choose between two types of command modes:

- The Maximum Torque Per Voltage (MTPV)
- The Maximum Torque Per Amps (MPTA)

For any command mode applied, the first step of the process consists of computing the Torque-speed curve (curve which bounded the domain) and the second step is to compute maps bounded by the Torque-speed curve (Efficiency maps, Iron loss maps…).

Torque-speed curve and efficiency map
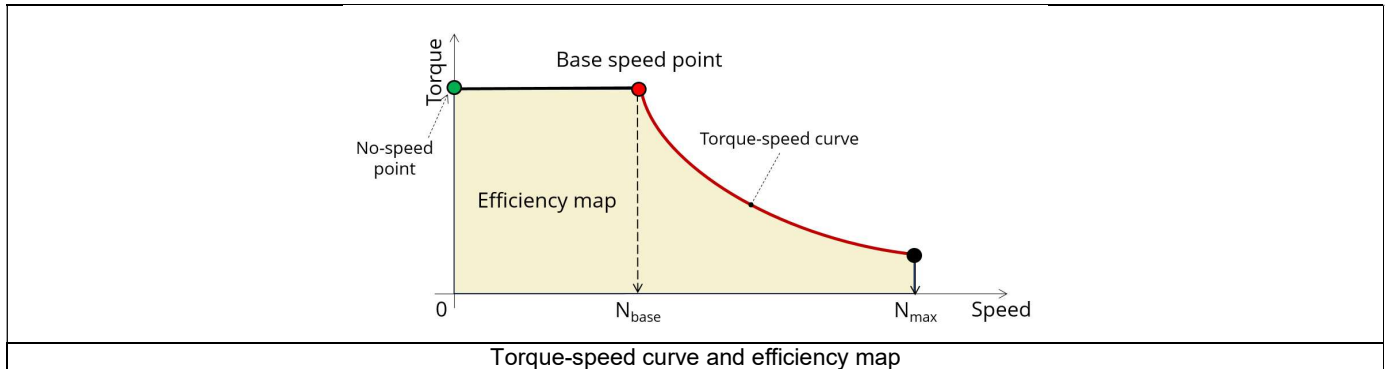
1.5.2   Maximum Torque Per Voltage command mode (MTPV)

1.5.2.1   Positioning and objective

The Maximum Torque Per Voltage command mode (MTPV) allows to compute the torque-speed curve which corresponds to the maximum potential of mechanical torque (or mechanical power) of a motor from the base speed point to the maximum speed point.
This command mode shows the full potential of the machine, but it is also the most difficult command mode to implement in terms of control and drive.

When this command is chosen, it is used to compute the torque speed curve from the base speed point to the maximum speed.
Using the base speed point, the torque speed curve is obtained by imposing the useful torque computed at the base speed point and by maximizing the efficiency.
The maps bounded by the considered torque-speed curve are computed by maximizing the efficiency for each paired values (Torque, Speed).

Torque speed curve with MTPV command mode
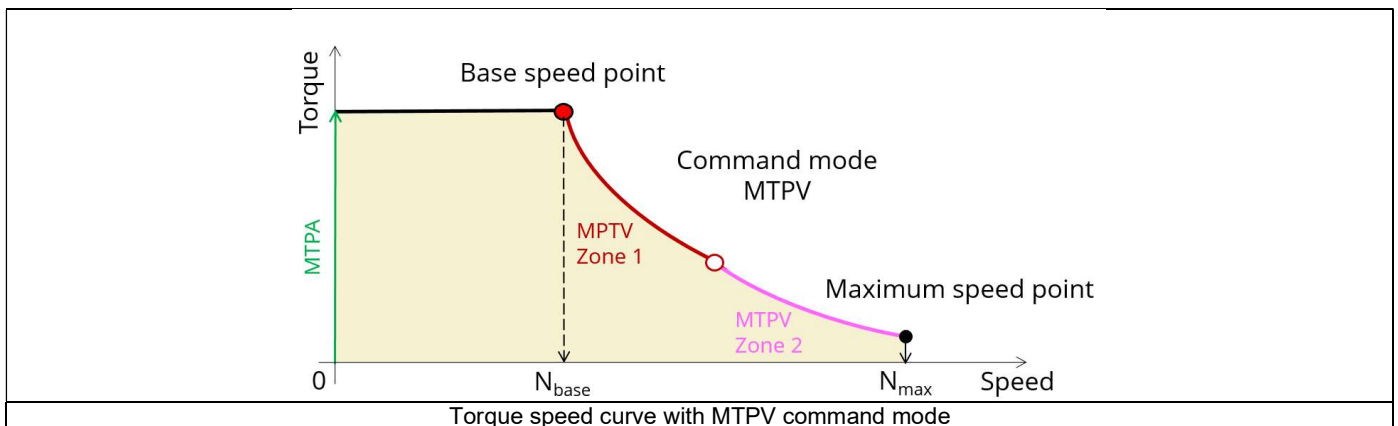
Over the speed range [N_{base}, $N_{max.}$] we distinguish two main zones, the Zone 1 commonly called "Flux weakening" and the Zone 2 commonly called "MTPV curve".
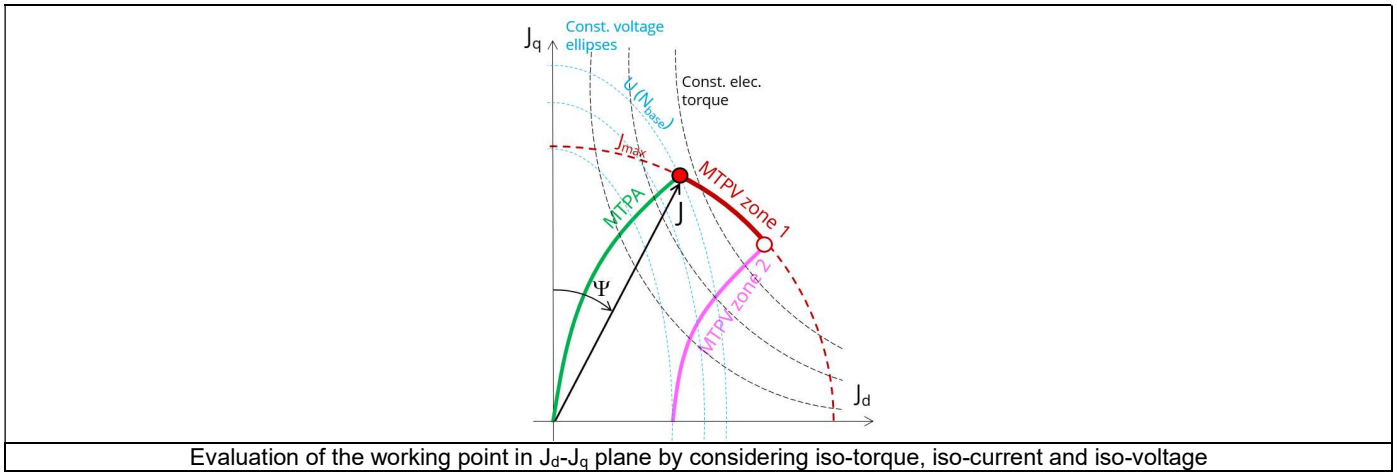
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Evaluation of the working point in J_d-J_q plane by considering iso-torque, iso-current and iso-voltage

In the first zone (MTPV zone 1), the maximization of the mechanical torque for a given speed is reached by keeping the maximum values of voltage and current, and by driving the control angle (Ψ).

$$U = U_{max}$$
$$I = I_{max}$$

In a second zone (MTPV zone 2), the maximization of the mechanical torque is reached by keeping the maximum values of voltage and by decreasing the line current below the maximum allowed value, and by driving the control angle (Ψ).

$$U = U_{max}$$
$$I < I_{max}$$

In FluxMotor®, MTPV label is used to mention the combination of these two zones (for both, the maximum torque is computed, at the maximum voltage available. The optimization process automatically deduces the best working zone according to the following constraints:

$$U = U_{max}$$
$$I \leq I_{max}$$

Note: The MTPV zone 2 is available only for motors which have, in D-Q current area, their iso-voltage ellipse center located inside the iso-current circle corresponding to the maximum value of current.

With MTPV command mode the mechanical power is not imposed over the speed range [N_b, N_{max}.] as commonly done.
In fact, over Zone 1 and Zone 2 the MTPV command mode imposes to maximize the mechanical torque at maximum voltage. Maximizing the mechanical torque at imposed speed is equivalent to maximizing the mechanical power.
In conclusion, the MTPV command mode allows to spotlight the potential of mechanical power that the machine can provide over a speed range from the base speed point to the maximum speed point with a given maximum line-line voltage and a maximum line current.
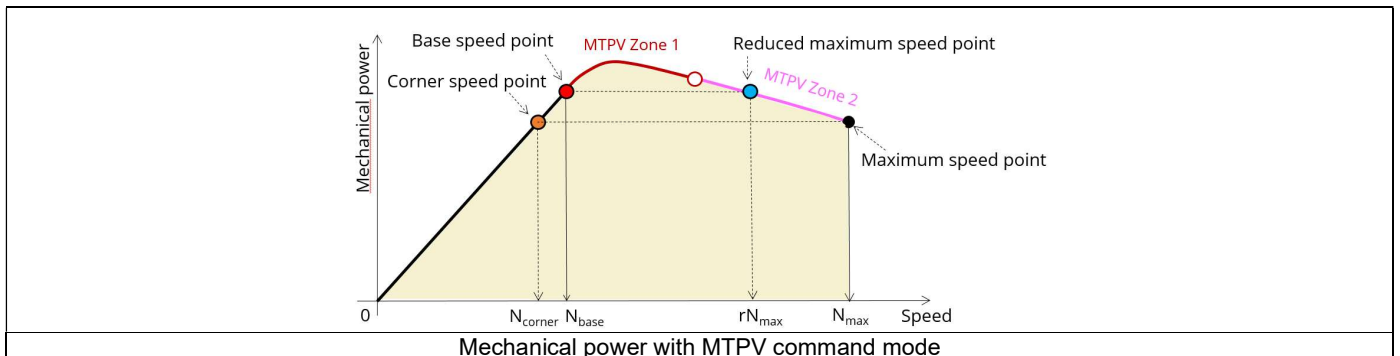
Mechanical power with MTPV command mode

Thanks to the MTPV results we can easily deduce the maximum mechanical power that the machine is able to provide over a range of speed.

For examples, referring to the previous figure:

- If we want to impose the mechanical power obtained at the maximum point speed, we can easily deduce the bound at low speed. We called this point as corner speed point (Orange point on the previous figure).

- If we want to impose the mechanical power obtained at the based speed point, we are able to deduce the bound at high speed. We called this point as reduced maximum speed point (Blue point on the previous figure).

Note: The corner point is equal to the base speed point when the mechanical power at maximum speed is equal to the mechanical power we get for the base speed.

1.5.2.2   Torque-speed curve – Computation and displaying

1) Base speed point

The first step consists of computing the base point (red point on the image shown below).
The target is to find the maximum reachable torque (T_{max}) considering:

- The maximum allowed Line-Line voltage (U = U max)
- The maximum allowed line current (I = Imax)

An optimization process is used, and the variable parameters are the speed (N), the D-axis and the Q-axis components of the phase current (J_d, J_q).

2) Maximum speed point

The second step consists of verifying that the maximum speed set by the user is reachable (black point on the image shown below).
The target is to find the maximum reachable torque (T_{max}) considering:

- The maximum allowed Line-Line voltage (U = U_{max})
- Line current less than or equal to the maximum allowed value (I ≤ I_{max})
- The maximum speed set by the user (N=$N_{max.}$)

An optimization process is used, and the variable parameters are the D-axis and the Q-axis components of the phase current (J_d, J_q).

If the user maximum speed is reachable, the used optimization process reaches convergence and the torque-speed curve identification process continues.
Sometimes, the maximum speed set by the user is not reachable by the machine.
With the MTPV command mode, the maximum speed depends on the characteristics of the motor, and especially on its capabilities for operating in the flux weakening zone. In this case, a computation of a reachable maximum speed is automatically done.

If the maximum speed indicated by the user is not reachable by the machine, an automatic correction is performed.
In that case, the target is to find the maximum reachable speed considering:

- Line-Line voltage equal to the maximum allowed value (U = $U_{max.}$)
- Line current less than or equal to the maximum allowed value (I ≤ $I_{max.}$)
- The mechanical torque obtained at the base speed divided by ten (T = T(Nb)/10)

The variable parameters are the speed (N), the D-axis and the Q-axis components of the phase current (J_d, J_q).

3) No speed working point

The third step consists to compute the no-speed working point (Green point in the image shown below).
The target is to find the maximum reachable efficiency for the machine by considering:

- Line-Line voltage less than or equal to the maximum allowed value (U ≤ U_{max})
- Line current less than or equal to the maximum allowed value (I ≤ I_{max})
- A null speed
- Imposed torque equal to the base speed torque (T=T(Nb)) if Nb < $N_{max.}$ or equal to the maximum speed torque (T = T($N_{max.}$)) if Nb > $N_{max.}$

An optimization process is used and the variable parameters are the D-axis and the Q-axis component of the phase current (J_d, J_q).
Note: At zero speed, losses match exactly with Joule losses. In that case, one can consider that MTPA is applied (Green point in the image shown below).

4) Torque-speed curve in the range]0, N_b[

The base speed, the maximum speed and the no-speed working points being fixed, the fourth step consists of computing the part of the torque-speed curve where the torque is constant (Black line in the image shown below).
The target is to find the maximum reachable efficiency for the machine by considering:

- Imposed torque equal to the base speed torque T=T(Nb) if Nb < N_{max}. or T = T(N_{max}.) if Nb > N_{max}.
- Imposed speed with N $\in$]0, Nb[
- Line-Line voltage less than or equal to the maximum allowed value (U ≤ U_{max})
- Line current less than or equal to the maximum allowed value (I ≤ I_{max})

The variable parameters are the D-axis and the Q-axis components of the phase current (j_d, j_q).

5) Torque speed curve in the range] Nb, N_{max} [

Then, the last step consists of computing the torque-speed curve over the speed range] Nb, N_{max} [(red curve in the image shown below). This step is done only when N_b < N_{max}.The target is to find the Maximum reachable torque by considering:

- Imposed speed with N$\in$]Nb , N_{max} [
- Line-Line voltage equal to the maximum allowed value (U = U_{max})
- Line current less than or equal to the maximum allowed value (I ≤ I_{max})

An optimization process is used, and the variable parameters are the D-axis and the Q-axis components of the phase current (J_d, J_q).

MTPV command modes – Torque-speed curve computation process		
P_1	**Base speed point**	Target: Maximum torque (T_{max})
	Constraints	I = I_{max}, U=U_{max},
	Variable parameters	J_d, J_q, Speed (N)
P_2	**Max. speed point**	Target: Maximum torque (T_{max})
	Constraints	I ≤ I_{max} U=U_{max} Speed = Maximum speed (N_{max}.)
	Variable parameters	J_d, J_q
P_3	**Null speed point**	Target: maximum efficiency
	Constraints	I ≤ I_{max} U ≤ U_{max} Speed = N = 0 Torque = base speed torque (T(N_b))
	Variable parameters	J_d, J_q
C_1	**Low speed zone**	Target: maximum efficiency
	Constraints	I ≤ I_{max} U ≤ U_{max} Speed $\in$]0, Nb[Torque = base speed torque (T(N_b))
	Variable parameters	J_d, J_q
C_2	**High speed zone**	Target: maximum torque (T_{max})
	Constraints	I ≤ I_{max} U = U_{max} Speed N $\in$]N_b, N_{max}.[
	Variable parameters	J_d, J_q

1.5.2.3 Computation and displaying maps

Evaluating the maps for all the electromagnetic quantities consists of computing the machine performance for each node of a grid bounded by the torque-speed curve (Yellow part in the image shown below).

