Altair® FluxMotor® 2026

Synchronous Machines with Wound Field – Inner Salient Pole – Inner Rotor

Motor Factory – Test – Performance mapping

General user information

Altairhyperworks.com

Contents

1 PERFORMANCE MAPPING – SINE WAVE – MOTOR – EFFICIENCY MAP

1.1 Overview

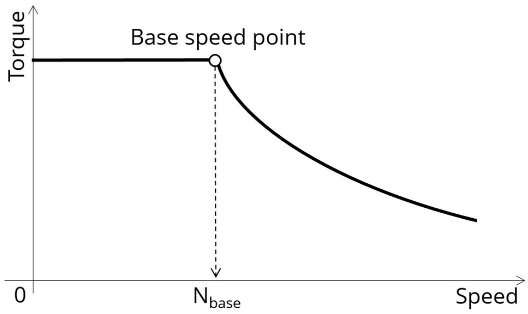
1.1.1 Positioning and objective

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 “Field current”, the maximum “Line current”, maximum “Line-Line voltage”, and the desired “Maximum speed” of the machine are considered.

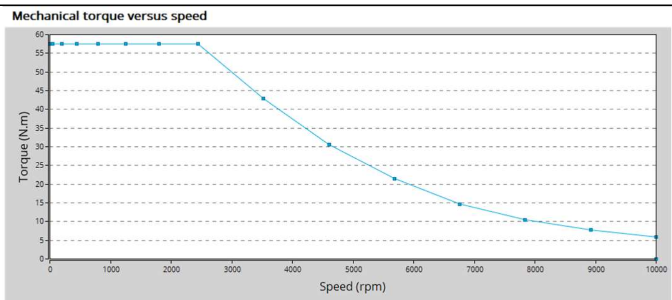
Only The Maximum Torque Per Volt command mode (MTPV) is available in this version. The Maximum Torque Per Amps command mode (MTPA) will be provided in the next releases.

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

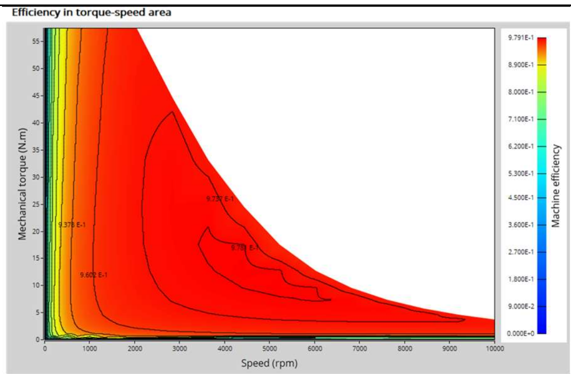


Characterization of the corner point on the torque-speed curve

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.



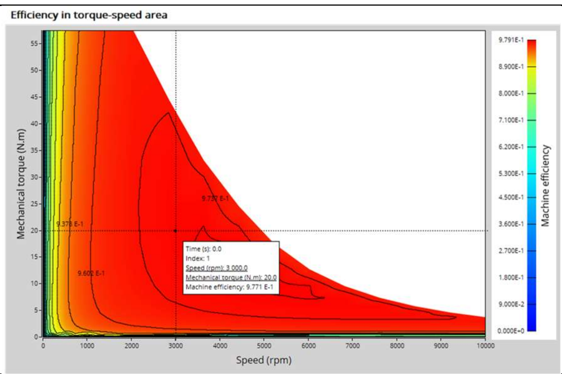
Mechanical torque versus speed - Example



Efficiency in torque-speed area - Example

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.

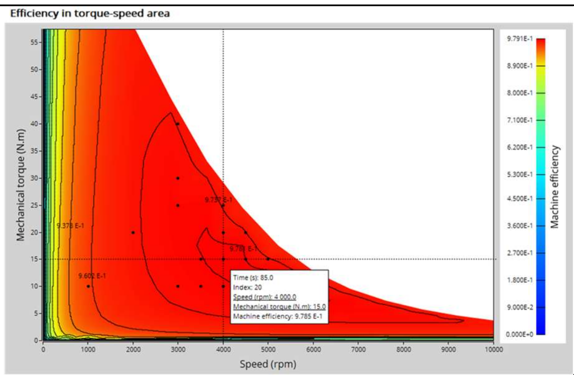


A “single” working point displayed on the efficiency map - Example

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”

