Grid Forming Specifications
General Conditions
(In addition to Article 8.3.4 - Non-synchronous storage unit)

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1. PREAMBLE

This document presents a draft of the requirements concerning Grid-Forming capabilities for Type C and Type D Electricity Storage Modules aiming to connect to the French electrical transmission grid.

These requirements are derived from both the recommendation on the amendments to the Requirements for Generators published by ACER in December 2023 [1] (RfG 2.0 draft) – specifically Articles Y(7) and 21(4) - and the ENTSO-E technical report on Grid-Forming capabilities [2]. They are primarily defined through:

- **Requirements on current limitation strategies, and**
- **Dynamic performance requirements**, which specify the expected behavior of the unit under the following conditions:
    1. Voltage angle and magnitude jumps, as well as variations in Short-Circuit Ratio
    2. Frequency variations

For the response to events, dynamic performance requirements will be specified in terms of:

- The expected value of active and reactive current or power output
- The response time to reach the expected active/reactive current or power output
- The rate of decay or potential overshoot in current/power excursion (when applicable)
- The damping of oscillations in active/reactive current or power

Please note the important following remarks for the draft version of the French Connection Network Code:

1. **All performances are valid as long as the converter connecting the Electricity Storage Module does not reach any current limitation, or the Electricity Storage Module is not fully charged or discharged.** In these cases, requirements will be adapted as far as possible, and any deviation to the requirements for these specific situations will be discussed between RTE and the asset owner. To allow for such discussions short term maximum current capability must be clearly defined.
2. **The use of a virtual (control) impedance in the control strategy is neither required nor prohibited**, provided that all performance-based requirements are met, in accordance with Article Y(7)(b) of RfG 2.0.
3. **For the sake of harmonisation and simplicity, the Grid-Forming behavior will be assessed at Power-Generating Unit (PGU).**
4. Concerning measurements, if the positive sequence value of the active/reactive current is evaluated from real measurement or EMT simulation, the expected value shall be reached within 20 ms more than the values indicated[1]
5. Power Generating Units with identical characteristics (tuning parameters, filter impedances, and transformer impedances) shall be tested once. Power Generating Units with differing characteristics shall each be tested separately.

The introduction of Grid-Forming requirements will lead to modifications in existing sections of the French Connection Network Code. In particular:

- Additional data requirements in the data fiche E1
- Reactive current injection will not be required for Grid-Forming units
- RMS, EMT, and frequency models requirements will be updated

The remainder of this document presents the detailed technical requirements and serves as a draft proposal for an update of the French Connection Network Code.

[1] According to IEC 61400-21 standard for positive sequence calculation

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2. ON THE VOLTAGE SOURCE BEHAVIOR WITHIN CAPABILITY LIMITS

This section outlines the requirement specified in Article Y, Sections 7 (a) to (c) of the draft NC RfG 2.0. In summary, these sections state that "*the power generating units internal voltage phasor (in amplitude, phase, and frequency) are considered constant upon inception of a network disturbance at the connection point However, if the Power Park Module capabilities and current limits are exceeded, instantaneous reaction of the PGU to maintain currents limits is allowed*."

The expected behavior, as described in the code, is thus the one of a voltage source behind an impedance x_{eff}, and can be explicitly specified using the test system shown in Figure 1.

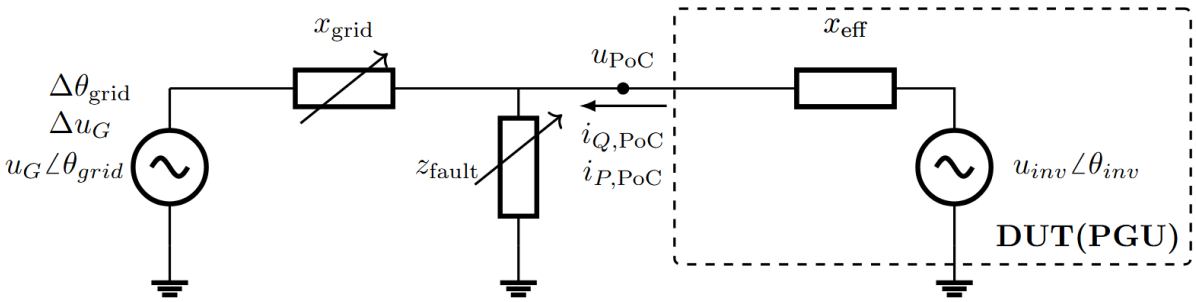


Figure 1 - Test system representation with the Power Generating Unit replaced by a voltage source behind impedance to define the expected behavior

For an assessment at the Power Generating Unit terminal, the value of x_{eff} is set at 0.27 pu.