1) **Maps at no-speed**

At no-speed losses match exactly with Joule Losses. One can consider that MTPA command is applied.
In that case, the target is to minimize the Joule losses by considering:

- Line-Line voltage less than or equal to the maximum allowed value ($U \leq U_{max}$)
- Line current less than or equal to the maximum allowed value ($I \leq I_{max}$)
- Speed = 0
- Imposed torque by the user discretization.

An optimization process is used, and the variable parameters are the D-axis and the Q-axis components of the phase current (J_d, J_q).

2) **Maps at no torque**

At zero torque, only iron losses and mechanical losses, which are depending of the speed, are computed. All other electromagnetic quantities are set to 0 (including efficiency).

3) **Maps at no-speed and no-torque**

When speed and torque are null all the quantities are equal to 0.

4) **Maps in the range]0, N_{max}]**

For each paired (torque, speed) working points, the target is to find the maximum reachable efficiency for the machine by considering:

- Imposed speed with $N \in [0, N_{max}]$
- Imposed torque with $T \in [0, Tb]$
- Line-Line voltage less than or equal to the maximum allowed value ($U \leq U_{max}$)
- Line current less than or equal to the maximum allowed value ($I \leq I_{max}$)
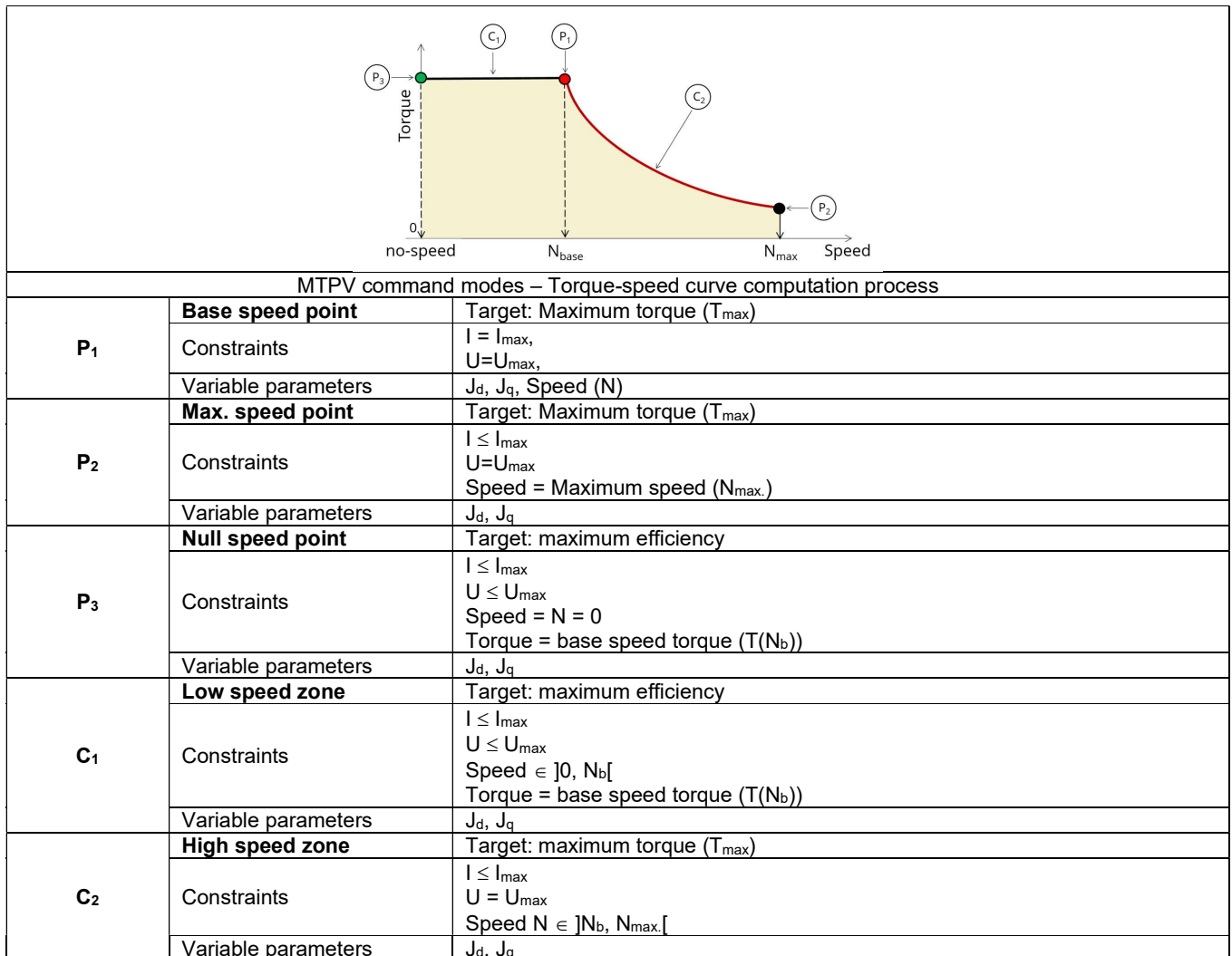
An optimization process is used, and variable parameters are the D-axis and the Q-axis components of the current (J_d, J_q).
Note, the computation of efficiency integrates the Joule losses, iron losses, mechanical losses, and additional losses (if used).

Note: Usually, at low speed, the Joule losses dominate other types of losses. Considering this, at low-speed results obtained with this process can be very close to results obtained with an MTPA command mode.
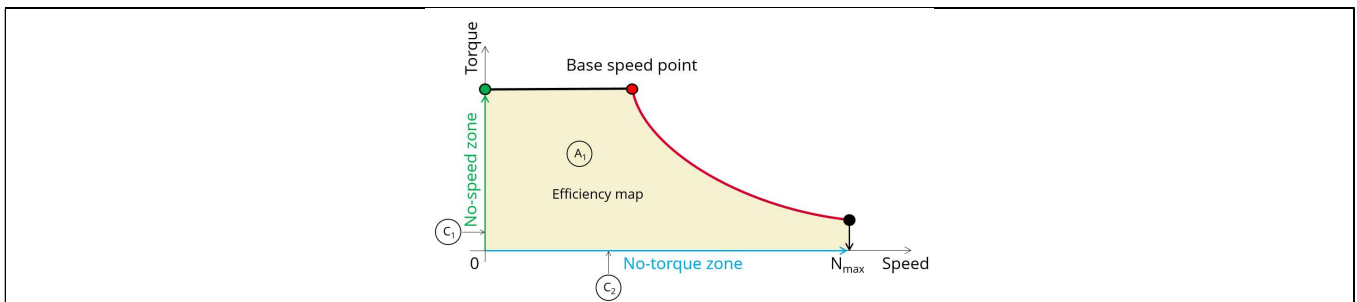
MTPV command modes – Efficiency map computation process		
C₁	**Null speed zone**	Target: Minimum Joule losses
	Constraints	$I \leq I_{max}$, $U \leq U_{max}$, Speed N = 0 User torque (got by user's discretization)
	Variable parameters	J_d, J_q
C₂	**Null torque zone**	
	Only iron losses and mechanical losses are computed All other quantities are set to 0, even the efficiency.	
A₁	**Efficiency map**	Target: Maximum efficiency
	Constraints	$I \leq I_{max}$ $U \leq U_{max}$ Targeted speed (got by user's discretization) Targeted torque (got by user's discretization)
	Variable parameters	J_d, J_q

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1.5.3   Maximum Torque Per Amps command mode – MTPA

1.5.3.1   Positioning and objective

The Maximum Torque Per Ampere command mode "MTPA" is one of the easiest to implement in terms of drive and control. That is why this command mode is still frequently used, especially for low cost applications.

In FluxMotor®, the "MTPA" command mode is applied to compute the torque-speed curve and maps mainly thanks to MTPA curves function of the speed. More details on the global process of computation are presented in the next section.

Torque speed curve with MTPA command mode
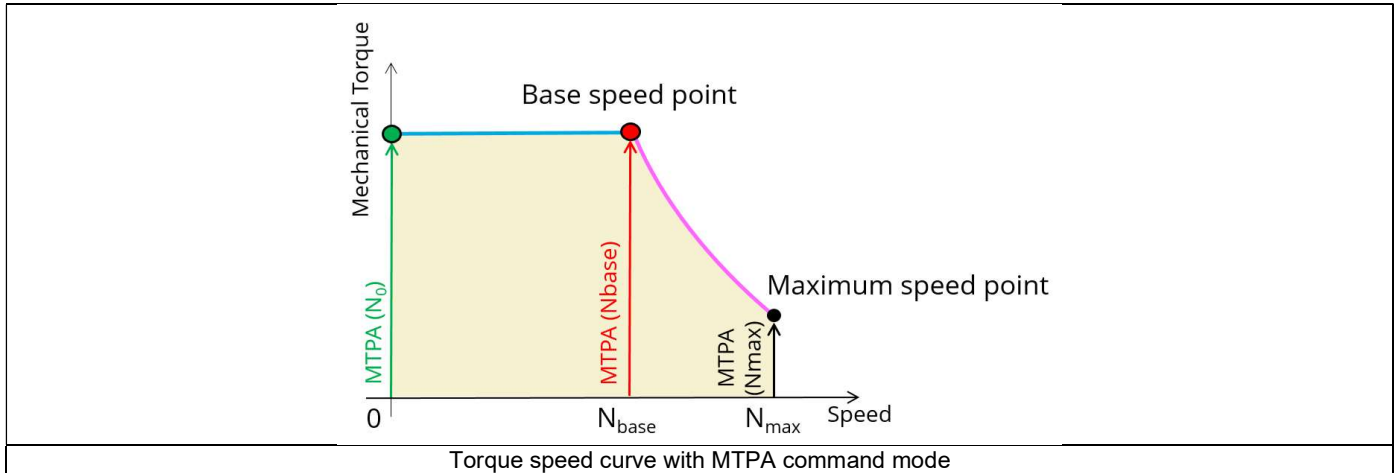
In FluxMotor®, we consider not just one MTPA curve but as many MTPA curves as speed discretization imposed by the user.
In fact, mechanical torque is not only a function of the current magnitude but also of the speed according to iron losses, mechanical losses, etc.
So, it is more rigorous to consider one MTPA curve for each speed.

Evaluation of the working point in Jd-Jq plane
by considering iso-torque, iso-current and iso-voltage
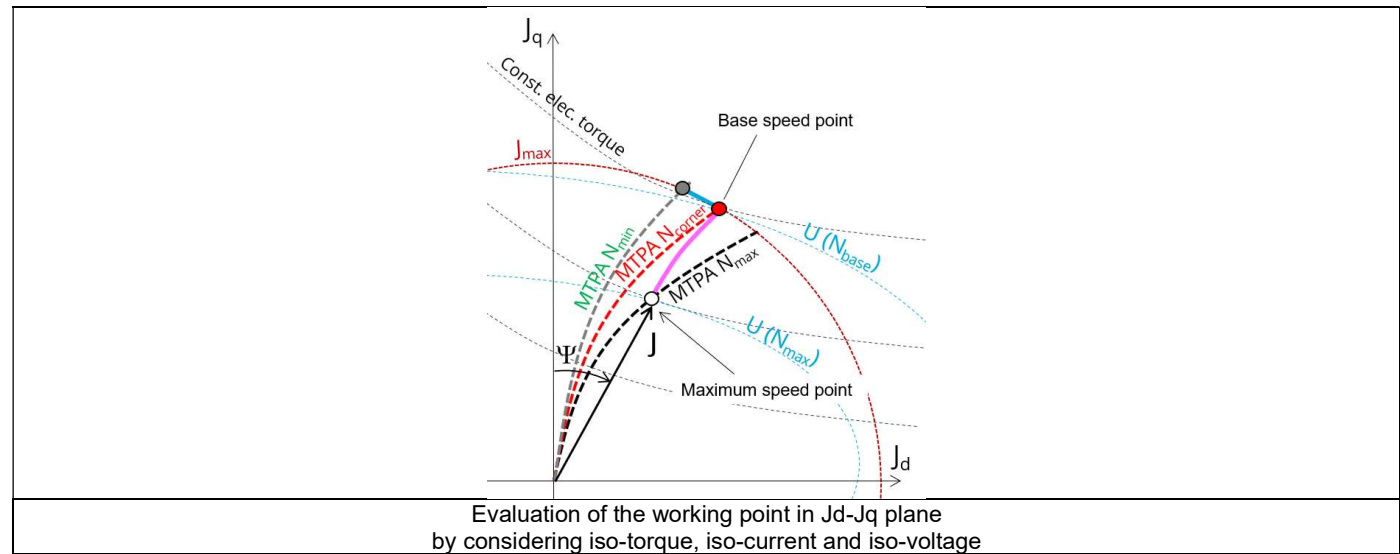
In most of the case, losses function of current and speed (iron losses, …) are just some percent of total losses. For such cases, MTPA curves are very close each other.
For some cases, losses function of current and speed dominate, so, MTPA curves present significant variations from each other as in the figure above.

1.5.3.2   Torque-speed curve – Computation and displaying

1)   Base speed point

The first step consists of computing the base speed point (Red point in the next image shown below).
The computation method is the same as the one which described for the MTPV command. In fact, the base speed point is the same in both the command: MTPV or MTPA.

The target is to find the maximum reachable torque ($T_{max.}$) considering:

- The maximum allowed line-line voltage ($U = U_{max}$)
- The maximum allowed line current ($I = I_{max}$)

An optimization process is used (integrating MTPA curves) and the variable parameters are the speed N, the D-axis and the Q-axis component of the phase current (J_d, J_q).

2)   Maximum speed point

The second step consists in verifying that the maximum speed set by the user ($N_{max.}$) is reachable (black point in the image shown below).

The target is to find the maximum reachable torque ($T_{max.}$) considering:

- The maximum allowed Line-Line voltage ($U = U_{max}$)
- The maximum allowed line current ($I \leq I_{max}$)
- The maximum speed set by the user ($N = N_{max}$)

An MTPA curve is used and variable parameters are the D-axis and the Q-axis components of the phase current (j_d, j_q). The identification is done by interpolation of data on MTPA curves.

When the user maximum speed is reachable, a working point will be found on the MTPA curve and the torque-speed curve identification process continues.
Sometimes, the maximum speed set by the user is unreachable by the machine according to its own limitation. In this case, a computation of a reachable maximum speed is automatically done.
A correction of the maximum speed could be performed if needed.
The target is to find the maximum reachable speed (N_{max}) considering:

- Line-Line voltage equal to the maximum allowed value ($U = U_{max}$)
- Line current less than or equal to the maximum allowed value ($I \leq I_{max}$)
- The useful torque obtained at the base speed divided by ten ($T = T(Nb)/10$)

An optimization process is used (integrating MTPA curves) and variable parameters are the speed (N), the D-axis and the Q-axis components of the phase current (J_d, J_q).

3)   Torque-speed curve in the range $[0, N_b[$

The base speed, the maximum speed and the no-speed working points being fixed, the third step consists of computing the part of the torque-speed curve where the torque is constant (Blue line in the image shown below).

The computation of operating points is done over $[0, N_b]$ when $N_b < N_{max.}$ and over $[0, N_{max.}]$ when $N_b > N_{max.}$

The target is to find the mechanical torque corresponding to the base speed T(Nb) on the different MTPA curves which are depending on the speed.

MTPA curves are used, and variable parameters are the D-axis and the Q-axis components of the phase current (J_d, J_q). The identification is done by interpolation of data on MTPA curves (which are depending on the speed).

