# Implementation Guidelines for the Network Code Requirements for Generators – Recommendations from the European wind industry

A paper from the WindEurope Task Force on Grid Connection Requirements

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# EXECUTIVE SUMMARY

The present document aims at facilitating the implementation of the European network code on requirements for generators by providing the views and expertise of the wind industry sector. The network code, developed by ENTSO-e and published in May 2016, provides a large number of not-fully-defined requirements and specifications. In many cases, these non-exhaustive requirements lead to ambiguity on the technical performance needed, as well as to uncertainty on the regulatory framework for implementing the new set of rules, which will be applicable as from May 2019. The combination of the legal framework uncertainty and the short adaptation time for the industry (only 1 year) creates a lot of pressure and risk on the wind industry. In addition, under this legal framework national TSOs are allowed to set onerous requirements without a proper techno-economic justification.

The industry is concerned that unjustified onerous technical requirements, along with legal uncertainty would lead to unnecessary higher costs, resulting in higher costs for consumers. To avoid this, WindEurope has formulated a set of recommendations, prepared consensually by all major European wind turbines and equipment manufacturers as well as project developers. WindEurope hopes that the proposals presented in this document will be reflected in the implementation guidelines that are under preparation.   The following main messages are presented in this document:

### With regards to fault-ride-through

- The voltage against time profiles of fault-ride-through should be further specified in national grid codes and should differentiate installations connected below and above 110KV networks. When necessary Fault-ride-Through should also be defined for over-voltage events, setting clear requirements, such as the ones proposed in this document.
- The fault clearing time after under-voltage events should remain within 150ms as a default value. Longer fault clearing times up to 250ms can be required, along with a grid study and statistical data that would justify the need for longer times (and higher costs).
- Wind power plants with connection point below 110kV should be allowed to maintain its voltage to values above zero before the fault clearing time. In general, this value should be as high as possible, as a result of local grid studies, since lower values are increasing the equipment costs.
- After a fault, wind power plants should provide at least 90% of its pre-fault active power after voltage recovers above 90 % of the pre-fault voltage. The time setting for post fault active recovery should be carefully designed and should be clearly defined in the code. A proposal is provided in this document.

### With regards to reactive power:

- Reactive power provision should be limited to the times when the wind power plant is producing active power. Below a 10% active power (minimum operating level), reactive power capability should not be required as this will lead to unnecessarily higher costs. Additionally, below an active power of 20% of the rated power, reactive power capability should be less stringent than for higher operating levels.

- Reactive power capabilities that go beyond the default ranges proposed (in this document) might be agreed between the relevant grid operator and the power generating module owner through a bilateral agreement and should be a remunerated service.
- National codes should differentiate plants connected to the distribution and transmission level. While withstanding voltage ranges as large as 22.5% are common practice at transmission level (above 110KV lines), no such requirement exists for systems connected at the distribution level (medium or lower voltage networks). Thus voltage ranges should be lower for plants connected to the distribution network.
- While the network code does not discard the option, national codes should limit the capability required to consume reactive power during under voltage events and the capability to produce reactive power during overvoltage events, especially in Medium Voltage (MV) networks, as this capability is generally not needed but increases equipment cost. If this capability is deemed necessary due to local constrains, it should be remunerated, based on a bilateral agreement between the plant owner and system operator.

A number of non-technical regulatory aspects are also very critical for the shift and efficient implementation of the network code. These aspects, which are out of the scope of this document, include the compliance and verification framework, the clarity on the scope of the regulation (existing plants, offshore vs. DC-connected wind plants) and the timing for implementation. Regarding the latter, WindEurope would like to extend the adaptation time for industry to at least a 2-year period (instead of 1), to allow for a smooth and coordinated transition to the new regulatory framework.

# CONTENT

# 1. INTRODUCTION

## 1.1. CONTEXT

The network code on *Requirements for grid connection of generators* (NC RfG) has been proposed by the European Commission in 2009 as part of third energy package to increase cross-border electricity exchange and maintain security of supply. As a consequence, a set of coherent requirements which should help tackle increasingly diverging and ambiguous grid connection requirements across the EU have been proposed within the NC RfG.

After 5 years of intense discussions between ENTSO-E, industry stakeholder, ACER and the European Commission, the NC RfG has entered into force as directly applicable regulation (i.e. become European law) in May 2016.

National authorities and system operators will need to adapt the NC RfG into national legislation within the 2 years after NC RfG comes into effect in national regulation. Industry will then be given only 1 year (until 3 years after NC RfG comes into effect) for adoption of the requirements into new equipment and power plants specifications. In some member states, TSOs have already initiated processes to update existing connection rules (grid codes). Figure 1 shows the increasing amount of actors that will need to be involved in the national transposition of the new rules. Thousands of equipment manufactures and project operators and developers will be affected by the new requirements. Their time for adaptation is set at just one year, highlighting the importance of carrying out a coordinated and transparent process with the participation of all involved parties. The industry has voiced concerns that this time is far too short and should be extended to a at least 2 years.