1.2 Main principles of computation

1.2.1 Introduction

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

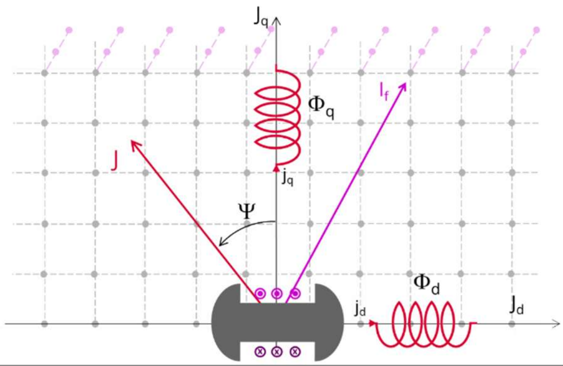
The process is separated into the two following parts:

- Raw data and Park model
- Identification of the torque-speed curves and maps – Overview

1.2.2 Raw data and Park's model

The first step consists of computing the raw data which characterize the machine in the three dimensions If - J_d - J_q. This is done using Finite Element modelling (Flux® – Magnetostatic application).

To do that, a grid of values (J_d, J_q) is considered for all levels of If.
For each node of this grid, the corresponding flux linkage through each phase is extracted (Φ_a, Φ_b, Φ_c). Fux density in regions (teeth and yoke of the machine) are also extracted.



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) are 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:

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

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

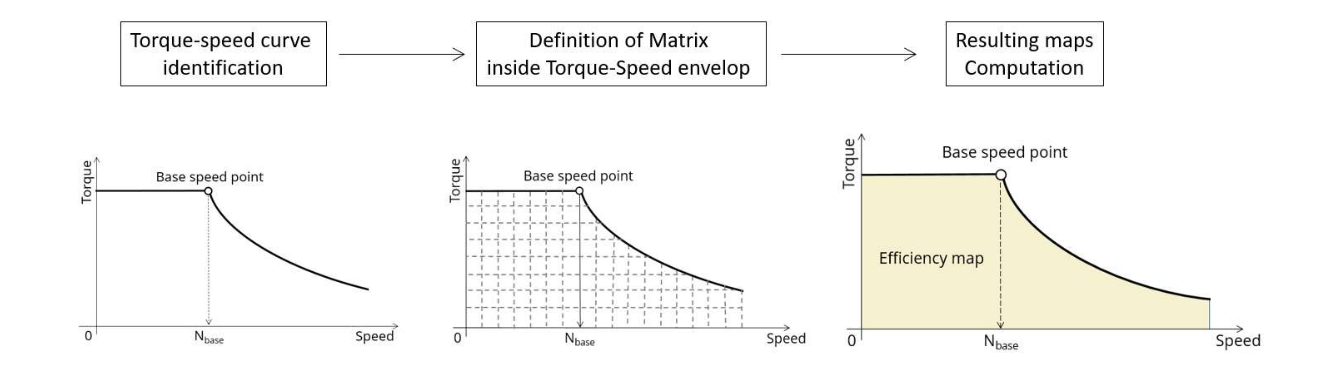
- D-axis flux-linkage component - Φ_d
- Q-axis flux-linkage component - Φ_q
- Electromagnetic torque T_{em}

- Stator iron losses $W_{ironStator}$ versus speed
- Rotor iron losses $W_{ironRotor}$ versus speed (only available if rotor position dependency is set to Yes)
- Joule losses in stator winding W_{Cus}
- Joule losses in rotor winding W_{Cur}
- Mechanical losses versus speed
- Amount of total losses W_{total} versus speed

1.2.3 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 performed by using the computed raw data (see previous section) with optimization processes.

- 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 1.3 (Command modes) dealing with the command modes

1.3 Command modes

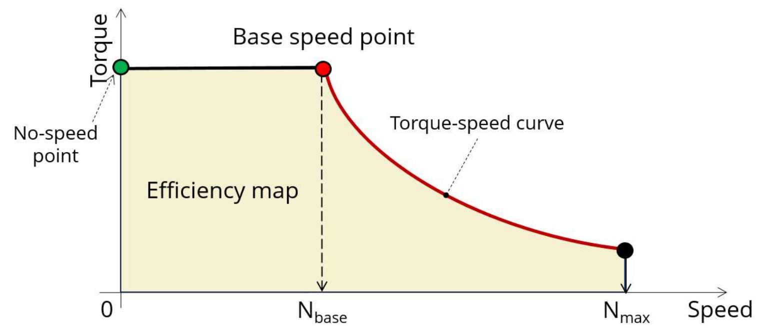
1.3.1 Introduction

The user can choose only one command modes in this version:

- The Maximum Torque Per Voltage (MTPV)

Note: The Maximum Torque Per Amps (MPTA) will be provided in the next releases.