4)   Torque-speed curve in the range $]Nb, N_{max}[$

Then, the last step consists of computing the torque-speed curve over the speed range $]N_b, N_{max}[$ (Pink line on the picture shown below).
This step is done only if $N_b < N_{max.}$
The target is to find the maximum reachable mechanical torque (T_{max}) considering:

- Imposed speed with $N \in]Nb, N_{max}[$
- Line-line voltage equal to the maximum allowed value ($U = U_{max}$)
- Line current less than or equal to the maximum allowed value ($I \leq I_{max}$)

MTPA curves are used, and variable parameters are the D-axis and the Q-axis components of the phase current (J_d, J_q). The identification is done by interpolation of data on MTPA curves (which are depending on the speed).
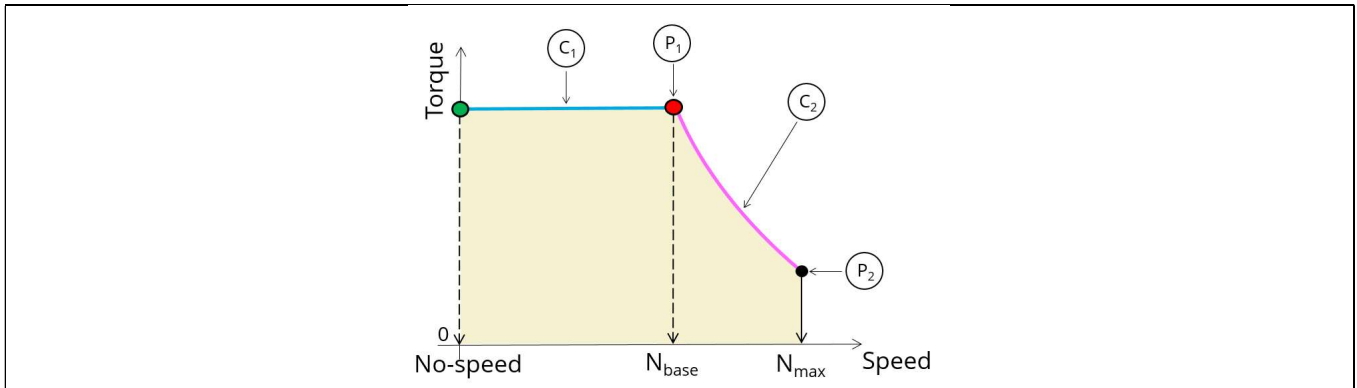
MTPA command modes – Torque-speed curve computation process			
P_1	**Base speed point**	Target: Maximum mechanical torque T_{max}.
	Constraints	$I = I_{max}$, $U = U_{max}$,
	Variable parameters	J_d, J_q, Speed
P_2	**Max. speed point**	Target: Maximum mechanical torque T_{max}.
	Constraints	$I \leq I_{max}$ $U = U_{max}$ Speed = Maximum speed
	Variable parameters	J_d, J_q
C_1	**Low speed zone**	Target: Mechanical torque = Base speed torque $T(N_b)$
	Constraints	$I \leq I_{max}$ $U \leq U_{max}$ Speed = $N \in [0, N_b[$
	Variable parameters	J_d, J_q
C_2	**High speed zone**	Target: Maximum mechanical torque T_{max}.
	Constraints	$I \leq I_{max}$ $U = U_{max}$ Speed = $N \in]N_b, N_{max.}[$
	Variable parameters	J_d, J_q

1.5.3.3 Computation and displaying of the efficiency map

Evaluating maps for all the electromagnetic quantities consists of computing the machine performances for each node of a grid bounded by the torque-speed curve. All working points defined by a value of torque and a value of speed are computed over $[0, T_b]$ and $[0, N_{max}]$. (Yellow part in the image shown below).

For each pair of "Torque - Speed" point, the target is to find the corresponding point on the corresponding MTPA curve:

- Imposed speed with $N \in [0, N_{max}]$
- Imposed torque with $T \in [0, T_b]$
- Line-Line voltage less than or equal to the maximum allowed value ($U \le U_{max}$)
- Line current less than or equal to the maximum allowed value ($I \le I_{max}$)

MTPA curves are used, and variable parameters are the D-axis and the Q-axis components of the phase current (J_d, J_q). The identification is done by interpolation of data on MTPA curves.

MTPA command modes – Efficiency map computation process		
	Efficiency map	Target: MTPA process
A₁	Constraints	$I \le I_{max}$ $U \le U_{max}$ $T = T_{target}$ (got by user's discretization) $N = N_{target}$ (got by user's discretization)
	Variable parameters	J_d, J_q

1.6   Test results

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

1.6.1   Test conditions

1.6.1.1   Inputs

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

- Context
- Standard parameters
- Advanced parameters

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

1.6.1.2   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

For more details, please refer to the document: MotorFactory_SMRSM_IR_3PH_Test_Introduction – section "Settings".

1.6.1.3   Winding characteristics

The winding characteristics are displayed into three locations

For more details, please refer to the document: MotorFactory_SMRSM_IR_3PH_Test_Introduction – section "Machine characteristics"

1.6.2   Main results

1.6.2.1   Machine performance – Base speed point

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

- General data
- Power balance

For more details, please refer to the document: MotorFactory_SMRSM_IR_3PH_Test_Introduction – section "Test generic information".
Note: For all convention (Motor / Generator), all test (DataSheet, Efficiency map, Working Point "U,I" etc) and all computed working point (Base speed, maximum speed, working point…), this table is the same.

1.6.2.2   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_SMRSM_IR_3PH_Test_Introduction – section "Test generic information".
Note: For all convention (Motor / Generator), all considered test (DataSheet, Efficiency map, Working Point "U,I" etc) and all computed working point (Base speed, maximum speed, working point…), this table is the same.

1.6.2.3 Machine performance – User working point

All the machine main electromagnetic data computed for a user working point are presented in this table with the following subsections:

- General data
- Power balance

For more details, please refer to the document: MotorFactory_SMRSM_IR_3PH_Test_Introduction – section "Test generic information".
Note: Whatever is the convention (Motor / Generator), whatever is the considered test (DataSheet, Efficiency map, Working Point "U, I" etc) and whatever is the computed working point (Base speed, maximum speed, working point…), this table is the same.

1.6.2.4 Machine performance – Duty cycle data

This section is displayed when the user wants to perform additional analysis on working points before running the test. User input parameter "User working point(s) analysis" = Duty cycle.

The following subsections are displayed:

- General data
- Power balance
- Energy balance

Mean values as well as minimum and maximum values of general data, power balance and energy balance are computed and displayed.

Notes:

The mean value of a quantity "Qty" is computed as:

$$\frac{1}{T_{\text{Duty cycle}}} \times \int_{0}^{T_{\text{Duty cycle}}} Qty \, dt$$

The minimum and maximum values are defined over the duty cycle.

1.6.2.5 Power electronics

This section is displayed when the user, before running the test, has selected "With power electronics stage" for "Electronics" settings.

All the main power electronics data computed for the user working point are presented in the table "Power electronics" with the following subsections:

- Inverter
- Base speed point
- Maximum speed point
- User working point (if set be the user)
- Duty cycle (if set be the user)

1.6.3   Curves

1.6.3.1   Torque-speed curves

List of torque-speed curves computed and displayed:

- Mechanical torque versus speed
- Electric current versus speed
- Phase voltage versus speed
- Control angle (Ψ) versus speed
- Powers versus speed
- Power factor versus speed
- Losses versus speed

1.6.3.2   Characteristic curves

1) Characteristic curves in J_d - J_q plane – iso-torque, iso-current, iso-voltage and working point

a) Example for a MTPV command mode

Characteristic curves in J_d - J_q area – MTPV command mode
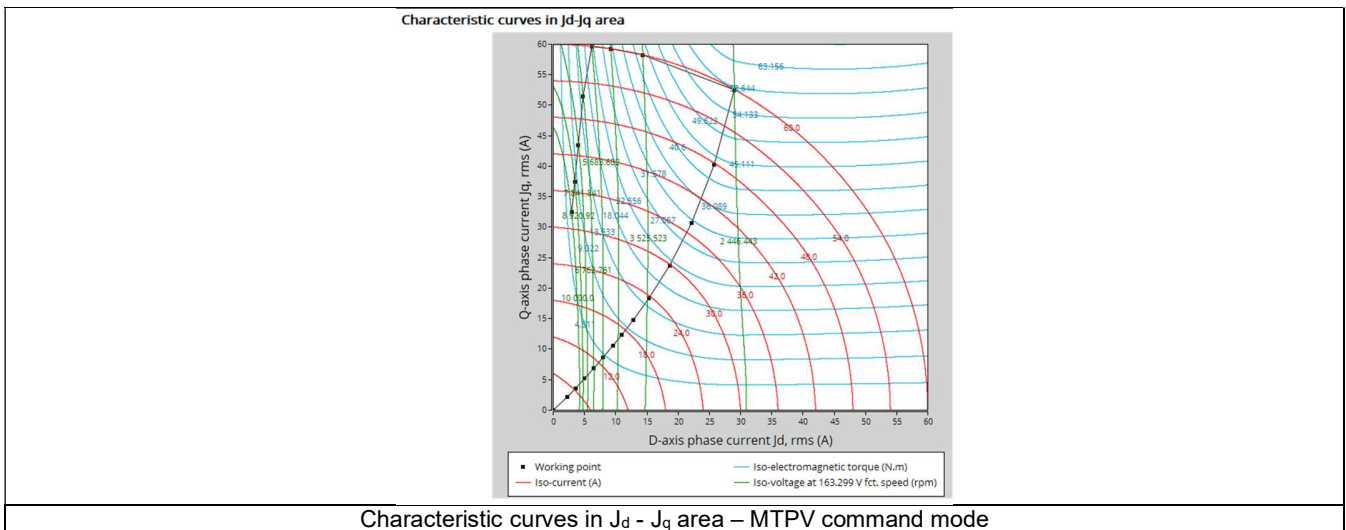
In this figure, we can see:

- The "MTPA curve at no-speed" which begins from the point [0;0] and ends at the base speed point (working point on the top left)

- The "MTPV Zone 1" also called "Flux Weakening" which begins from the base speed point, follow the iso-circle of the maximum value of current and finish at the crossing with MTPV zone 2

- The "MTPV zone2" also called "MTPV curve" shows that the center of iso-voltage ellipse is inside the iso-current circle so this motor can reach high level of speed.

b)   Example for a MTPA command mode
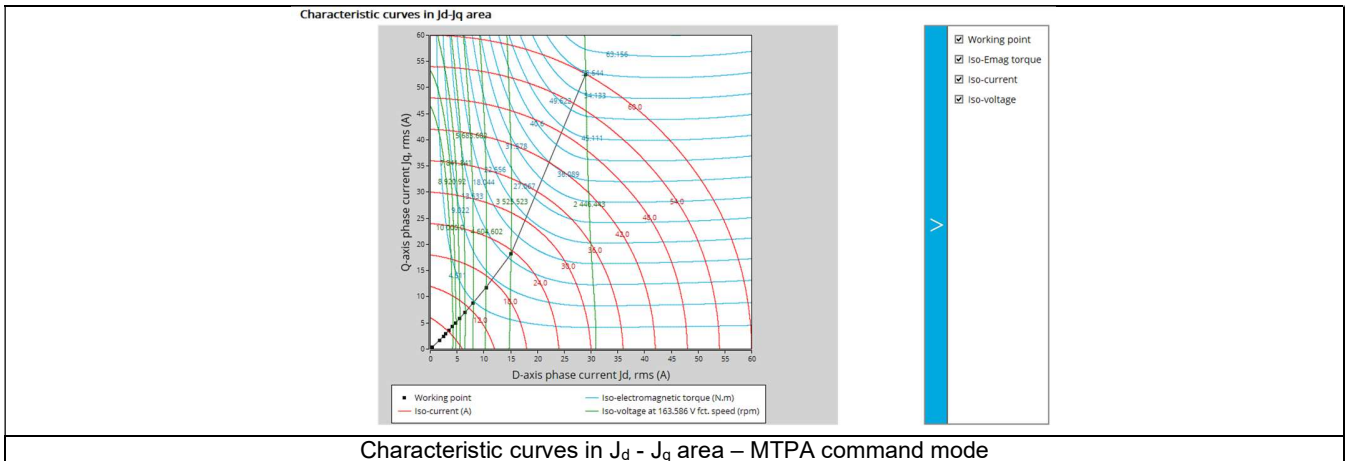
Characteristic curves in J_d - J_q area – MTPA command mode

In this figure, we can see the "MTPA curve at the base speed" which begins from the point [0;0] and ends at the base speed point (working point on the top left).

2)   Torque versus control angle (Ψ) for different electric current values and working points

a)   Example for a MTPV command mode

Electromagnetic torque versus current and control angle – MTPV command mode
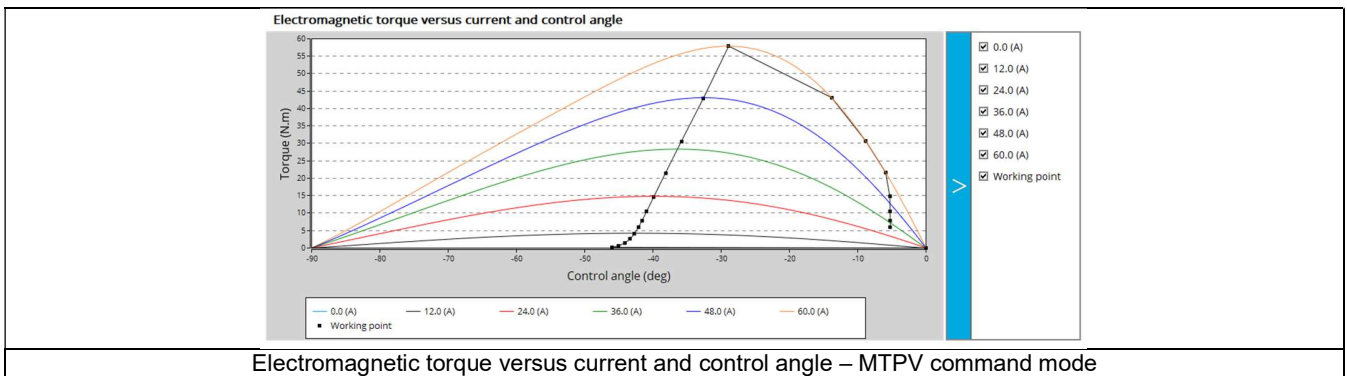
This figure displays the same kind of information (MTPA curve at no-speed, MTPV Zone1 and MTPV zone 2) as for the figure "Characteristic curves in J_d - J_q area" but in the Torque versus control angle area.

b)   Example for a MTPA command mode

Electromagnetic torque versus current and control angle – MTPA command mode
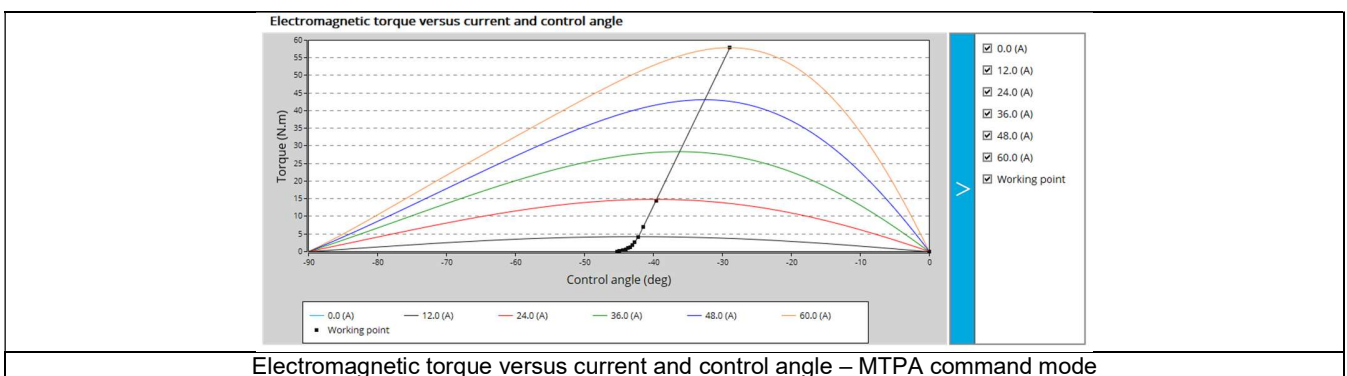
This figure displays the same kind of information as for the figure (MTPA curve at the base speed) "Characteristic curves in J_d - J_q area" but in the Torque versus control angle area.