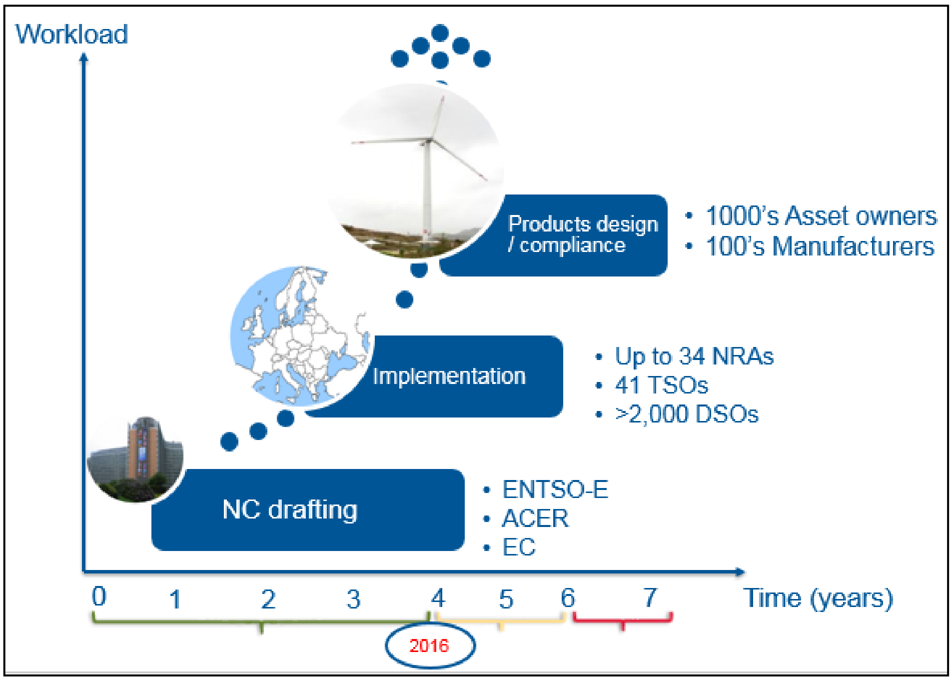


*Figure 1. Timeline and actors involved in the national implementation of the RfG NC*

In view of the challenges ahead (Figure 2), ENTSO-E is tasked to develop implementation guidelines that will support national TSOs and regulators in the adoption of the NC RfG in a coordinated way. Such guidelines are expected to be ready by Q3 2016. The main objective of these non-binding guidelines is to further specify non-exhaustive requirements and to address issues such as testing and compliance, possible harmonization efforts, and the role of existing grid connection standards. In total, ENTSO-E plan to develop a set of 20 Implementation guidelines documents (IGD)[1].

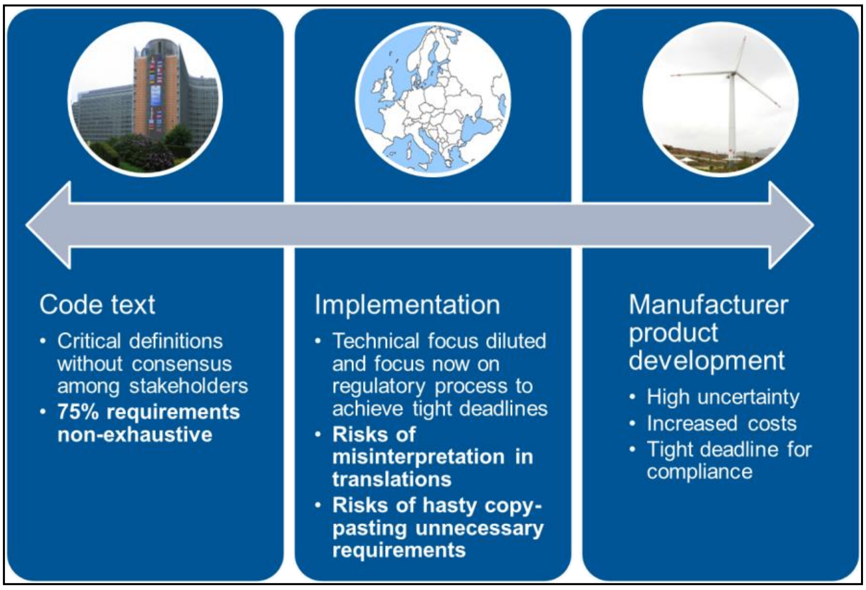


*Figure 2. Summary of main challenges for the RfG NC implementation at national level The NC RfG contains numerous non-exhaustive requirements (up to 75% of all requirements are considered to be non-exhaustive). These requirements will be only specified during the national Implementation process. If those requirements are not clearly defined, lack completeness or explicitness, wind power projects are likely to be delayed or increase their costs significantly[2].*

The wind industry, represented by WindEurope considers that the 5 following points (Figure 3) should be addressed in the implementation guidelines and in the upcoming process to effectively develop grid codes across Europe, avoid regulatory uncertainty, unnecessary requirements and potentially higher overall energy system costs.

[1] ENTSO-E Workshop on Network codes development, 29 February, 2016 Link

[2] Generators (from all technologies) have voiced concerns that the NC RfG has also been used to shift costs from network operators to generators by unjustifiable higher requirements for connection.

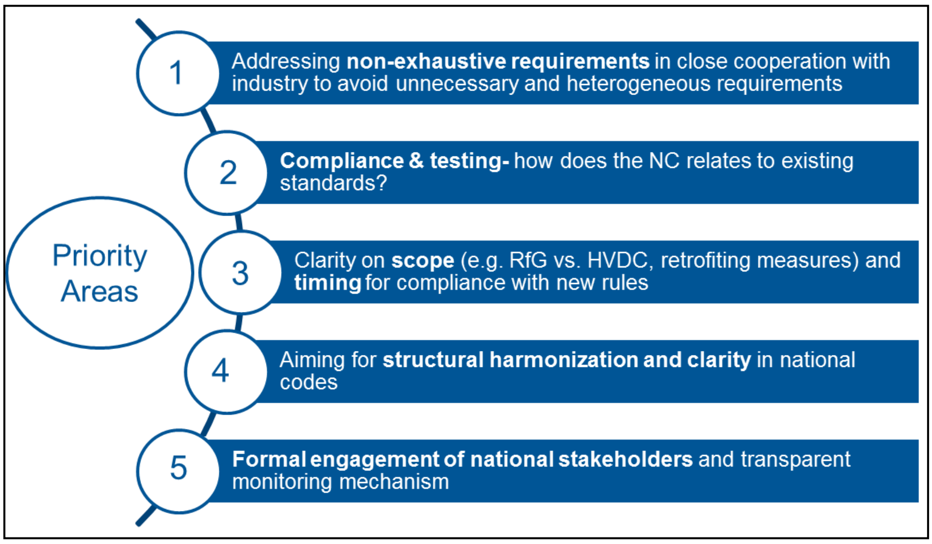


*Figure 3. Areas that require further work and should be addressed in ENTSO-E implementation guidelines*