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…).



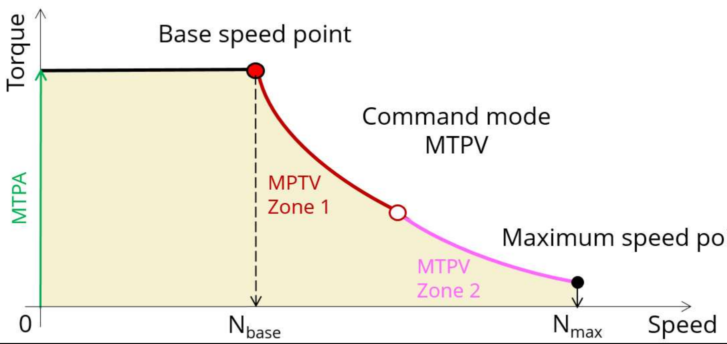
Torque-speed curve and efficiency map

1.3.2 Maximum Torque Per Voltage command mode (MTPV)

1.3.2.1 Positioning and objective

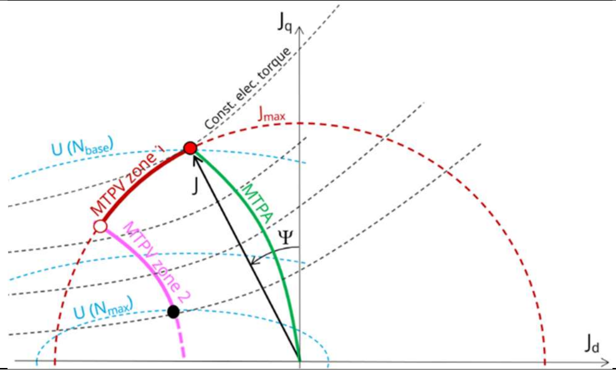
The Maximum Torque Per Voltage command mode (MTPV) allows to compute the torque-speed curve which corresponds to the maximum potential of mechanical torque (or mechanical power) of a motor from the base speed point to the maximum speed point.
This command mode shows the full potential of the machine, 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".



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).

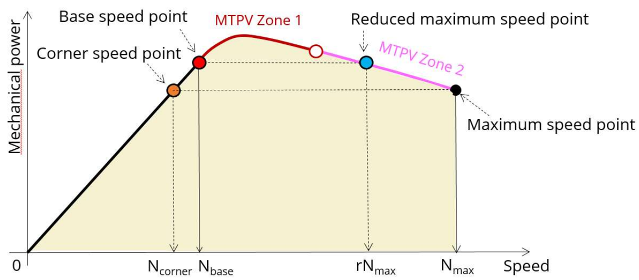
$$U = U_{max}$$
$$I < I_{max}$$

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 maximizing 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 detect 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 can 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.

1.3.2.2 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) and the field current If.

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 ($U = U_{max}$)
- Field current less than or equal to the maximum allowed value ($If \leq If_{max}$)
- Line current less than or equal to the maximum allowed value ($I \leq I_{max}$)
- 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) and the field current If.

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 ($U = U_{max}$.)
- Field current less than or equal to the maximum allowed value ($If \leq If_{max}$)
- Line current less than or equal to the maximum allowed value ($I \leq I_{max}$)
- 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) and the field current I_f.

3) No speed working point

The third step consists of computing 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 ($U \leq U_{max}$)
- Field current less than or equal to the maximum allowed value ($If \leq If_{max}$)
- Line current less than or equal to the maximum allowed value ($I \leq I_{max}$)
- 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) and the field current If.