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1.6.4   Torque-speed Maps

List of torque-speed maps computed and displayed:

- Efficiency in torque-speed area
- Electrical current (Phase, D-axis, Q-axis)
- Phase voltage (Phase, D-axis, Q-axis)
- Control angle (Ψ) in torque-speed area
- Power (System electrical, machine electrical, mechanical)
- Power factor in torque-speed area
- Losses (System total, machine total, Joule, iron, mechanical, power electronics, additional) in torque-speed area

Note: When a user's working point has been targeted or if a duty cycle is considered, the corresponding working points are displayed on all the maps described above.

1.6.5   Duty cycle curves

List of curves dealing with the duty cycle when expected:

- Speed versus time
- Mechanical torque versus time
- Control angle versus time
- Current versus time (Phase, D-axis, Q-axis)
- Voltage versus time (Phase, D-axis, Q-axis)
- Power factor versus time
- Power versus time (system electrical, machine electrical and mechanical)
- Efficiency versus time
- Losses versus time (System total, machine total, Joule, Iron, mechanical, power electronics and additional)

2   PERFORMANCE MAPPING – SINE WAVE – GENERATOR – EFFICIENCY MAP

2.1   Overview

2.1.1   Positioning and objective

The aim of the test "**Performance mapping – Sine wave – Generator – Efficiency map**" is to characterize the behavior of the machine in the "Torque-Speed" area.

This test gives an overview of the electromagnetic behavior of the generator as a function of its speed.
Electrical power, mechanical torque, output voltage, electrical current, power balance, power factor and control angle are plotted versus speed.

Input parameters define the zone in which the evaluation of the machine behavior is performed.
Input parameters like the "maximum Line-Line voltage", the "maximum line current" and the targeted "Maximum speed" of the machine are considered.
One type of command mode is available: The Maximum Torque Per Amps command mode (MTPA).

Characterization of the corner speed point on the torque-speed curve
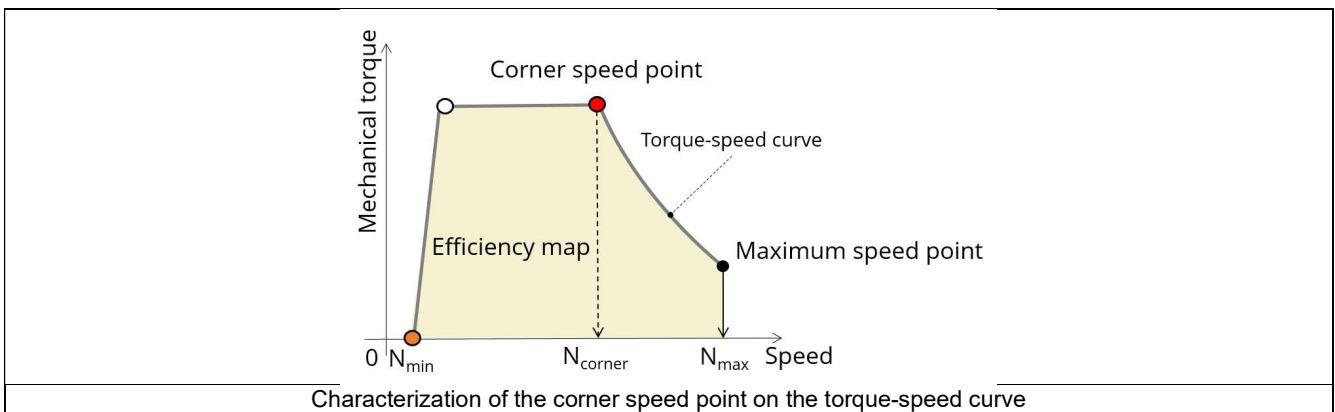
In the results, the performance of the machine at the corner speed point for the maximum speed set by the user is presented.

A set of curves (like Torque-Speed curve) and maps (like Efficiency map) are computed and displayed.

Mechanical torque versus speed - Example

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Efficiency in torque-speed area - Example
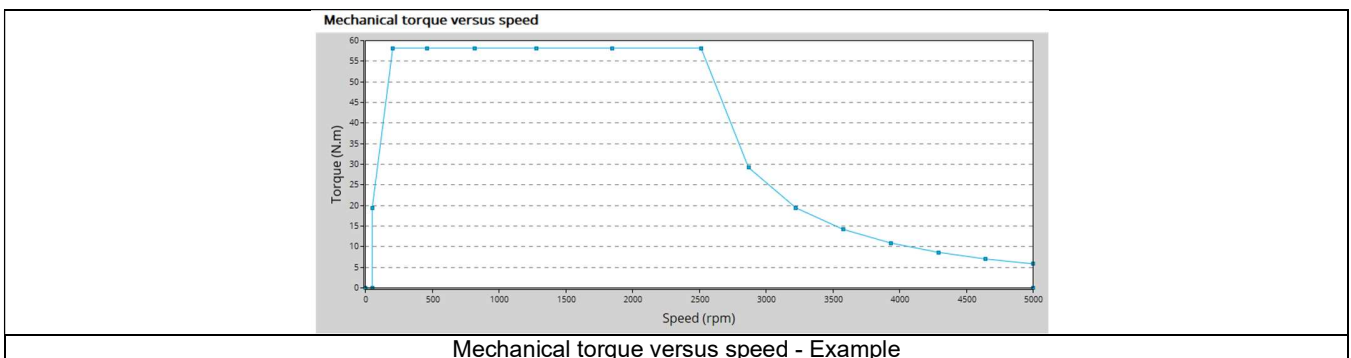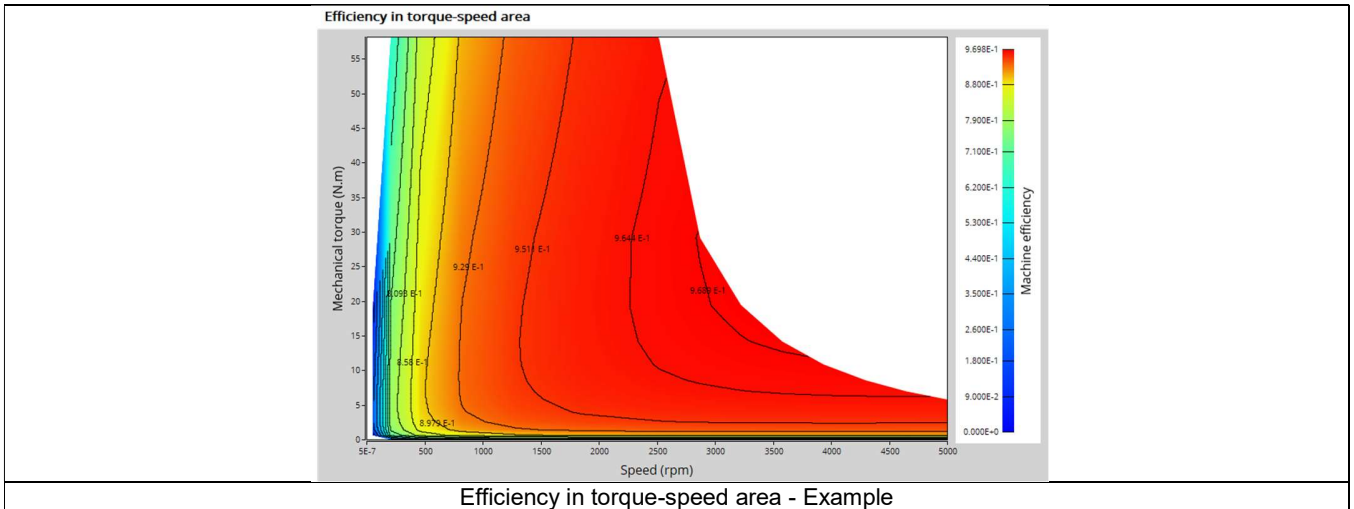
Note In addition, in J_d-J_q plane, a graph shows the working points computed for the torque speed curve. The iso-electromagnetic torque, the iso-current and the iso-voltage are also displayed in J_d-J_q plane.
These results help the user to understand the possible performance of the machine in its electric environment.

Characteristics curves in J_d-J_q area - Example
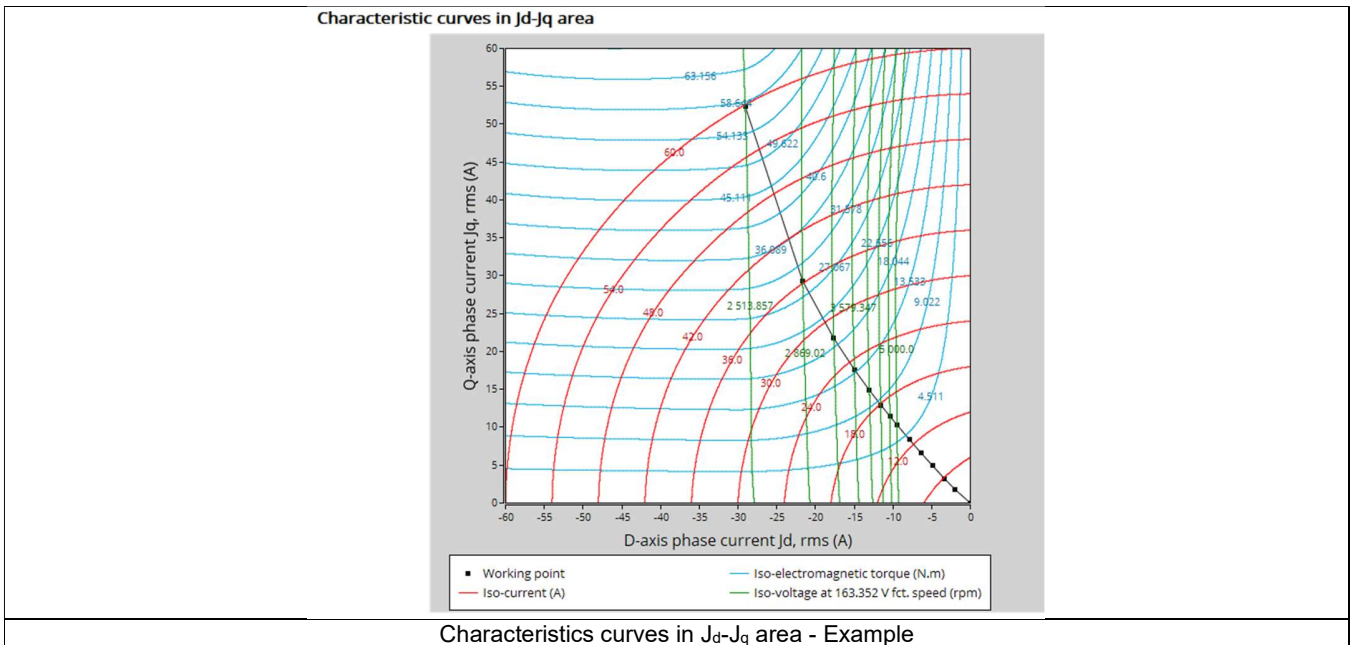
Moreover, two additional features are available in this test.
The first one allows extracting one point from the efficiency map to get the machine performance, for this specific working point (general data + power balance).

Note: The considered working point is then displayed on all the maps available.

A "single" working point displayed on the efficiency map - Example

The second feature allows the user to define a duty cycle by giving a list of working points (speed, torque) versus the time. The displayed results illustrate the machine performance over the considered duty cycle (mean, min, and max values).

The time variation of the main quantities is also displayed (Mechanical torque, speed, control angle, current, voltage, power, efficiency, losses).

All the corresponding points are displayed on the provided maps.
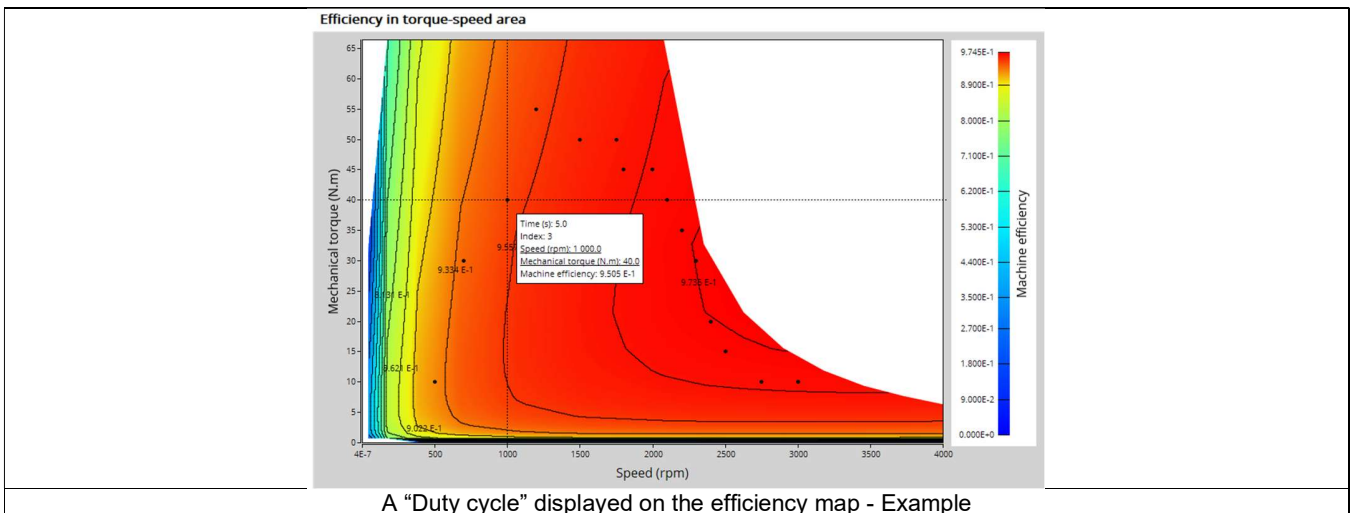
A "Duty cycle" displayed on the efficiency map - Example

The following table helps to classify the test "**Performance mapping – Sine wave – Generator – Efficiency map**".

Family	Performance mapping
Package	Sine wave
Convention	Generator
Test	Efficiency map

Positioning of the test "Performance mapping – Sine wave – Generator – Efficiency map"

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2.1.2   User inputs

The main user input parameters needed to perform this test are the maximum allowed supplied Line-Line voltage, the line current, the targeted maximum speed and the command mode. Winding temperatures must also be set.
When required, the location of the working points (single or duty cycle) to be evaluated must be defined as inputs.

Warning! Default values of advanced inputs have been set to get the best compromise between accuracy and computation time.
The three main advanced user input parameters adjusting the compromise between accuracy and computing time are: the number of computations for J_d-J_q, for speed and for torque.