## 1.2. AIM AND SCOPE OF THIS DOCUMENT

The present document provides a number of detailed specifications to the NC RfG requirements that have been left open, or *non-exhaustive*. In particular, the requirements related to *fault-ride-through* (chapter 3) and *reactive power (Chapter 4)* are considered to be the most critical ones for wind power producers, posing technical challenges and potentially raising costs of wind energy, if badly implemented.

This document should be treated as a complementary document to NC RfG.

WindEurope would like to see the recommendations raised in this document as part of ENTSO-E implementation guidelines. Additionally, this document might support the ongoing discussions at national level, since it provides the consensual views of major European wind turbines and equipment manufacturers as well as project developers.

This document has been prepared by WindEurope's Task Force on Grid Connection Requirements. WindEurope, through its task force, has been already working towards a structural harmonization of national grid codes since 2006, well before the EU launched the initiative on network codes. Since 2009, WindEurope (previously EWEA) has been involved in discussions with ENTSO-E and the energy regulators on the NC RfG. As a result of these efforts, the European Commission has included wind industry proposals replacing entire articles of the NC RfG. For example, an article relevant for voltage support from wind power generators and one for the provision of fast-fault current injection support during faults.

WindEurope is continuously striving to find industry-wide consensus on specific parameters for grid connection requirements. These specifications have been identified, structured and presented by WindEurope in 2009 in the *Generic grid code Format document*[3].

The current document presents aspects related to FRT and reactive power. Additional aspects are being discussed and might be published in the near future.

[3] http://www.ewea.org/fileadmin/ewea_documents/documents/publications/091127_GGCF_Final_Draft.pdf

# 2. DEFINITIONS

The following definitions present a recap of some of the definitions from the NC RfG plus additional terms that are frequently used throughout this document.

| Term | Definition | Relationship to NC RfG |
|---|---|---|
| Power Park Module (PPM) | 'Power park module' or 'PPM' means a unit or ensemble of units generating electricity, which is either non-synchronously connected to the network or connected through power electronics, and that also has a single connection point to a transmission system, distribution system including closed distribution system or HVDC system. | Similar to the NC RfG |
| Point of Connection (PoC) | Point of connection or 'connection point' means the interface at which the power generating module (thus a Power Park Module), demand facility, distribution system or HVDC system is connected to a transmission system, offshore network, distribution system, including closed distribution systems, or HVDC system, as identified in the connection agreement. | Similar to the NC RfG |
| Minimum regulating level | It means the minimum active power, as specified in the connection agreement or as agreed between the relevant system operator and the power generating facility owner, down to which the power generating module can control active power. | Similar to the NC RfG |
| Minimum Operating Level | It means the minimum active power, as specified in the connection agreement or as agreed between the relevant system operator and the power generating facility owner, at which the power generating module (i.e. PPM) can be operated stably for an unlimited time;<br><br>Above the minimum operating level, a PPM shall be able of ramping upwards at any of the specified ramp rates (given available wind). The minimum operating level shall not be lower than 10% of Registered Capacity, as specified in the connection agreement. | Similar, with Additions from the Irish Grid code |
| Fault ride-through (FRT) | Fault-ride-through (FRT) is the capability of a generator to be able to remain connected to the grid and operate through periods of low or high voltage at the connection point caused by secured faults. Further specifications are presented in Section 3. | Similar to the NC RfG |

# 3. FAULT-RIDE-THROUGH

The European wind industry considers the following specifications and requirements to be sensible for the national implementation of articles 14.3 and 16.3 of the NC RfG.

## 3.1.FAULT-RIDE-THROUGH DESCRIPTION

- Fault-ride-through (FRT) is the capability of a PPMs to be able to remain connected to the network and operate through periods of low or high voltage at the connection point caused by secured faults.
- Such voltage deviations can be caused by short-circuits (faults) in the network or other events.
- The FRT requirement is only valid within a pre-defined voltage-against-time profile. Outside the pre-defined voltage-against-time profile the generator may disconnect from the grid in accordance with the protection scheme.
- During this voltage drop/increase the generator may provide active current and provide/absorb reactive current as/if required by the relevant grid operator.
- The generator shall be able to return to its pre-deviation operation state after the voltage has returned within normal limits.
- The size of the voltage deviation at the point of connection (PoC) of the PPM depends on the fault location, grid topology and the equipment between the fault and the PPM.
- FRT capability requirement within a specific voltage-against-time-profile depends on the physical power system needs and shall be in line with system planning standards, protection standards and operational procedures.

## 3.2. FRT VOLTAGE PROFILE FOR UNDER VOLTAGES

Power park modules shall be capable of continuing stable operation after the power system has been disturbed by secured faults in accordance with a voltage-against-time-profile at the connection point.

The voltage-against-time-profile shall be expressed by the lower limit of the course of the phase-to-phase voltages on the network voltage level at the connection point where measuring equipment can be installed, as a function of time before, during and after the fault.

This lower limit shall be defined by the relevant network operator by using the parameters and ranges set out in Table 1 for power park modules of type B, C & D with connection point below 110kV and in Table 2 for power park modules of type D with connection point at or above 110kV. These parameters and ranges are described as voltage-against-time profile in Figure 4 as border lines (envelop lines). They apply to all types of faults (symmetrical and asymmetrical i.e. one-, two- or three-phase faults) and the bold line shall represent the minimum voltage of all phases.