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).
- Imposed speed with N ∈]0, Nb[
- Line-Line voltage less than or equal to the maximum allowed value ($U \leq U_{max}$)
- Field current less than or equal to the maximum allowed value ($If \leq If_{max}$)
- Line current less than or equal to the maximum allowed value ($I \leq I_{max}$)

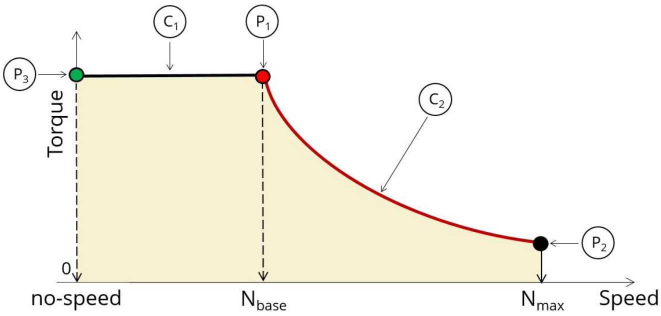
The variable parameters are the D-axis and the Q-axis components of the phase current (j_d, j_q) and the field current If.

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∈]Nb , N_{max} [
- Line-Line voltage equal to the maximum allowed value ($U = U_{max}$)
- Field current less than or equal to the maximum allowed value ($If \leq If_{max}$)
- Line current less than or equal to the maximum allowed value ($I \leq I_{max}$)

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) and the field current If.



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, If, Speed (N)
P_2	**Max. speed point**	Target: Maximum torque (T_{max})
	Constraints	$If \leq If_{max}$ $I \leq I_{max}$ $U=U_{max}$ Speed = Maximum speed ($N_{max.}$)
	Variable parameters	J_d, J_q, If
P_3	**Null speed point**	Target: maximum efficiency
	Constraints	$If \leq If_{max}$ $I \leq I_{max}$ $U \leq U_{max}$ Speed = N = 0 Torque = base speed torque ($T(N_b)$)
	Variable parameters	J_d, J_q, If
C_1	**Low speed zone**	Target: maximum efficiency
	Constraints	$If \leq If_{max}$ $I \leq I_{max}$ $U \leq U_{max}$ Speed $\in$ $]0, N_b[$ Torque = base speed torque ($T(N_b)$)
	Variable parameters	J_d, J_q, If
C_2	**High speed zone**	Target: maximum torque (T_{max})
	Constraints	$If \leq If_{max}$ $I \leq I_{max}$ $U = U_{max}$ Speed N $\in$ $]N_b, N_{max.}[$
	Variable parameters	J_d, J_q, If

1.3.2.3 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 ($U \leq U_{max}$)
- Field current less than or equal to the maximum allowed value ($If \leq If_{max}$)
- 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) and the field current If.

2) Maps at no torque

At zero torque, only iron losses and mechanical losses, which depend on 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.

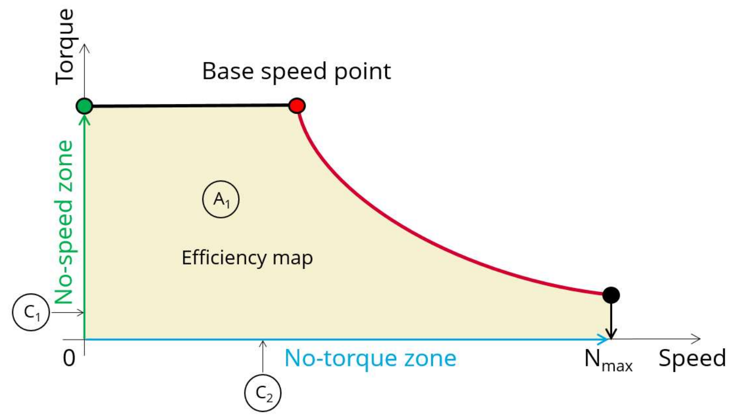
4) Maps in the range]0, N_{max}]

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 ($U \leq U_{max}$)
- Field current less than or equal to the maximum allowed value ($If \leq If_{max}$)
- 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

C_1	**Null speed zone**	Target: Minimum Joule losses
	Constraints	$I_f \leq If_{max}$ $I \leq I_{max}$, $U \leq U_{max}$, Speed N = 0 User torque (got by user's discretization)
	Variable parameters	J_d, J_q, If
C_2	**Null torque zone**	
	Only iron losses and mechanical losses are computed All other quantities are set to 0, even the efficiency.	
A_1	**Efficiency map**	Target: Maximum efficiency
	Constraints	$If \leq If_{max}$ $I \leq I_{max}$ $U \leq U_{max}$ Targeted speed (got by user's discretization) Targeted torque (got by user's discretization)
	Variable parameters	J_d, J_q, If