2.1.3   Main outputs

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

2.1.3.1   Main test results

1)   Machine performance – Corner speed point
- General data
- Power balance

2)   Machine performance – Maximum speed point
- General data
- Power balance

3)   Machine performance – User working point (when expected)
- General data
- Power balance

4)   Machine performance – Duty cycle (when expected)
- General data
- Power balance
- Energy balance

2.1.3.2   Torque-speed curves
- Torque versus speed
- Current versus speed
- Voltage versus speed
- Control angle versus speed
- Power versus speed
- Power factor versus speed
- Losses versus speed

2.1.3.3   Characteristic curves
- Electromagnetic torque versus current and control angle
- Characteristic curves in Jd-Jq area

2.1.3.4   Torque-speed maps
- Efficiency in torque-speed area
- Current in torque-speed area
- Voltage in torque-speed area
- Control angle in torque-speed area
- Power in torque-speed area
- Power factor in torque-speed area
- Losses in torque-speed area

2.1.3.5 Duty cycle curves (when expected)

- Speed versus time
- Mechanical torque versus time
- Control angle versus time
- Current versus time
- Voltage versus time
- Power factor versus time
- Power versus time
- Efficiency versus time
- Losses versus time

Note: When a user working point has been targeted or if a duty cycle is considered, the corresponding working points are displayed on all the maps described above.

2.2   Settings

Two buttons give access to the following setting definition:

- Thermal settings – Definition of the winding temperatures.
- Mechanics settings - Definition of mechanical loss model parameters

For more details, please refer to the document: MotorFactory_SMRSM_IR_3PH_Test_Introduction – section "Settings".

2.3   Inputs

2.3.1   Introduction

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

2.3.2   Standard inputs

2.3.2.1   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.
In this case, the current definition mode should be « **Density** »

Electric current can be defined directly by indicating the value of the maximum line current (the RMS value is required).
In this case, the current definition mode should be « **Current** »

2.3.2.2   Maximum line current, rms

When the choice of the current definition mode is "**Current**", the maximum rms value of the line current supplied to the machine: "**Max. line current, rms**" (*Maximum line current, rms value*) must be provided.
Note: The number of parallel paths and the winding connections are automatically considered in the results.

2.3.2.3   Maximum current density, rms

When the choice of current definition mode is "**Density**", the rms value of the maximum current density in electric conductors "**Max. current dens., rms**" (*Maximum current density in conductors, rms value*) must be provided.
Note: The number of parallel paths and the winding connection are automatically considered in the results.

2.3.2.4   Maximum Line-Line voltage, rms

The rms value of the maximum Line-Line voltage supplying to the machine: "**Max. 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.

2.3.2.5   Command mode

One command mode is available:

- The maximum Torque Per Amps (MTPA)

The first step of the process consists of computing the torque-speed curve and the second step is to compute the efficiency map bounded by the torque-speed curve.
More information is available on this topic in section 2.4 (Main principles of computation)

2.3.2.6   Maximum speed

The computation and analysis of the torque-speed curves are performed over a given speed range.
The maximum allowed value for the « **Maximum speed** » corresponds to 53000 rad/s - about 506000 rpm.
Notes: As a function of the maximum speed value, following different cases must be considered:

Case 1: The maximum speed is lower than the base speed N_{base} (corner point speed of the torque-speed curve) $N_{max} < N_{base}$.
In that case, whatever is the command mode (MTPA or MTPV), the behavior of the machine will be studied over the speed range [0, N_{max}].

This allows the user to precisely choose the range of speed to be considered for computing and displaying the torque-speed curve and especially maps like efficiency map.

Case 2: The maximum speed is greater than the base speed (corner point speed) $N_{max} > N_{base}$.
The relevance of the maximum speed given by the user is analyzed to evaluate if it is reachable by the machine.
If the user maximum speed is unreachable by the machine, the correction of this value is automatically performed.
The resulting new maximum speed is linked to a limit torque. This limit torque is obtained by applying a reduction coefficient to the base point torque.

2.3.2.7 Rotor position dependency

It defines the rotor position dependency of electromagnetic data used for the optimization of the efficiency map such as D-axis magnetic flux, Q-axis magnetic flux, electromagnetic torque, iron losses. By default, the rotor position dependency is set to "No" but it can be set to "Yes". In this case the computation will be done along the two dimensions J_d - J_q , with an additional fourth axis corresponding to the rotor position θ_r.

Note: This option allows to have a better accuracy in the evaluation of magnetic flux, electromagnetic torque as well as iron losses. It is worth noting that only with rotor position dependency that the rotor iron losses can be evaluated.

2.3.2.8 Additional losses

Note: "Additional losses" input is not available in the current version (The input label is written in grey).

2.3.2.9 User working point(s) analysis

It is possible to perform additional analysis on working point(s) located under the torque speed curve. The user input "**User working point(s) analysis**" *(additional analysis on working point(s))* gives three possibilities to the user:
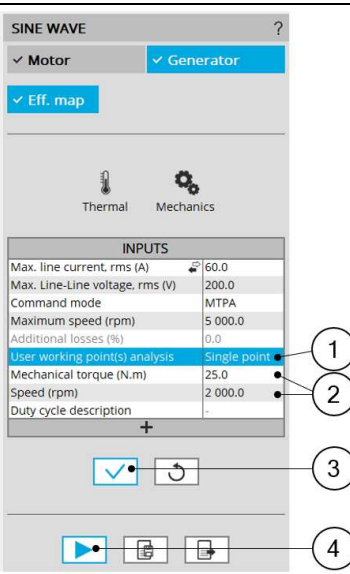
    1) User working point(s) analysis = None (=default mode)

This corresponds to the basic configuration of the test, with no additional working point analysis.

    2) User working point(s) analysis = Single point

This allows computing the machine performance on a working point which must be specified by the user with the targeted speed and torque.
In that case the next two fields must be filled in with the targeted speed and mechanical torque.

	User working point analysis = Single point	
1	Select the "Single point" option to perform a computation on one working point.	
2	Define the targeted working point mechanical torque and speed.	
3	Button to validate and consider the user inputs	
4	Button to run the computation	

    3) User working point(s) analysis = Duty cycle

This allows computing the machine performance all over the considered duty cycle.
This duty cycle must be defined by using the next field: "Duty cycle description" and by clicking on the button "Set values".
Two ways are possible to fill in the table: either filling the table line by line or by importing an excel file in which all the working point of the duty cycle are defined.

Note: A working point is defined by a time, the speed, and the mechanical torque.

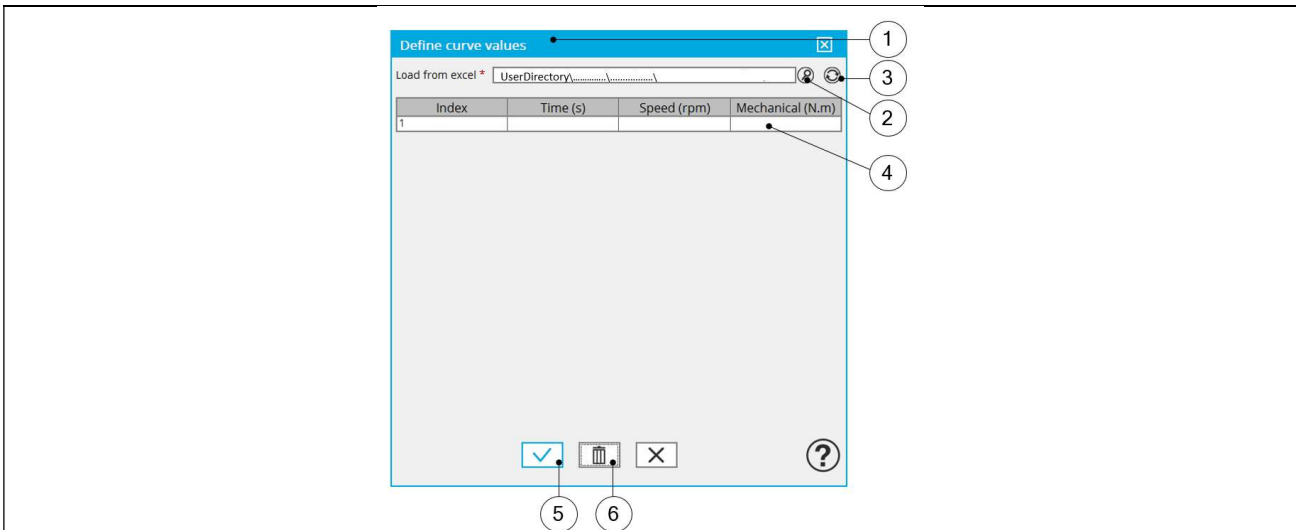|	User working point analysis = Duty cycle
1	Select the "Duty cycle" option
2	Click in the button "Set values" of the field "Duty cycle" to open a dialog box to define the duty cycle. Refer to the next illustration which shows how to fill the Duty cycle table.
3	Button to validate and consider the user input data
4	Button to run the computations

Note: Once the efficiency map is computed and displayed all the additional computations dealing with the user working points are given instantaneously.

	User working point analysis = Duty cycle – Dialog box to define the duty cycle
1	Dialog box opened after having clicking on the button "Set values" in the field "Cycle description"
2	Browse the folder to select an Excel file in which the duty cycle is described.
3	Button to refresh the table data when the considered Excel file has been modified
4	Fields to be filled in with data to describe the duty cycle to be taken into account

Note: A template corresponding to the Excel file format to be considered is stored in the folder Resource/ Template of FluxMotor®. An example of this template is displayed below.

Excel file template to define the duty cycle

2.3.3   Advanced inputs

2.3.3.1   Number of computed electrical periods

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

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

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

2.3.3.2   Number of computations for J_d, J_q

First, it is needed to compute the D-axis and Q-axis flux linkage in the J_d - J_q plane.

To get maps in the J_d - J_q plane, a grid is defined. The number of computation points along the d-axis and q-axis can be defined with the user input « **No. Comp. for J_d, J_q** » *(Number of computations for D-axis and Q-axis currents)*.
The default value is equal to 5. This default value provides a good compromise between accuracy and computation time. The minimum allowed value is 5.
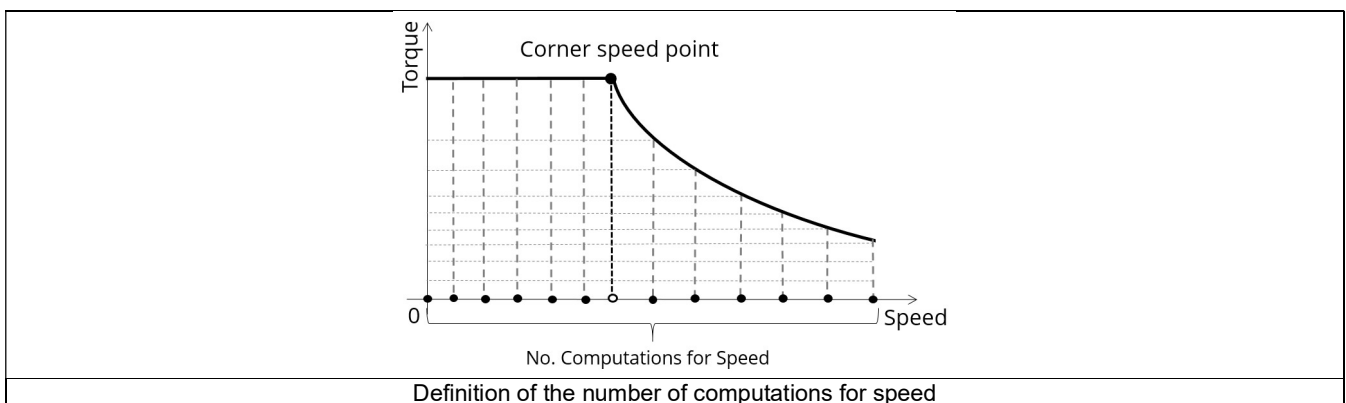
2.3.3.3   Number of computations for speed

The "**No. comp. for speed**" (*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 15. The minimum allowed value is 5. 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.

2.3.3.4   Number of computations for torque

With the "Low Speed" command mode, the number of computations for torque is imposed by the input parameter "**No. comp. for torque**" *(Number of computations for torque)* - Black points in the graph shown below.
The default value is equal to 7. The minimum allowed value is 3. The maximum recommended value is 20.

The number of computations for torque is imposed by the number of computations for speed in the speed range [N_{base}; N_{max}] (Red points in the image shown below).
The advanced user input parameter "**No. comp. 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).

Definition of the number of computations for torque – MTPV command mode
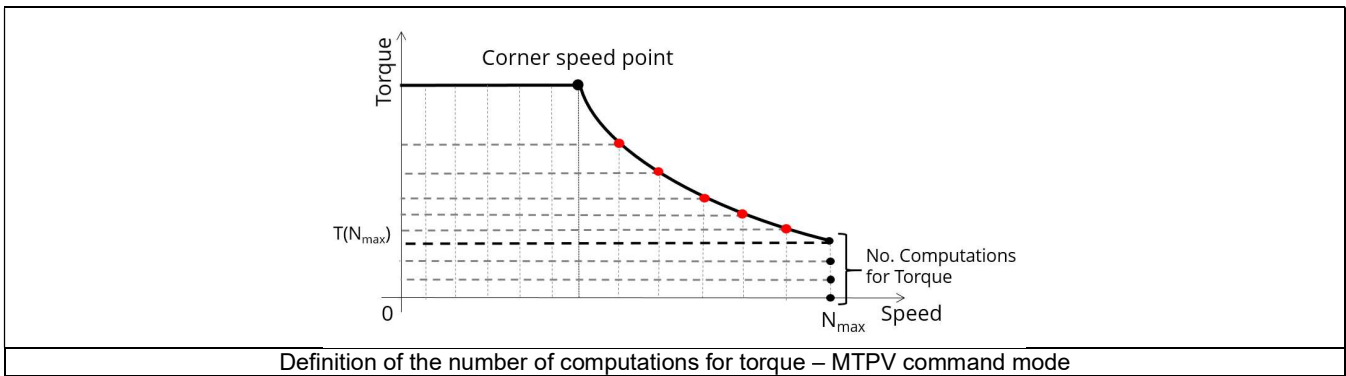
2.3.3.5   Skew model – Number of layers

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

2.3.3.6   Mesh order

To get the results, the original computation is performed using a Finite Element Modeling.
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.

2.3.3.7   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 to a higher mesh density inside the airgap and increasing the computation accuracy.

The imposed Mesh Point (size of mesh elements touching points of the geometry), inside the Flux®, 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.

2.3.3.8   Rotor d-axis location

The computations are performed by considering a relative angular position between rotor and stator.

For the reluctance synchronous machines, the rotor d-axis location is defined and automatically used to perform computations.
This value is characterized by the saliency topology. This is important to keep in mind this information it.

For more details, please refer to the document: MotorFactory_SMRSM_IR_3PH_Test_Introduction – section "Rotor and stator relative position".

2.4 Main principles of computation

2.4.1 Introduction

This part deals with the process to get the torque-speed curves and maps (For example - efficiency map).