The following describe the requirements indicated Figure 4 in further detail:

- In area A the power park module shall stay in stable operation during a temporary voltage deviation outside the continuous voltage operation range and may provide an active current and reactive current if required by the relevant grid operator as specified in Chapter 4 from this document.
- The maximum voltage drop during faults shall be defined within the ranges set by Table 1 for power park modules of type B, C & D with connection point below 110kV and Table 2 for power park modules of type D with connection point at or above 110kV.
- In area B disconnection of the power park module is allowed, but the power park module may stay connected until reaching the generator design limits or the limits set by the grid protection settings. These grid protection parameters shall be agreed between the power park module owner and the grid operator.
- The described voltage-against-time profile does not reflect the specific voltage behaviour during faults.
- All phase-to-phase voltages shall stay above the defined voltage-against-time profile for LVRT (The bold line shall be the maximum allowed voltage drop of all phases).
- The representative border line on the graph is referring to the nominal voltage in p.u. value.

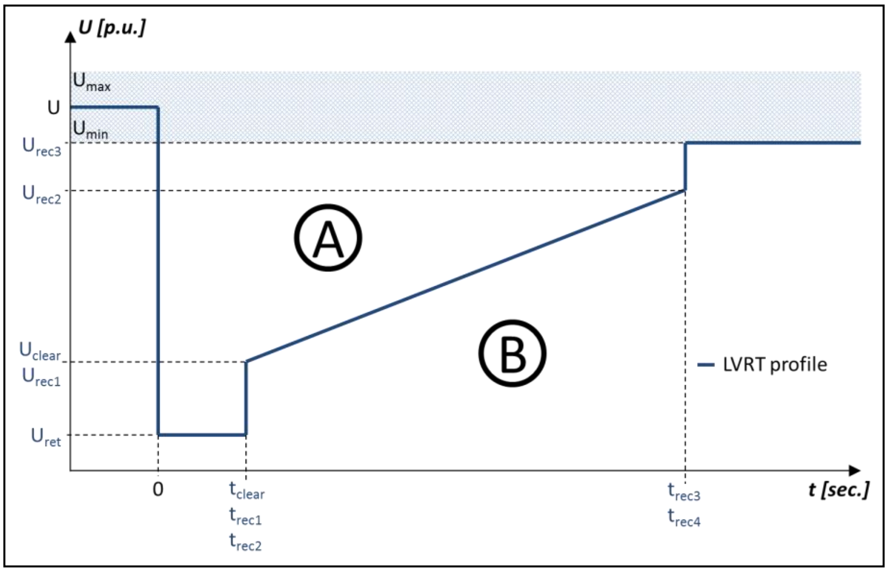


*Figure 4 - LVRT profile of Power Park Module of type B, C & D.*

*Figure 4* represents the lower limit of a voltage-against-time profile of the voltage at PoC, expressed by the ratio of its actual value and its nominal value in per unit before, during and after a fault where:

- *U is the prefault voltage at the connection point (PoC),*
- *$U_{min}$ and $U_{max}$ are the minimum and maximum steady state voltage according to Table 6.1 and 6.2 from RfG. For PPMs with connection point below 110kV, $U_{min}$ is the minimum steady-state grid voltage of the local grid.*
- *$U_{ret}$ is the retained voltage at the connection point during a fault,*
- *$t_{clear}$ is the instant when the fault has been cleared.*
- *$U_{rec1}$, $U_{rec2}$, $U_{rec3}$, $t_{rec1}$, $t_{rec2}$, $t_{rec3}$ and $t_{rec4}$ specify certain point limits of voltage recovery after fault clearance.*

| Voltage parameters [p.u.] | | Time parameters [seconds] | |
|---|---|---|---|
| $U_{ret}$ [4] | 0.05 to 0.15 | $t_{clear}$ | 0.14 to 0.15[5] |
| $U_{clear}$ | $U_{ret}$ to 0.15 | $t_{rec1}$ | $t_{clear}$ |
| $U_{rec1}$ | $U_{clear}$ | $t_{rec2}$ | $t_{rec1}$ |
| $U_{rec2}$ | 0.85 | $t_{rec3}$ [6] | 1.5 to 3.0 |
| $U_{rec3}$ | $U_{min}$ | $t_{rec4}$ | $t_{rec3}$ |

*Table 1 - Parameters for LVRT capability of power park modules of type B, C & D with connection point below 110kV applicable at PoC.*

| Voltage parameters [p.u.] | | Time parameters [seconds] | |
|---|---|---|---|
| $U_{ret}$ | 0 | $t_{clear}$ | 0.14 to 0.15[7] |
| $U_{clear}$ | $U_{ret}$ | $t_{rec1}$ | $t_{clear}$ |
| $U_{rec1}$ | $U_{clear}$ | $t_{rec2}$ | $t_{rec1}$ |
| $U_{rec2}$ | 0.85 | $t_{rec3}$ [6] | 1.5 to 3.0 |
| $U_{rec3}$ | $U_{min}$ | $t_{rec4}$ | $t_{rec3}$ |

*Table 2 - Parameters for LVRT capability of power park modules of type D with connection point at or above 110kV applicable at PoC.*

## 3.3. FRT VOLTAGE PROFILE FOR HIGH VOLTAGES

Power park modules shall be capable of continuing stable operation after the power system has been disturbed by secured faults in accordance with a voltage-against-time-profile at the connection point.

The voltage-against-time-profile shall be expressed by the higher limit of the course of the phase-to-phase voltages on the network voltage level at the connection point where measuring equipment can be installed, as a function of time before, during and after the fault.