2.1 With regards to voltage source behavior in case of phase jumps

When a phase jump occurs in the grid, the unit is expected to deliver active power to the grid as a consequence of its internal phase angle being constant.

The approach of an equivalent circuit (cf Figure 1 and [2]) is used to define the expected active power change. With this approach, a theoretical analytically calculated peak active current change ($\Delta\, i_{\text{P,PGU}}$) is obtained for an angle change $\Delta\theta_{grid}$ in the grid:

$$\Delta i_{P,PGU,Peak} \approx -\frac{1}{x_{eff} + x_{grid}}\left(\sin\left(\Delta\theta_{grid} + \delta'\right) - \sin(\delta')\right)$$

With:

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– $\Delta i_{\mathrm{P,PGU,Peak}}$ being the expected theoretical peak which is analytically calculated.

– δ' being the phase difference between the grid terminal voltage angle θ_{grid} and the internal voltage θ_{inv} of the Power Generating Unit prior to the phase jump event

– $\Delta\theta_{grid}$ being the angle change applied by which the terminal voltage angle θ_{grid} jumps from its steady state value. It must be large enough to generate at least a jump of 30 % of active power.

The Power Generating Unit can then be assumed to behave as a voltage source if the following criteria are met:

– **Peak contribution:** 50% of $\Delta i_{p,\,PGU,\,Peak}$ is delivered within 10 ms

– **Tolerance band:** the active current must settle, about the final value, within a tolerance band equal to the greater of ±2% of the rated current and $\pm$ 5% of $\Delta i_{P,PGU,Peak}$.

– **Damping ratio:** the active and reactive current should have a damping of at least 50%. The damping factor shall be evaluated with pencil matrix method. The method has been implemented and can be tested here.

In addition, the current response must be instantaneous and free of any delay. A physical response is required; control or measurement delays are not acceptable.
Current limitation within the converter may restrict the current to its short-term maximum capacity.

2.2 With regards to voltage source behavior in case of amplitude jumps

When an amplitude step occurs in the grid, the unit is expected to deliver reactive power to the grid as a consequence of its internal voltage amplitude being constant.

The approach of an equivalent circuit (cf Figure 1 and [2]) is used to define the expected reactive power change. With this approach, a theoretical analytically peak reactive current change ($\Delta\, i_{\mathrm{Q,PGU}}$) is obtained for an amplitude change Δu_G in the grid:

$$\Delta i_{Q,\,PGU} \approx \frac{\Delta u_G}{x_{eff} + x_{grid}}$$

– $\Delta i_{\mathrm{Q,PGU}}$ being the expected theoretical reactive current response.

– Δu_G being the voltage jump at the Thevenin equivalent.

Δu_G must be large enough to generate at least a jump of 15% $\Delta i_{Q,PGU}$.

The Power Generating Unit can then be assumed to behave as a voltage source if the following criteria are met:

- **Peak contribution:** 90% of $\Delta i_{Q,\,PGU}$ is delivered within 10 ms.
- **Tolerance band:** the reactive current must settle, about the final value, within a tolerance band equal to the greater of ±2% of the rated current and $\pm$ 5% of $\Delta i_{Q,\,PGU}$
- **Settling time:** the reactive current must settle, about the final value, 80 ms after the event
- **Damping ratio:** the active and reactive current should have a damping of at least 50%. The damping factor shall be evaluated with pencil matrix method[3]. The method has been implemented and can be tested here.

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The current response must be instantaneous and free of any delay. A physical response is required; control or measurement delays are not acceptable.
Current limitation within the converter may restrict the current to its short-term maximum capacity.

2.3 With regards to voltage source behavior in case of Short Circuit Ratio jumps

When topology changes on the grid and therefore a Short Circuit Ratio change occurs on the grid, the unit is expected to deliver active power to the grid as a consequence of its internal phase angle being constant.

The approach of an equivalent circuit (cf Figure 1 and [2]) is used to define the expected active power change. With this approach, a theoretical analytically peak active current change $\Delta i_{P,PGU,Peak}$ is obtained for an impedance change from $x_{grid,1}$ to $x_{grid,2}$ in the grid, with an initial active power P_0

$$\Delta i_{P,PGU,Peak} \approx -\frac{\left(x_{grid,2} - x_{grid,1}\right) P_0}{x_{eff} + x_{grid,2}}$$

With:

– $\Delta i_{\mathrm{P,PGU,Peak}}$ being the expected theoretical peak which is analytically calculated.