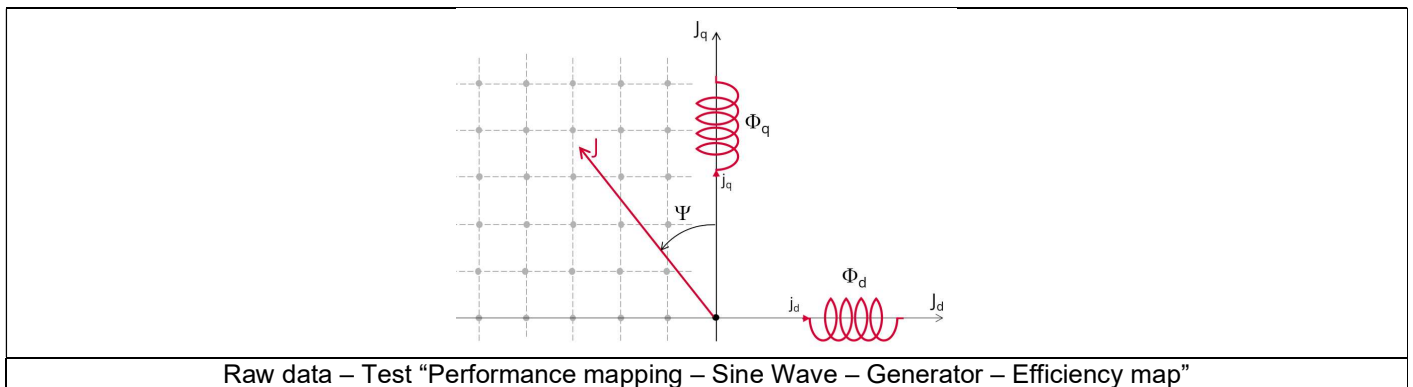The process is separated into the two following parts:
- Raw data and Park model
- Identification of the torque-speed curves and maps – Overview

2.4.2 Raw data and Park's model

The first step consists to compute the raw data which characterize the machine in the J_d-J_q plane. This is done using Finite Element modelling (Flux® – Magnetostatic application).
To do that, a grid of (J_d, J_q) values is considered.
Flux linkage through each phase (Φ_a, Φ_b, Φ_c) and flux density in regions (teeth and yoke of the machine) are computed and extracted as a function of (J_d, J_q).

Raw data – Test "Performance mapping – Sine Wave – Generator – Efficiency map"

The second step consists of using the raw data with the Park's model.
D-axis flux-linkage component (Φ_d) and Q-axis flux-linkage component (Φ_q) is computed according to the Park's transformation.

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

1) If rotor position dependency is set to "No", the flux linkage maps, and the following formula are used:

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

Park's model - Motor convention - Torque equation

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

2) If rotor position dependency is set to "Yes", the Electromagnetic torque T_{em} is computed thanks to finite element computation and virtual work method to get the best evaluation of the ripple torque.

Note: In case the Rotor position dependency is set to "Yes", **Electromagnetic torque T_{em}** average value computed with the Park's equation or with virtual works are equal.
Note: The computations are the same as those performed in the test "Characterization - Model – Motor - Maps" with or without rotor position dependency. Here are the obtained results which are used to build the next step, that is, curves and maps in the torque-speed area:

Here are the obtained results which are used to build the next step, that is, curves and maps in the torque-speed area:

- D-axis flux-linkage component - Φ_d
- Q-axis flux-linkage component - Φ_q
- Electromagnetic torque T_{em}
- Stator iron losses W_{iron} versus speed
- Joule losses in stator winding W_{Cus}
- Mechanical losses versus speed
- Total losses W_{total} versus speed

2.4.3   Identification process for the torque-speed curves and maps – Overview

Below presented are the four main steps involved in building the efficiency map and other associated results. These steps are similar for all the command modes with only some specifications (for more information, refer to command mode paragraphs).
These steps are performed by using the computed raw data (see previous section) with optimization functions or dedicated functions like MTPA curves (for more information, refer to command mode paragraphs).

- Building of the Torque-speed curve and other associated results
- Define the grid of the torque speed maps
- Building of the maps in torque-speed area
- Torque-speed curves and maps correction

Main steps of the computation algorithm
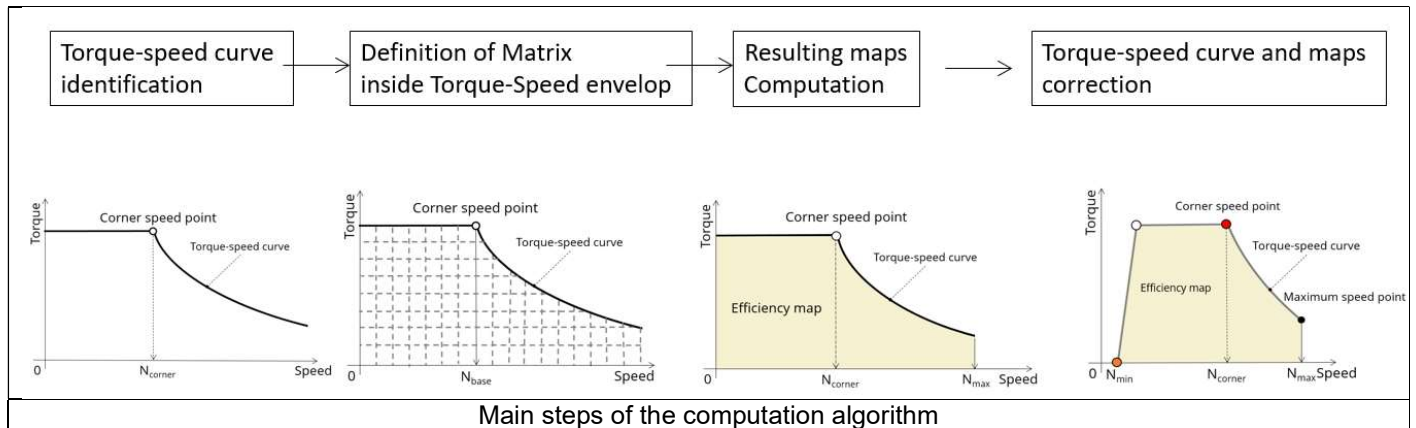
2.5   Command modes

2.5.1   Introduction

The user can choose one type of command mode:

- The Maximum Torque Per Amps (MPTA)

For any command mode applied, the first step of the process consists of computing the Torque-speed curve (curve which bounded the domain) and the second step is to compute maps bounded by the Torque-speed curve (Efficiency maps, Iron loss maps…).


Torque-speed curve and efficiency map - Generator operating mode
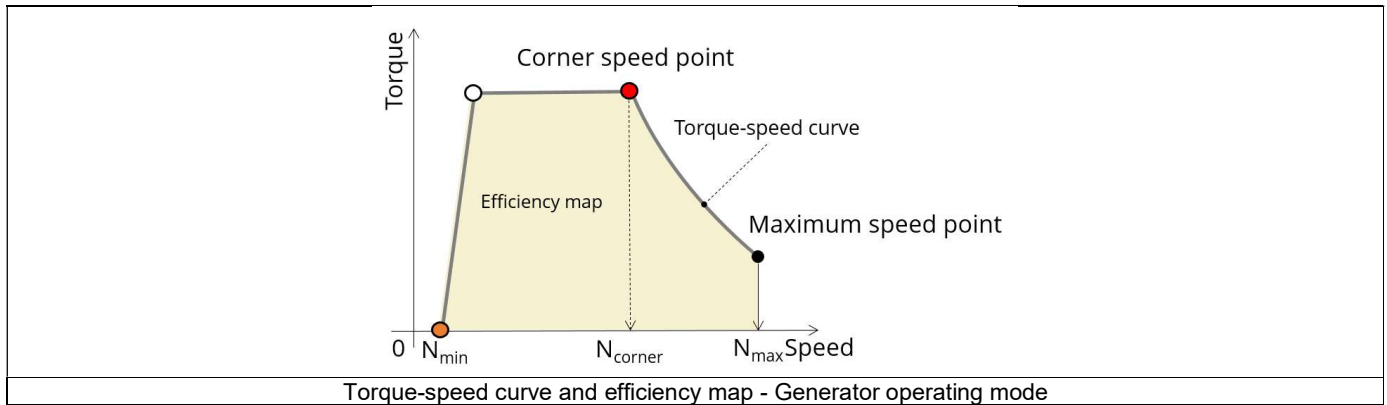
2.5.2   Maximum Torque Per Amps – MTPA

2.5.2.1   Positioning and objective

1) Main concept

The maximum torque per amps command mode "MTPA" in terms of drive and control, is one of the easiest to implement. That is why this command mode is still used frequently, especially for low-cost applications.

In FluxMotor®, the "MTPA" command mode is applied to compute the torque-speed curve and maps mainly thanks to MTPA curves function of the speed (more details on the global process of computation are presented in the next section).

Torque speed curve with MTPA command mode – Generator operating mode
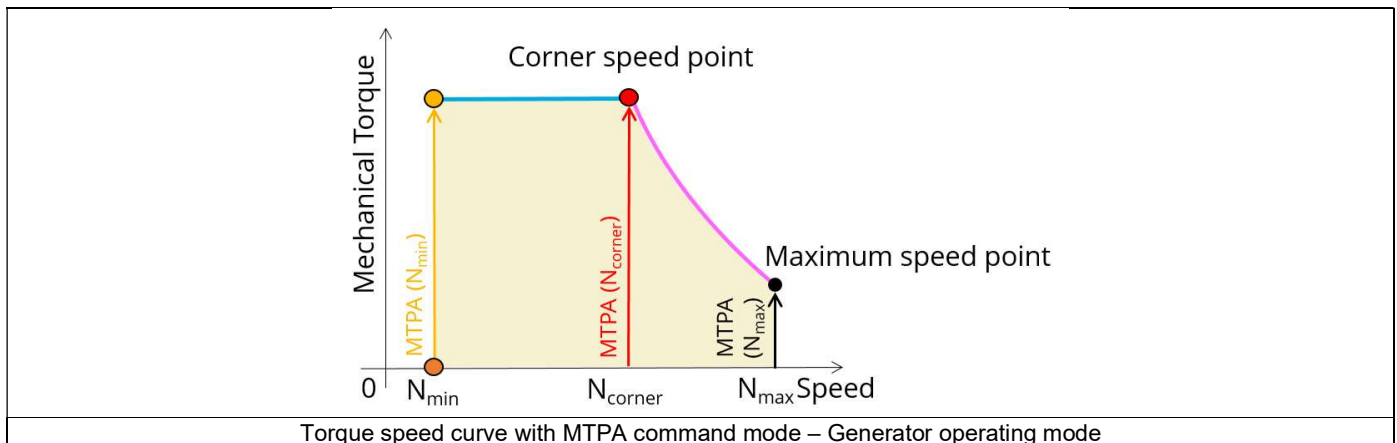
In FluxMotor®, we consider not just one MTPA curve but as many MTPA curves as speed discretization imposed by the user.
In fact, the mechanical torque is function of current magnitude but also of the speed according to iron losses.
So, it is more rigorous to consider one MTPA curve for each speed.

Evaluation of the working point in Jd-Jq plane
by considering iso-torque, iso-current and iso-voltage
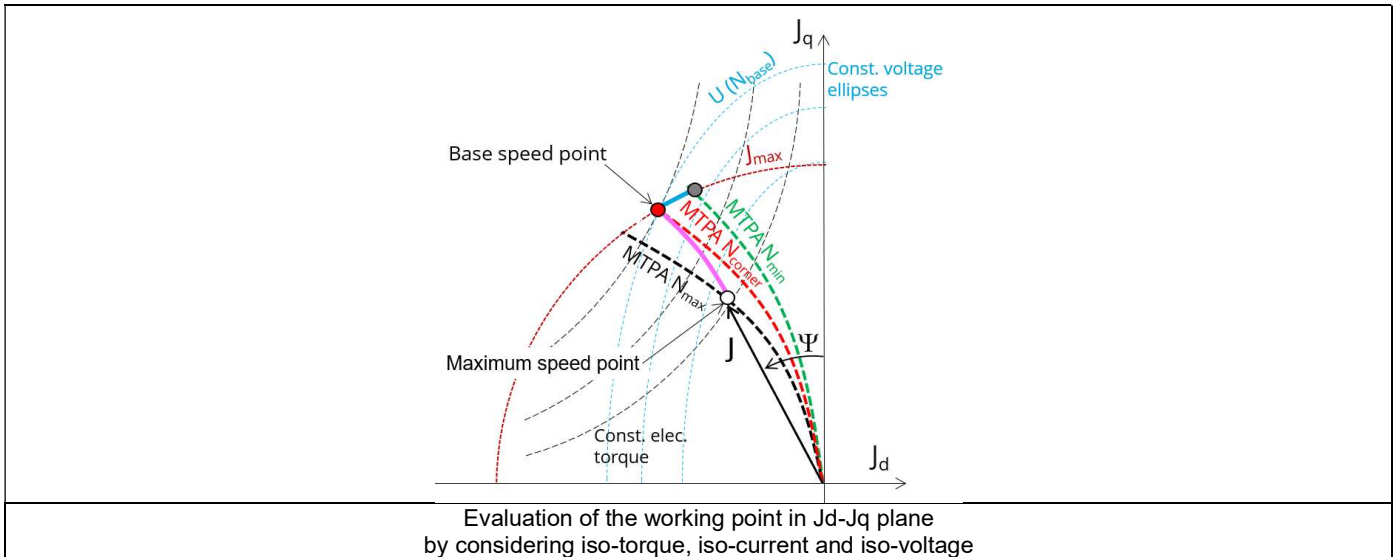
In the most of case, losses function of current and speed (iron losses, etc) are just some percent of total losses. For such cases, MTPA curves are very close to each other.

For some cases, losses function of current and speed dominate, so, MTPA curves present significant variations from each other as in the figure above.

2)   Minimum speed point

Note that, in generator operating mode, a minimum speed is needed to be able to supply electrical current.

In fact, mechanical power provided on the shaft must be higher than losses otherwise the electrical power is negative and no current can be supplied by the generator

This aspect is considered in FluxMotor® process and according to the discretization in speed imposed by the user, a minimum speed able to supply electrical current is deduced.
Higher the discretization of speed, more accurate is the computed "minimum speed" but higher is the computation time.
With a high discretization we get results as presented below:

Torque speed curve with MTPA command mode – Generator operating mode
High discretization of speed
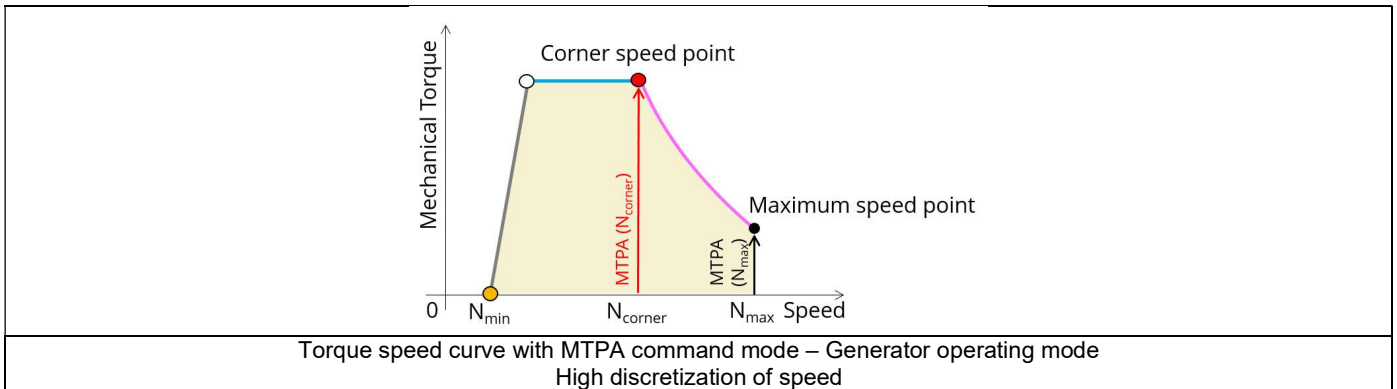
3)   Corner speed point and constant mechanical torque part

In generator operating mode, we speak about "Corner speed point" while in motor operating mode, we speak about "Based speed point".
In FluxMotor® terminology, the last working point of the constant torque part of the torque-speed curve is called "Base speed point" only if it is obtained for the maximum allowed line-line voltage and maximum line current. If it is not in the case, we called as "Corner speed point".
In generator operating mode, with FluxMotor® process, the mechanical power and the electric power are computed from the electromagnetic power (obtained with Park's model) following the power balance presented by the figure below.