This higher limit shall be defined by the relevant network operator by using the parameters and ranges set out in Table 3 for power park modules of type B, C & D with connection point below 110kV and in Table 4 for power park modules of type D with connection point at or above 110kV. These parameters and ranges are described as voltage-against-time profile in Figure 5 as border lines (envelop lines). They apply to all types of faults (symmetrical and asymmetrical i.e. one-, two- or three-phase faults) and the

[4] *For power park modules of type B, C & D with connection point below 110kV, $U_{ret}$ shall be as high as possible based on a local grid study since lower values are increasing the equipment costs.*

[5] *Longer fault clearing times up to 0.25s can be required upon verification from the state regulator authority. The request shall be submitted together with grid study and statistical data proving the need of longer fault clearing time.*

[6] *$t_{rec3}$ shall be chosen based on a local grid study and historical statistic data. Higher values increase technology costs.*

[7] See footnote 5

bold line shall represent the maximum voltage of all phases. The following describe the requirements indicated in Figure 5 in further detail:

- In area A the power park module shall stay in stable operation during a temporary voltage deviation outside the continuous voltage operation range and may provide an active current and absorb reactive current if required by the relevant grid operator as specified in Section 4 of this document.
- The maximum voltage increase during faults shall be defined within the ranges set by Table 3 for power park modules of type B, C & D with connection point below 110kV and Table 4 for power park modules of type D with connection point at or above 110kV.
- In area B disconnection of the power park module is allowed, but the power park module may stay connected until reaching the generator design limits or the limits set by the grid protection settings. These grid protection parameters shall be agreed between the power park module owner and the relevant system operator.
- The described voltage-against-time profile does not reflect the specific voltage behavior during faults.
- All phase-to-phase voltages shall stay below the defined voltage-against-time profile for HVRT (The bold line shall be the maximum allowed voltage increase of all phases).
- The representative border line on the graph is referring to the nominal voltage in p.u. value.

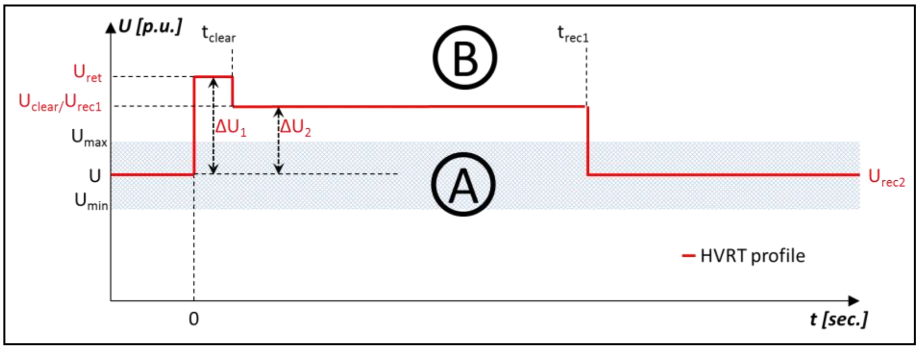


Figure 5 - HVRT profile of Power Park Module of type B, C & D.

*Figure 5* represents the higher limit of a voltage-against-time profile of the voltage at the connection point, expressed by the ratio of its actual value and its nominal value in per unit before, during and after a fault where:

- *U is the pre-fault voltage at the connection point.*
- *$U_{min}$ and $U_{max}$ are the minimum and maximum steady state voltage according to Table 6.1 and 6.2 from NC RfG. For power park modules with connection point below 110kV, $U_{max}$ is the maximum steady-state grid voltage of the local grid.*
- *$U_{ret}$ is the elevated voltage at the connection point during a fault.*
- *$\Delta U_1$ and $\Delta U_2$ are the maximum allowed voltage change from the pre-fault voltage for the specific time periods during the fault at the point of connection.*
- *$t_{clear}$ is the instant when the fault has been cleared.*
- *$U_{rec1}$, $U_{rec2}$, $t_{rec1}$, $t_{rec2}$ and $t_{rec3}$ specify certain points limits of voltage recovery after fault clearance.*

| Voltage parameters [p.u.] | | Time parameters [seconds] | |
|---|---|---|---|
| $U_{ret}$ | $U+\Delta U_1 \leq 1.2$ | $t_{clear}$ | 0.1 |
| $U_{clear}$ | $U+\Delta U_2 \leq 1.15$ | $t_{rec1}$ | 1 |
| $U_{rec1}$ | $U_{clear}$ | | |
| $U_{rec2}$ | $U_{max}$ according to the local MV grid | | |
| $\Delta U_1$ | 0.1 | | |
| $\Delta U_2$ | 0.05 | | |

*Table 3 - Parameters for HVRT capability of power park modules of type B, C & D with connection point below 110kV applicable at PoC.*

| Voltage parameters [p.u.] | | Time parameters [seconds] | |
|---|---|---|---|
| $U_{ret}$ | $U+\Delta U_1 \leq 1.2$ | $t_{clear}$ | 0.1 |
| $U_{clear}$ | $U+\Delta U_2 \leq 1.15$ | $t_{rec1}$ | 1 |
| $U_{rec1}$ | $U_{clear}$ | | |
| $U_{rec2}$ | $U_{max}$ – 1.1 to 1.15 (according to table 6.1 and 6.2 from RfG) | | |
| $\Delta U_1$ | 0.1 | | |
| $\Delta U_2$ | 0.05 | | |

*Table 4 - Parameters for HVRT capability of power park modules of type D with connection point at or above 110kV applicable at PoC.*

## 3.4. SEQUENCE OF FRT EVENTS

- Power park modules shall be capable to ride through voltage deviations caused by secured faults cleared within the times specified in Tables 1 and Table 2 as $t_{clear}$.
- Power park modules shall be able to ride through any voltage deviation that starts earliest 60 seconds after maximum two consecutive voltage deviations caused by the same fault and with an auto-reclosing scheme applied (please see below).
- Power park modules are allowed to trip if a sequence of voltage deviations leads to excessive thermal or mechanical stress especially but not limited to mechanical oscillations / resonances.