– P_0 is the active power before the event

The Power Generating Unit can then be assumed to behave as a voltage source if the following criteria are met:

- **Peak contribution:** 50% of $\Delta i_{\mathrm{P,PGU,Peak}}$ is delivered within 10 ms.
- **Tolerance band:** the active current must settle, about the final value, within a tolerance band equal to the greater of ±2% of the rated current and $\pm$ 5% of $\Delta i_{P,PGU,Peak}$.
- **Damping ratio:** the active and reactive current should have a damping of at least 50%. The damping factor shall be evaluated with pencil matrix method[3]. The method has been implemented and can be tested here[2].

The current response must be instantaneous and free of any delay. A physical response is required; control or measurement delays are not acceptable.
Current limitation within the converter may restrict the current to its short-term maximum capacity.

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2 Test_damping_python_app_RTE - Colab

3. ON THE SYNTHETIC INERTIA CONTRIBUTION WITHIN CAPABILITY LIMITS

This section details the requirement specified in Article 21, Section 4 of the draft NC RfG 2.0

"The electricity storage module shall be capable of contributing to limiting the transient frequency deviation under both high and low frequency conditions.
(a) The relevant TSO, in coordination with the relevant system operator, shall specify the contribution to synthetic inertia. The power park module shall be capable of contributing to limiting the transient frequency deviation under high and low frequency conditions."

Using the system introduced in Figure 1, **while the frequency changes, the unit is expected to provide an additional active power ΔP:**

$$\Delta P = T_{R,PPM} \cdot \frac{df/f_{Rated}}{dt} \cdot P_{Rated}$$

With $T_{R,PPM} = 5\ s$

The Power Generating Unit can then be assumed to behave adequately if the following criteria are met:

- **Peak contribution:** 90% of ΔP is delivered within 100 ms.
- **Tolerance band:** the active current must settle within a tolerance band of ±2% of the rated current around the final value 100 ms after the end of frequency variation
- **Damping ratio:** the active and reactive current should have a damping of at least 50%. The damping factor shall be evaluated with pencil matrix method[3]. The method has been implemented and can be tested here[3].

The current response must be instantaneous and free of any delay. A physical response is required; control or measurement delays are not acceptable.
The unit is not expected to provide more current/power than its short-term rating, moreover, inertia is only required if energy is available in the storage.

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3 Test_damping_python_app_RTE - Colab

4. ON THE CURRENT LIMITATION STRATEGIES

The inverters are not expected to deliver more than their short term rated current during transient event. Therefore, current limitation is necessary to protect the unit, and voltage source behavior might be temporarily lost.

The current limitation strategy should not modify current angle, only its amplitude can be limited to keep safe operation of the inverter as shown in Figure 2**.**

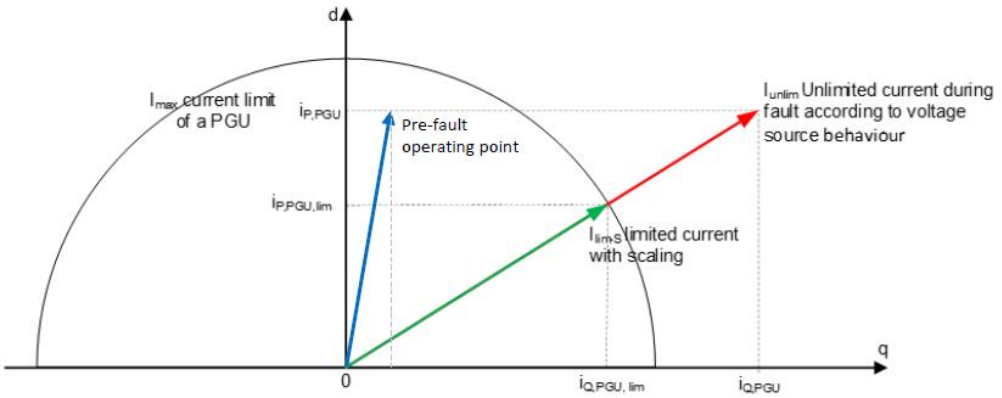


Figure 2 - Current limitation strategy as proposed by [2]

5. REFERENCES

[1] ACER, Recommendation on the amendments to the network codes on requirements for grid connection of generators – named RfG 2.0 in this document, https://www.acer.europa.eu/sites/default/files/documents/Recommendations_annex/ACER_Recommendation_03-2023_Annex_1a_NC_RfG_TC_to_original.pdf

[2] ENTSO-E, Technical Report on Grid Forming Capabilities, https://eepublicdownloads.entsoe.eu/clean-documents/Publications/SOC/20240503_First_interim_report_in_technical_requirements.pdf

[3] Pencil Matrix : Open Access article Fernández Rodríguez, A., de Santiago Rodrigo, L., López Guillén, E. et al., "Coding Prony's method in MATLAB and applying it to biomedical signal filtering", BMC Bioinformatics 19, 451 (2018), ***https://doi.org/10.1186/s12859-018-2473-y***

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