Power balance in generator operating mode – FluxMotor® process
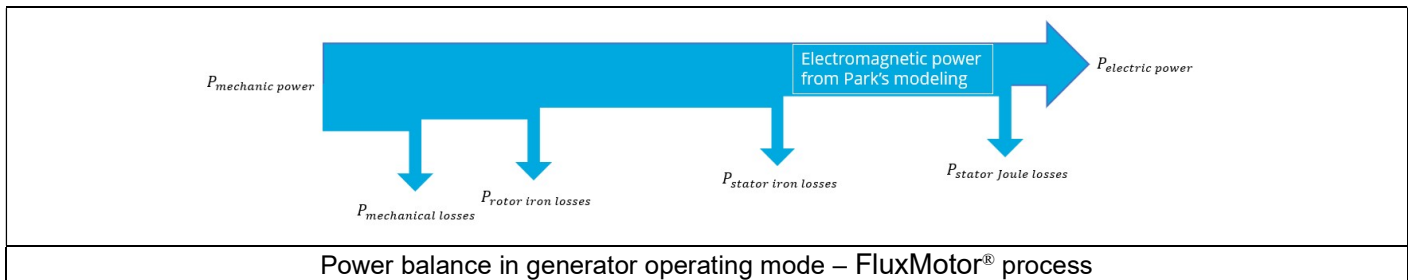
When we work with a maximum current and with a control angle for maximizing the electromagnetic torque (maximize the electromagnetic power obtained with Park's model); the mechanical torque will increase with the speed because some losses (like iron and mechanical losses) increase with the speed.

According to this point, it can provide a torque-speed curve with a reachable constant mechanical torque part at low speed, the process of computation imposed us to reach the value of no-speed mechanical torque at the corner speed point.
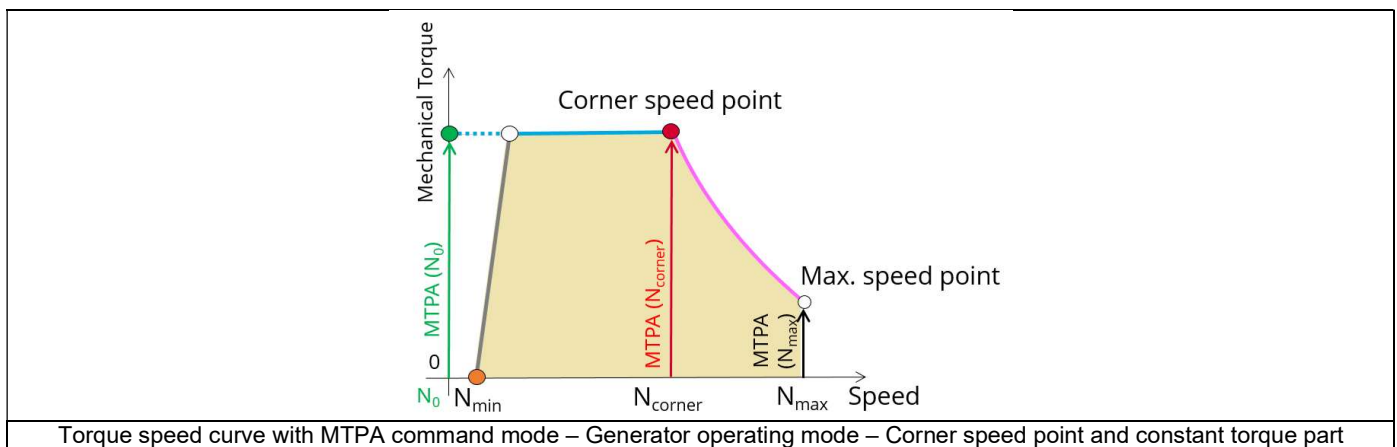
Torque speed curve with MTPA command mode – Generator operating mode – Corner speed point and constant torque part

Note: The computed torque at no-speed corresponds to an unavailable working point in generator operating mode; it is just used in the process for computing the corner speed point and the constant mechanical torque part.

2.5.2.2   Torque-speed curve – Computation and displaying

1)   No-speed point

The first step consists of computing the no-speed point (Green point in the next image shown below).

The target is to find the maximum reachable mechanical torque (T_{max}) considering:
- Line-line voltage less than or equal to the maximum allowed value ($U ≤ U_{max}$)
- The maximum allowed line current ($I = I_{max}$)

MTPA curve at no-speed is used and variable parameters are the D-axis and the Q-axis components of the phase current (J_d, J_q). The identification is done by interpolation of data on MTPA curves.

Note: The computed torque at no-speed corresponds to an unavailable working point in generator operating mode, it is just used for the process of computation of the corner speed point and of the constant mechanical torque part.

2)   Corner speed point

The second step consists of computing the corner speed point (Red point in the next image shown below).

The target is to find the maximum reachable speed (N_{max}) considering:
- Line-Line voltage equal to the maximum allowed value ($U = U_{max}$)
- Line current less than or equal to the maximum allowed value ($I ≤ I_{max}$)
- The Mechanical torque obtain at no-speed ($T = T(N0)$)

An optimization process is used (integrating MTPA curves) and variable parameters are the speed (N), the D-axis and the Q-axis components of the phase current (J_d, J_q).

3) Maximum speed point

The third step consists of verifying that the maximum speed set by the user (N_{max}) is reachable (Black point in the image shown below).

The target is to find the maximum reachable torque (T_{max}) considering:
- The maximum allowed Line-Line voltage ($U = U_{max}$)
- The maximum allowed line current ($I \leq I_{max}$)
- The maximum speed set by the user ($N = N_{max}$)

An MTPA curve is used, and variable parameters are the D-axis and the Q-axis components of the phase current (J_d, J_q). The identification is done by interpolation of data on MTPA curves.

 If the user maximum speed is reachable, it will be found on the MTPA curve and the Torque-speed curve identification process continues. Sometimes, the maximum speed set by the user is unreachable by the machine. In this case, a computation of a reachable maximum speed is automatically done.

The second step can include the correction of the maximum speed if needed as previously explained.

The target is to find the maximum reachable speed (N_{max}) considering:
- Line-line voltage equal to the maximum allowed value ($U = U_{max}$)
- Line current less than or equal to the maximum allowed value ($I \leq I_{max}$)
- The mechanical torque obtained at the corner speed point divided by ten ($T = T(Nc)/10$)

An optimization process is used (integrating MTPA curves) and variable parameters are the speed (N), the D-axis and the Q-axis components of the phase current (J_d, J_q).

4) Torque-speed curve in the range]0, N_c[

The corner speed, the maximum speed and the no-speed points being fixed, the forth step consists of computing the part of the torque-speed curve where the torque is constant (Blue line in the image shown below).

The computation of operating points is done over]0, N_c[if «$N_c < N_{max}$» but over]0,N_{max}[if «$N_c > N_{max}$».

The target is to find the corner speed mechanical torque (T_c) on MTPA curves for each speed.

MTPA curves are used and variable parameters are the D-axis and the Q-axis components of the phase current (J_d, J_q). The identification is done by interpolation of data on MTPA curves.

Note: At low speed, some computed working points can be unreachable in generator operating mode, (resulting negative electrical power). In this case, a correction is done; see the last subsection 2.5.2.4 (Torque-speed curves and maps correction).

### 5) Torque-speed curve in the range]N_c, N_{max} [

Then, the last step consists of computing the torque-speed curve over the speed range]N_c, N_{max} [(Pink line in the image shown below). This step is done only if $N_c < N_{max}$.

The target is to find the maximum reachable torque (T_{max}) considering:

- Imposed speed with $N \in$]Nc, N_{max} [
- Line-Line voltage equal to the maximum allowed value ($U = U_{max}$)
- Line current less than or equal to the maximum allowed value ($I \leq I_{max}$)

MTPA curves are used, and variable parameters are the D-axis and the Q-axis components of the phase current (J_d, J_q). The identification is done by interpolation of data on MTPA curves.

Note: At high speed, some computed working points can be unreachable in generator operating mode, (resulting negative electrical power). In this case, a correction is done, see the last subsection 2.5.2.4 (Torque-speed curves and maps correction).
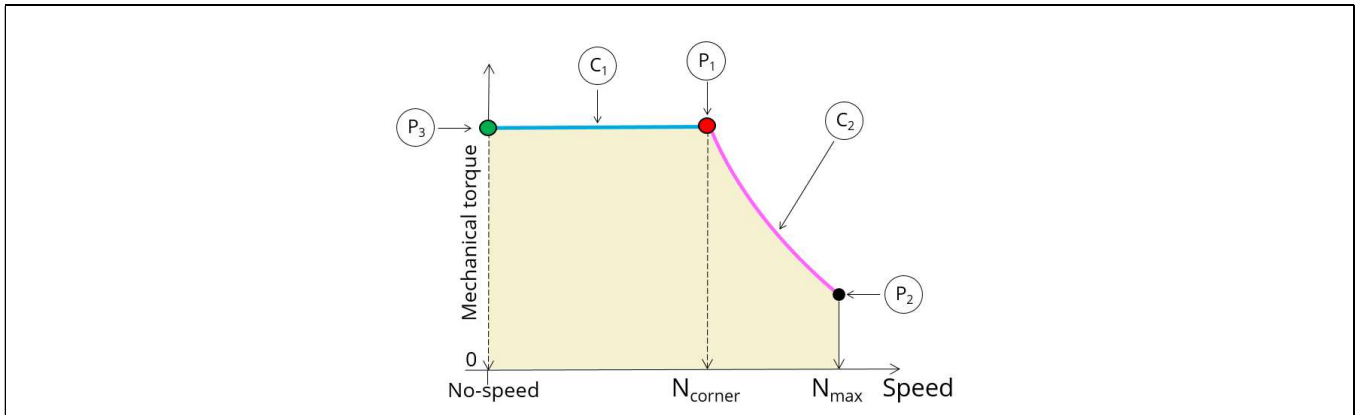
| MTPA command modes – Torque-speed curve computation process		
P₃	**No-speed point**	Target: Maximum mechanical torque ($T_{max.}$)
	Constraints	$I = I_{max}$ $U \leq U_{max}$
	Variable parameters	J_d, J_q
P₁	**Corner speed point**	Target: Maximum speed (N_{max})
	Constraints	$I \leq I_{max}$ $U = U_{max}$ $T = T(N_0)$
	Variable parameters	J_d, J_q, Speed
P₂	**Max. speed point**	Target: Maximum mechanical torque ($T_{max.}$)T
	Constraints	$I \leq I_{max}$ $U = U_{max}$ $N = N_{max}$
	Variable parameters	J_d, J_q
C₁	**Low speed zone**	Target: $T = T_b$
	Constraints	$I \leq I_{max}$ $U \leq U_{max}$ $N \in [0, N_b[$
	Variable parameters	J_d, J_q
C₂	**High speed zone**	Target: Maximum mechanical torque ($T_{max.}$)
	Constraints	$I \leq I_{max}$ $U = U_{max}$ $N \in]N_b, N_{max}[$
	Variable parameters	J_d, J_q

2.5.2.3 Efficiency map – Computation and displaying

Evaluating maps for all the electromagnetic quantities consists of computing the machine performance for each node of a grid bounded by the torque-speed curve. All working points defined by a value of torque and speed are computed over $[0, T_c]$ and $[0, N_{max}]$. (Yellow part in the image shown below).

For each pair of "Torque - Speed" point, the target is to find the corresponding point on the corresponding MTPA curve:
- Imposed speed with $N \in [0, N_{max}]$
- Imposed torque with $T \in [0, T_c]$
- Line-Line voltage less than or equal to the maximum allowed value ($U \leq U_{max}$)
- Line current less than or equal to the maximum allowed value ($I \leq I_{max}$)

MTPA curves are used, and variable parameters are the D-axis and the Q-axis components of the phase current (J_d, J_q). The identification is done by interpolation of data on MTPA curves.
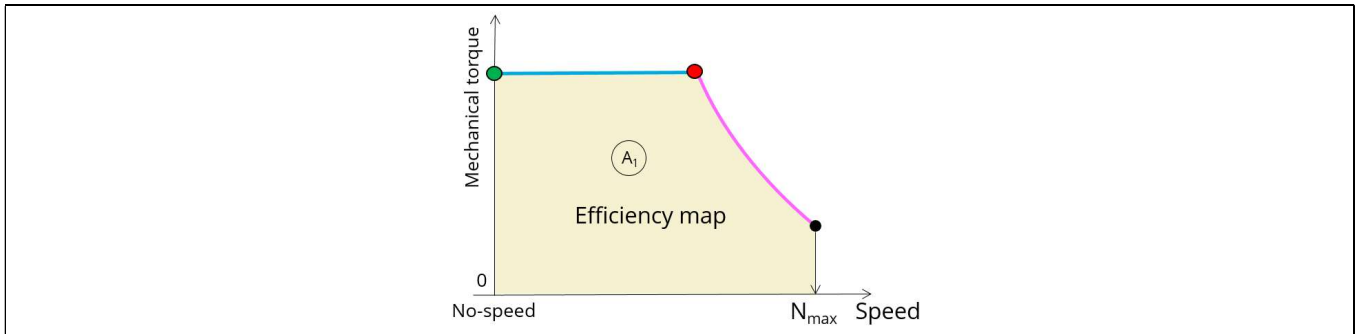
MTPA command modes – Efficiency map computation process		
A₁	**Efficiency map**	Target: MTPA process
	Constraints	$I \leq I_{max}$ $U \leq U_{max}$ $T = T_{target}$ (got by user discretization) $N = N_{target}$ (got by user discretization)
	Variable parameters	J_d, J_q

Note: At low and high speed, some computed working points can be unreachable in generator operating mode, (resulting negative electrical power). In this case, a correction is done, see the last subsection 2.5.2.4 (Torque-speed curves and maps correction).