## 3.5. RECLOSURE

- If applicable to the network to which they are connected to power park modules shall be capable of remaining connected to the network during single-phase or three-phase auto-reclosures on lines within the meshed network.
- The reclosing time (also known as dead time) shall be as short as possible and not exceed:
  - 300ms for MV networks.
  - 400ms for HV networks.
  - 1 second for EHV networks.
- All further details regarding this capability shall be subject to coordination and agreements on protection schemes and settings.

## 3.6. P/Q POWER PRODUCTION BEFORE FRT EVENT

- The FRT requirements described above (section 3.1. to 3.5) shall apply within the steady state active and reactive power operating range as specified for the PPM at the PoC point. The requirements do not apply when the PPM is operating below the Minimum Operating Level.

## 3.7. FRT ACTIVE POWER RECOVERY TIME

- The PPM shall provide at least 90% of its pre-fault active power after voltage recovery above 90 % of the pre-fault Voltage.
- The **active power recovery time capability** shall be within 1s after the voltage recovers for the first time above 90% of the pre-fault Voltage and unless another fault is detected.
- The **active power recovery time setting capability** shall be between the PPM's active power recovery time capability and 10 seconds.
- The **active power recovery time setting** shall be specified by the relevant system operator in consultation with stakeholders and in accordance to the following principles:

  1) Priority between fast fault current requirements and active power recovery requirements.
  2) Dependency between active power recovery times and duration of voltage drop.
  3) A defined limit of the maximum allowed time for active power recovery.
  4) Adequacy between the level of voltage recovery and the minimum magnitude for active power recovery.
  5) Adequate damping of active power oscillations.

## 3.8. FRT–POST FAULT OSCILLATORY BEHAVIOUR (ACTIVE POWER)

Active power oscillations after voltage recovery shall be adequately damped – the averaged active Power shall be above 90% of the pre-fault value assuming the similar wind conditions as pre-fault.

# 4. REACTIVE POWER CAPABILITY

The following Reactive power specifications for PPM should be seen as complementary to the requirements in the Article 21.3 from NC RfG.

## 4.1. REACTIVE POWER CAPABILITY AT MAXIMUM CAPACITY

The relevant system operator in coordination with the relevant TSO shall specify the reactive power provision capability requirements in the context of varying voltage. To that end, it shall specify a U-Q/$P_{max}$-profile that may take any shape within the boundaries of which the power park module shall be capable of providing reactive power at its maximum capacity.

The U-Q/$P_{max}$-profile shall be specified by each relevant system operator in coordination with the relevant TSO in conformity with the following principles:

- The U-Q/$P_{max}$-profile shall not exceed the U-Q/$P_{max}$-profile envelope, represented by the inner envelope in Figure 6 for power park modules of type C & D with connection point below 110kV and Figure 7 for power park modules of type D with connection point at or above 110kV.
- The dimensions of the U-Q/$P_{max}$-profile envelope (Q/$P_{max}$ range and voltage range) shall be within the values specified for each synchronous area in Table 5 for power park modules of type C & D with connection point below 110kV and Table 6 for power park modules of type D with connection point at or above 110kV.
- The position of the U-Q/$P_{max}$-profile envelope shall be within the limits of the fixed outer envelope set out in Figure 6 for power park modules of type C & D with connection point below 110kV and Figure 7 for power park modules of type D with connection point at or above 110kV.
- The specified U-Q/$P_{max}$ profile may take any shape, having regard to the potential costs of delivering the capability to provide reactive power production at high voltages and reactive power consumption at low voltages.
- In case a Power Generation Facility Owner of a Power Park Module has declared a Reactive Power capability beyond the Voltage or Q/$P_{max}$ range specified by Figure 6 and Figure 7, the Reactive Power capability shall not be deliberately limited unless required by the relevant Network Operator.
- Q/$P_{max}$ ranges larger than the ranges specified in Table 5 and Table 6 may be agreed between the relevant grid operator and the power generating module owner through a bilateral agreement and should be remunerated service.

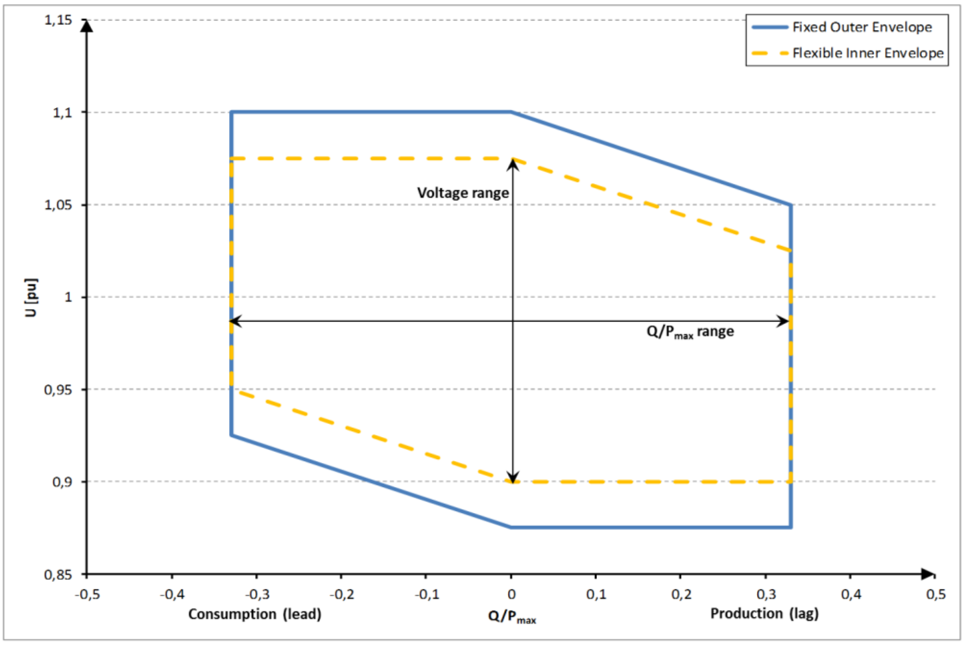


*Figure 6 U-Q/$P_{max}$-profile of a power park module of type C & D with connection point below 110kV. The diagram represents boundaries of a U-Q/$P_{max}$-profile by the voltage at the connection point, expressed by the ratio of its actual value and its reference 1 pu value, against the ratio of the reactive power (Q) and the maximum capacity ($P_{max}$). The position, size and shape of the inner envelope are indicative.*