2.5.2.4 Torque-speed curves and maps correction

As seen in the two previous subsections, the torque-speed curves and maps are computing in all the torque and speed ranges as show below:
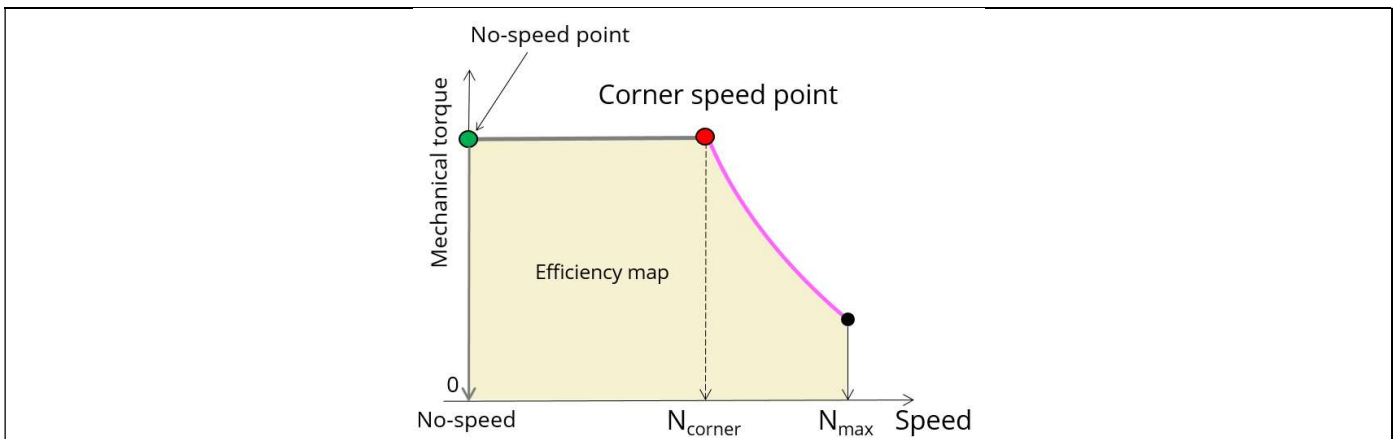

Torque speed curves and maps with MTPA command mode before correction of unreachable generator working points

As seen previously, in generator operating mode, a minimum speed is needed to make the generator able to supply an electrical current. Mechanical power (i.e. mechanical torque and speed) must be higher than losses otherwise the electrical power is negative and no electrical current is supplied.
At low speed, a minimum speed limit always exists to make the generator able to supply electrical current. In FluxMotor® this limit is called "Minimum speed point".
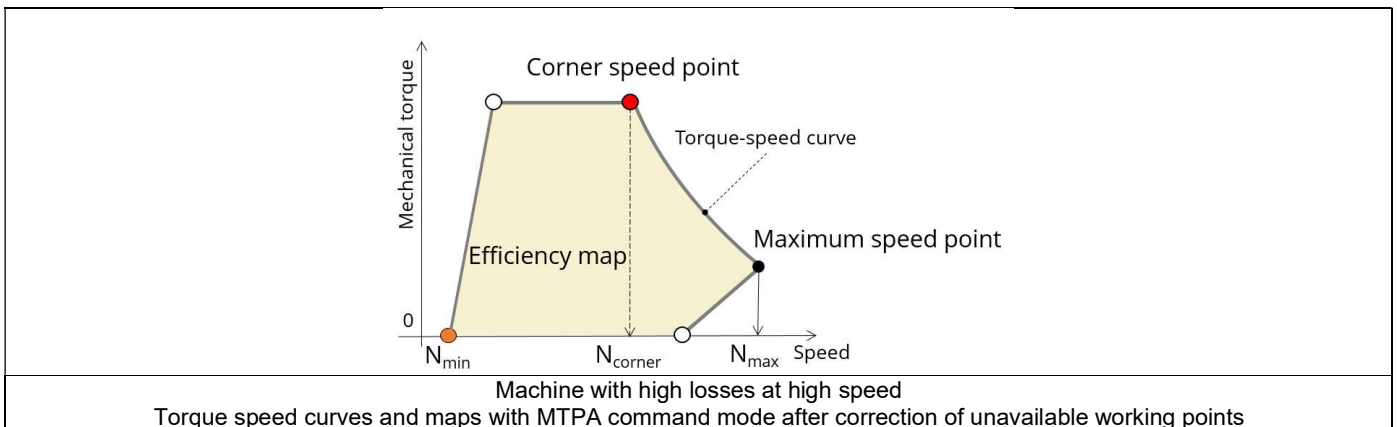
So, after the computation of the overall torque speed curves and maps a correction is done by detecting all the working points with negative electrical power. These points are considered as unreachable, and the resulting torque-speed curves and maps look like as the following figure:
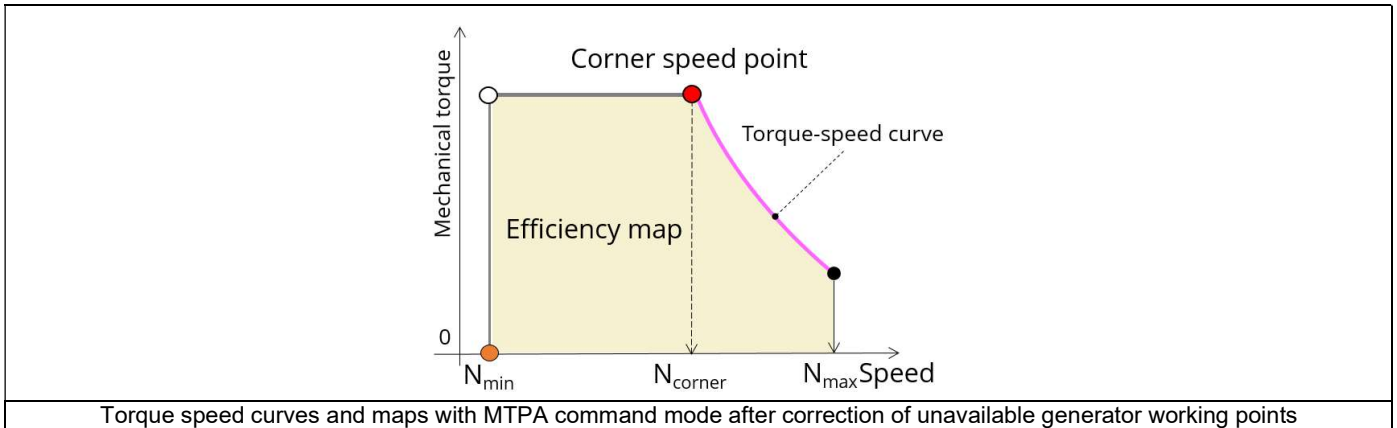
Torque speed curves and maps with MTPA command mode after correction of unavailable generator working points

Higher the discretization of speed, more accurate is the computed "minimum speed" but higher is the computation time.
With a high discretization we obtain results as presented below:

Torque speed curves and maps with MTPA command mode after correction of unavailable working points
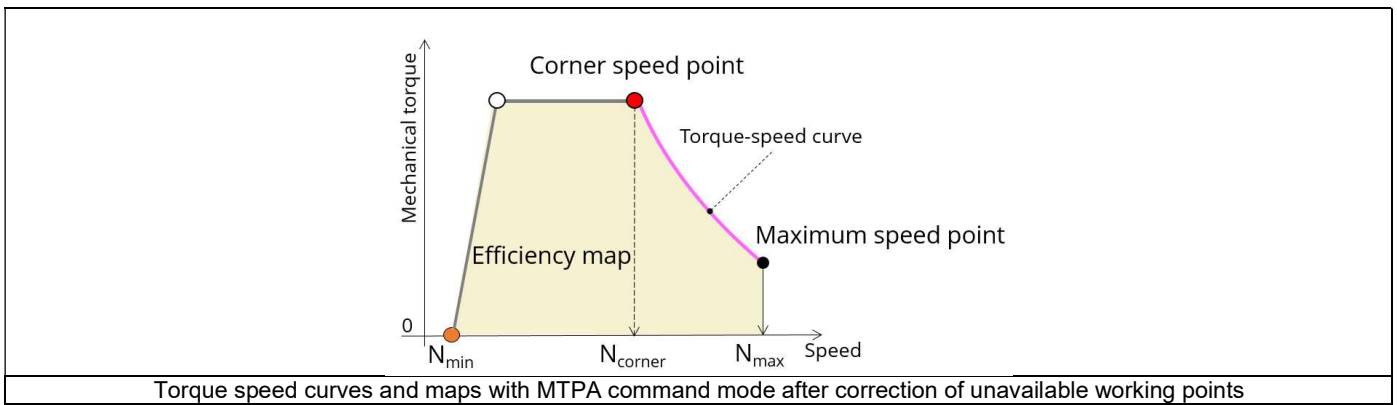
Additional unreachable working points can exist. In this case, the resulting torque speed curves and maps look as the following figure:

Machine with high losses at high speed
Torque speed curves and maps with MTPA command mode after correction of unavailable working points

2.6   Test results

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

2.6.1   Test conditions

2.6.1.1   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 2.3 (Inputs).

2.6.1.2   Settings

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

- Thermal
- Mechanics

For more details, please refer to the document: MotorFactory_SMRSM_IR_3PH_Test_Introduction – section "Settings".

2.6.1.3   Winding characteristics

The winding characteristics are displayed.

For more details, please refer to the document: MotorFactory_SMRSM_IR_3PH_Test_Introduction – section "Test generic information".

2.6.2   Main results

2.6.2.1   Machine performance – Corner speed point

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

- General data
- Power balance

For more details, please refer to the document: MotorFactory_SMRSM_IR_3PH_Test_Introduction – section Test generic information".
Note: Whatever is the convention (Motor / Generator), whatever is the considered test (DataSheet, Efficiency map, Working Point "U,I" etc) and whatever is the computed working point (Corner speed, maximum speed, working point etc), this table is the same.

2.6.2.2   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_SMRSM_IR_3PH_Test_Introduction – section Test generic information".
Note: Whatever is the convention (Motor / Generator), whatever is the considered test (DataSheet, Efficiency map, Working Point "U,I" etc) and whatever is the computed working point (Corner speed, maximum speed, working point etc), this table is the same.

2.6.2.3 Machine performance – User working point

All the machine main electromagnetic data computed for a user working point are presented in this table with the following subsections:

- General data
- Power balance

For more details, please refer to the document: MotorFactory_SMRSM_IR_3PH_Test_Introduction – section Test generic information".
Note: Whatever is the convention (Motor / Generator), whatever is the considered test (DataSheet, Efficiency map, Working Point "U, I" etc) and whatever is the computed working point (Corner speed, maximum speed, working point etc), this table is the same.

2.6.2.4 Machine performance – Duty cycle data

This section is displayed before running the test, when the user wants to perform additional analysis on some working points. To do that the user must set the input: "User working point(s) analysis" on the value "Duty cycle".

The following subsections are displayed:

- General data
- Power balance
- Energy balance

Mean values as well as minimum and maximum values of general data, power balance and energy balance are computed and displayed.

Notes:

The mean value of a quantity "Qty" is computed as:

$$\frac{1}{T_{\text{Duty cycle}}} \int_{0}^{T_{\text{Duty cycle}}} \text{Qty dt}$$

The minimum and maximum values are defined over the duty cycle.

2.6.3   Curves

2.6.3.1   Torque-speed curves

List of torque-speed curves computed and displayed:

- Mechanical torque versus speed
- Electric current versus speed
- Phase voltage versus speed
- Control angle (Ψ) versus speed
- Powers versus speed
- Power factor versus speed
- Losses versus speed

2.6.3.2   Characteristic curves

1) Characteristic curves in J_d - J_q plane – iso-torque, iso-current, iso-voltage and working point

Characteristic curves in J_d - J_q area – MTPA command mode
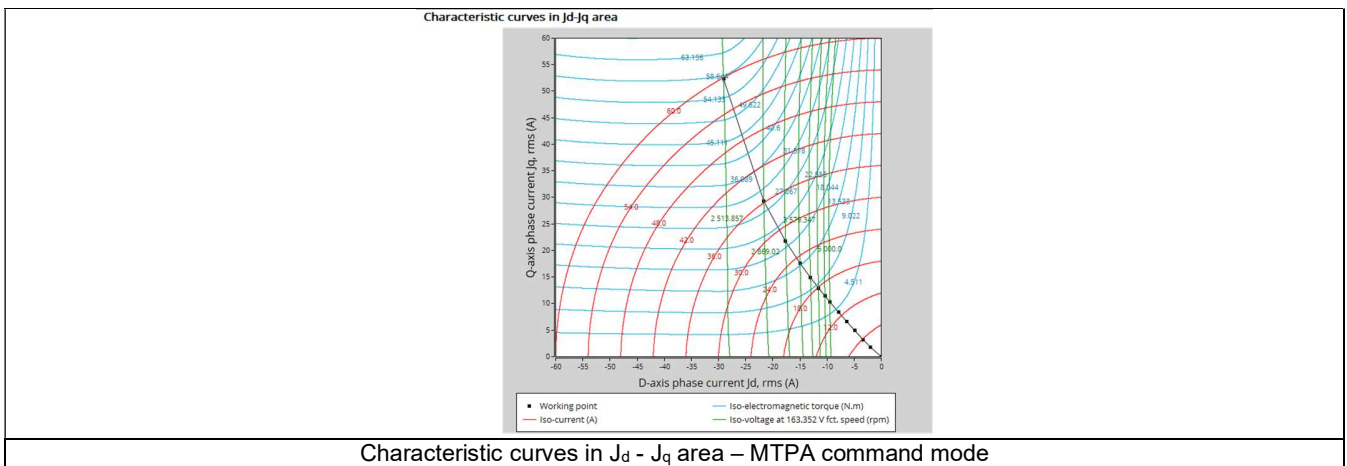
In this figure, we can see the "MTPA curve at the base speed" which begins from the point [0;0] and finish at the base speed point (working point on the top left).

2) Torque versus control angle (Ψ) for different electric current values and working point

Electromagnetic torque versus current and control angle – MTPA command mode
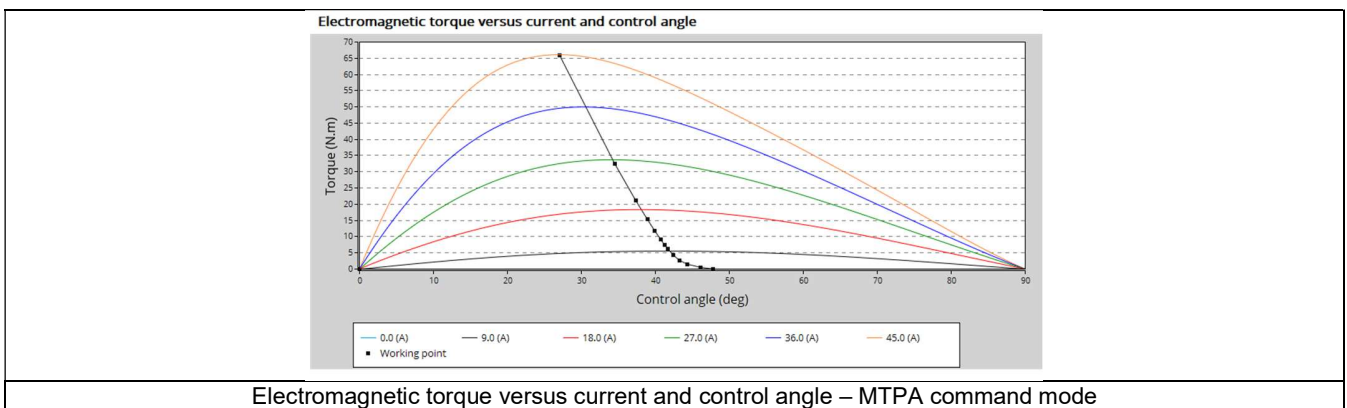
This figure displays the same kind of information given in the (MTPA curve at the base speed) "Characteristic curves in J_d - J_q area" but in the Torque versus control angle area.

2.6.4 Torque-speed Maps

List of torque-speed maps computed and displayed:

- Efficiency in torque-speed area
- Electrical current (Phase, D-axis, Q-axis)
- Phase voltage (Phase, D-axis, Q-axis)
- Control angle (Ψ) in torque-speed area
- Power (Machine electrical, mechanical)
- Power factor in torque-speed area
- Losses (Machine total, Joule, iron, mechanical, additional) in torque-speed area

Note: When a user working point has been targeted or if a duty cycle is considered, the corresponding working points are displayed on all the maps described above.

2.6.5 Duty cycle curves

List of curves dealing with the duty cycle when expected:

- Speed versus time
- Mechanical torque versus time
- Control angle versus time
- Current versus time (Phase, D-axis, Q-axis)
- Voltage versus time (Phase, D-axis, Q-axis)
- Power factor versus time
- Power versus time (Machine electrical and mechanical)
- Efficiency versus time
- Losses versus time (Machine total, Joule, Iron, mechanical and additional)