| Synchronous area | Maximum range of Q/$P_{max}$ | Maximum range of steady-state voltage level in PU |
|---|---|---|
| Continental Europe | 0.66 | 0.175 |
| Nordic | 0.66 | 0.175 |
| Great Britain | 0.66 | 0.175 |
| Ireland and Northern Ireland | 0.66 | 0.175 |
| Baltic | 0.66 | 0.175 |

*Table 5 Parameters for the inner envelope for power park modules of type C & D with connection point below 110kV as in Figure 6*

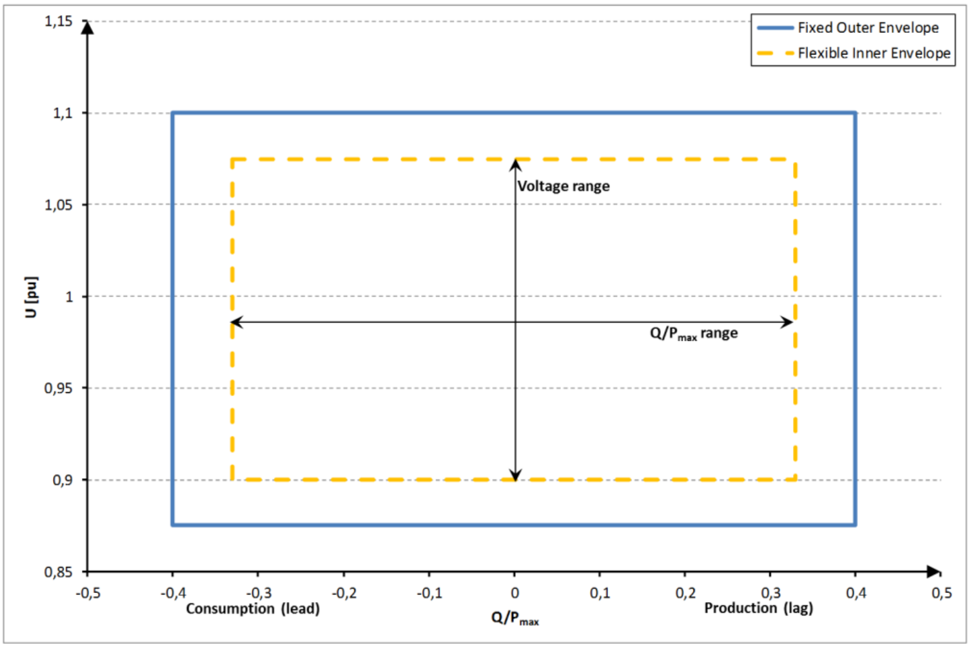


*Figure 7 U-Q/$P_{max}$-profile of a power park module of type D with connection point at or above 110kV. The diagram represents boundaries of a U-Q/$P_{max}$-profile by the voltage at the connection point, expressed by the ratio of its actual value and its reference 1 pu value, against the ratio of the reactive power (Q) and the maximum capacity ($P_{max}$). The position, size and shape of the inner envelope are indicative.*

| Synchronous area | Maximum range of Q/$P_{max}$ | Maximum range of steady-state voltage level in PU |
|---|---|---|
| Continental Europe | 0.66 | 0.225 |
| Nordic | 0.66 | 0.150 |
| Great Britain | 0.66 | 0.225 |
| Ireland and Northern Ireland | 0.66 | 0.218 |
| Baltic | 0.66 | 0.220 |

*Table 6 Parameters for the inner envelope for power park modules of type D with connection point at or above 110kV as in Figure 7*

The reactive power provision capability requirement applies at the connection point. For profile shapes other than rectangular, the voltage range represents the highest and lowest values. The full reactive power range is therefore not expected to be available across the range of steady-state voltages.

## 4.2. REACTIVE POWER CAPABILITY BELOW MAXIMUM CAPACITY

The relevant system operator in coordination with the relevant TSO shall specify the reactive power provision capability requirements and shall specify a P-Q/$P_{max}$-profile that may take any shape within the boundaries of which the power park module shall be capable of providing reactive power below maximum capacity.

The P-Q/$P_{max}$-profile shall be specified by each relevant system operator in coordination with the relevant TSO, in conformity with the following principles:

- The P-Q/$P_{max}$-profile shall not exceed the P-Q/$P_{max}$-profile envelope, represented by the inner envelope in Figure 8 for power park modules of type C & D with connection point below 110kV and Figure 9 for power park modules of type D with connection point at or above 110kV.
- The Q/$P_{max}$ range of the P-Q/$P_{max}$-profile envelope is specified for each synchronous area in Figure 8;
- The active power range of the P-Q/$P_{max}$-profile envelope at zero reactive power shall be 1 pu.
- The P-Q/$P_{max}$-profile can be of any shape and shall include conditions for reactive power capability at any power above the minimum operating level.
- Reactive power capability below minimum operating level (i.e. at zero active power) may be agreed between the relevant grid operator and the power generating facility owner through a bilateral agreement and should be a remunerated service.
- The position of the P-Q/$P_{max}$-profile envelope shall be within the limits of the fixed outer envelope set out in Figure 8 for power park modules of type C & D with connection point below 110kV and Figure 9 for power park modules of type D with connection point at or above 110kV.

When operating at an active power output below maximum capacity ($P<P_{max}$), the power park module shall be capable of providing reactive power at any operating point inside its P-Q/$P_{max}$-profile, if all units of that power park module which generate power are technically available that is to say they are not out of service due to maintenance or failure, otherwise there may be less reactive power capability, taking into consideration the technical availabilities.

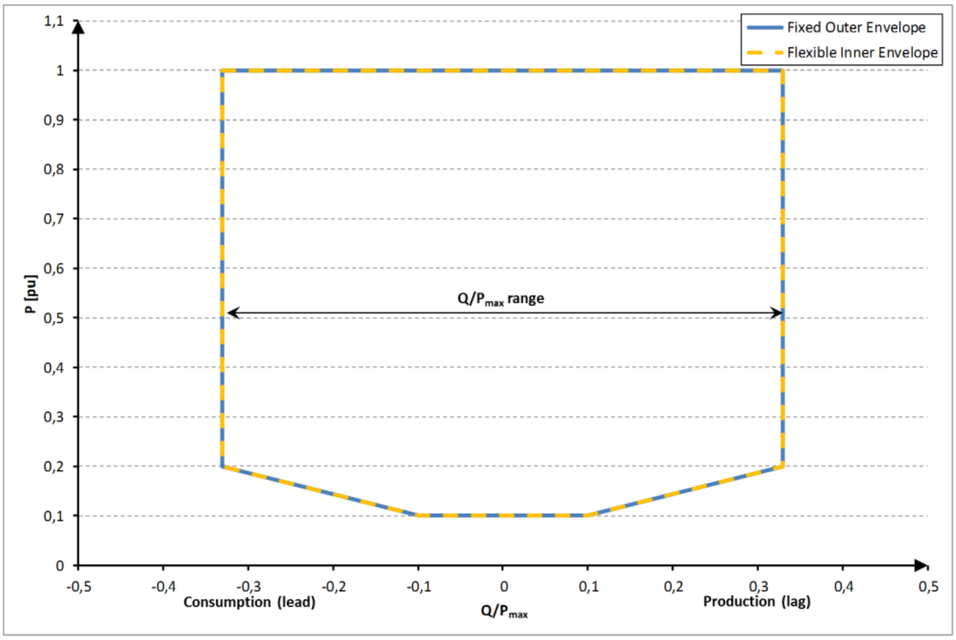


*Figure 8 P-Q/$P_{max}$-profile of a power park module of Type C & D with connection point below 110kV. The diagram represents boundaries of a P-Q/$P_{max}$-profile at the connection point by the active power, expressed by the ratio of its actual value and the maximum capacity pu, against the ratio of the reactive power (Q) and the maximum capacity ($P_{max}$). The position, size and shape of the inner envelope are indicative.*

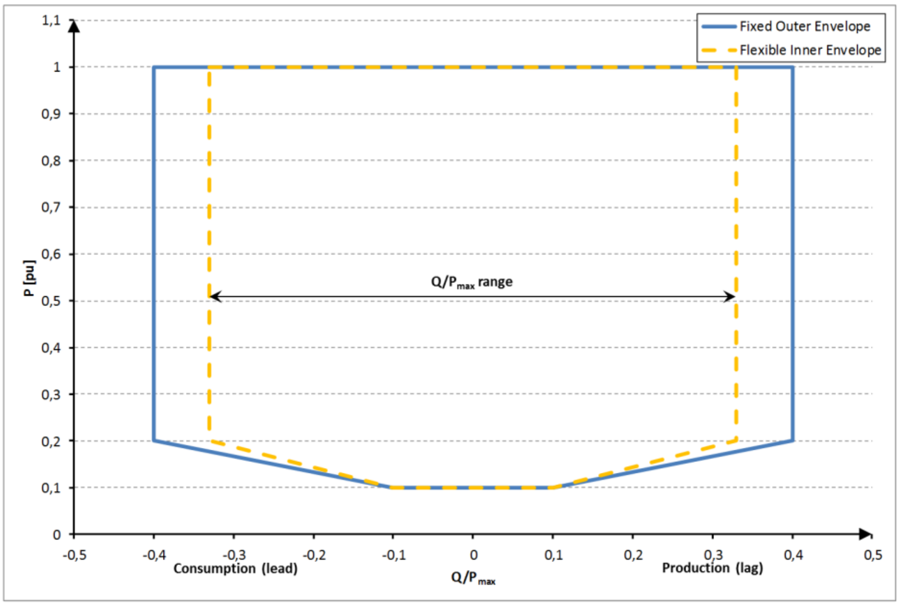


*Figure 9 P-Q/$P_{max}$-profile of a power park module of Type D with connection point at or above 110kV. The diagram represents boundaries of a P-Q/$P_{max}$-profile at the connection point by the active power, expressed by the ratio of its actual value and the maximum capacity pu, against the ratio of the reactive power (Q) and the maximum capacity ($P_{max}$). The position, size and shape of the inner envelope are indicative.*

The power park module shall be capable of moving to any operating point within its P-Q/$P_{max}$ profile in appropriate timescales to target values requested by the relevant system operator.

# 5. LIST OF ABBREVIATIONS

- RMS: Root Mean Square
- HVRT: High Voltage Ride Through (also known as Over Voltage Ride Through)
- HVDC: High Voltage Direct Current
- LVRT: Low Voltage Ride Through
- NC RfG: Network Code requirements for generators
- LV: low voltage
- MV: medium voltage
- HV: High voltage
- EHV: Extra high voltage

## CONTACT

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