European Network of
Transmission System Operators
for Electricity

entsoe

IMPLEMENTATION GUIDELINE FOR NETWORK CODE “Requirements for Grid Connection Applicable to all Generators”

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Content

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1. Executive Summary

ENTSO-E released its latest Network Code on "Requirements for Generators" (NC RfG)[1] in March 2013. The network code received a favourable recommendation from ACER in March 2013, acknowledging its contribution to Europe's energy goals and supporting its adoption as a binding EU legislation[2].

Throughout the development of this code, the rationale for its European-wide requirements in light of present situations and future system developments have been regularly discussed among network operators, impacted stakeholders and regulators. This background is reflected among others in various supporting documents, available on the ENTSO-E website[3].

Requirements for grid connection in the NC RfG all have a cross-border impact, but need to be tailored to manage and make best use of local system characteristics (network, load, generation portfolio and technology). This document is drafted by ENTSO-E with the objective to give guidance for national implementation of the NC RfG. It focuses on a selection of so-called non-exhaustive requirements in the code, which have been regularly discussed with various stakeholders in the past years and need further consideration when being implemented on national level. It describes for a given requirement the elements to be further specified, it lists various conditions to consider and it stresses the strongest interdependencies with other requirements (be it in the same or other codes). This document neither sets a precedent for nor does it tabulate the outcome of all Member State implementations, which are often driven by further detailed studies and interlinked with other national grid code requirements.

This ENTSO-E document informs interested parties on the underlying principles of a selection of the non-exhaustive requirements in the NC RfG. This non-binding document supports the network code, but does not supplement the code, nor can it be used as a substitute thereof.

Section 2 provides further clarification on the need for national flexibility to ensure cost-efficient implementation of the network code. Section 3 then addresses relevant requirements of the NC RfG.

1 https://www.entsoe.eu/fileadmin/user_upload/_library/resources/RfG/130308_Final_Version_NC_RfG.pdf
2 http://www.acer.europa.eu/Official_documents/Acts_of_the_Agency/Pages/Recommendations.aspx
3 https://www.entsoe.eu/major-projects/network-code-development/

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2. Background on the development of this document

The Network Codes will become binding after a comitology procedure driven by the European Commission and scrutinized by both the Council and the European Parliament. The Network Codes will be adopted as an EU Regulation. Being part of the EU law- they supersede national legislation (existing or new) in Member States. In other words, in case of conflict between the Network Code and the conflicting national legislation, the former prevail and the latter must be ignored by national courts so that the EU law can take effect. No further action is necessary on national level to enforce EU Network Codes from a legal perspective (they are directly applicable), although most if not all Member States are likely to adapt corresponding national rules, to provide for consistency, clarity and transparency of the national legal framework. This process raises a number of immediate questions discussed more fully below:

1. How will a Network Code be implemented at a national level?
2. Will the Network Code be applied in non-EU countries?
3. What is a non-exhaustive requirement?
4. Why is there room for national choices in a European Network Code?

2.1. How will a network code be implemented at a national level?

The process for implementing the NC RfG at a national level is not defined in the code itself but left to subsidiarity. It means that Member States shalldefine what processes should be employed.

However every Member State currently has processes to assess and apply requirements to existing and prospective users of its transmission and distribution networks. These existing processes should be the starting point for national implementation and can in many cases be readily adapted for use to apply Network Codes.

A transition period- three years after the entry into force of the Network Code allows for modification of these national implementation processes. This transition period also grants sufficient time for necessary changes to be made to existing contractual arrangement, e.g. example connection agreements with users to which the Network Code shall apply.,

Although the general responsibility for rendering the Network Code fully applicable at the expiry of the 3-year transition period in principle lies with the Member States, the practical management of that transitional phase is likely to be passed to both national regulators and system operators.

2.2. Will Network Codes be applied in non-EU countries?

For the non-EU countries which are parties to the EEA Agreement (the European Economic Area Agreement), the EEA Agreement, provides for the inclusion of EU legislation, that covers the four freedoms ð the free movement of goods, services, persons and capital ð throughout the 30 EEA States. The Agreement guarantees equal rights and obligations within the Internal Market for citizens and economic operators in the EEA. As a result of the EEA Agreement, EU law on the four freedoms is incorporated into the domestic law of the participating countries of the European Free Trade Association. All new relevant EU legislation is also introduced through the EEA Agreement so that it applies throughout the EEA, ensuring a uniform application of laws relating to the internal market. As energy legislation covering the functioning of the internal market falls within the scope of the EEA-Agreement, the entire body of Network Codes will almost certainly be EEA relevant, and hence be applicable and binding after decision by the EEA Committee and national implementation. The regular implementation procedures according to the EEA Agreement will apply.

As Switzerland is not a party to the EEA Agreement, the enforceability of the NC transformed into EU Regulation will need to be assessed in the context of the pending negotiations between Switzerland and the

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EU. However, Swiss law is also based on the principle of subsidiarity. Under this principle, self-regulating measures can be taken by the parties of the sector if they reach the conclusion that these rules should become common understanding of the sector. Based on the subsidiarity principle it is currently considered by the Swiss authorities to introduce under Swiss law, new rules compliant to relevant EU regulations by the parties of the sector.

For the countries that are parties to the Energy Community Treaty[4], the Ministerial Council of the Energy Community decided on 6 October 2011 that the Contracting Parties shall implement the Third Package by January 2015, at the latest. Moreover, it decided ñto start aligning the regionôs network codes with those of the European Union without delayò. The Network Codes will be adopted by the Energy Community upon proposal of the European Commission. The relevant Network Codes shall be adopted by the Permanent High Level Group. The Energy Community Regulatory Board stressed on 5 September 2013 ñthe importance to implement the NCs in the Energy Community in a timely and coherent manner in coordination with the European developments.ò

2.3. What is a non-exhaustive requirement?

EU Network Codes contain a number of non-exhaustive requirements, especially the NC RfG, and the other codes in the grid connection domain. A non-exhaustive requirement within a Network Code does not provide for a full harmonisation of that requirement. This means that with regard to those the NC RfG does not contain all the information or parameters necessary to apply the requirement immediately and thus needs further specification at national level. This specification will result in rendering the non-exhaustive EU requirements exhaustively defined as a national or project specific rules. As mentioned above, this may require updating and amending respective technical regulations (e. g. existing national grid codes) accordingly. The three year transition period from the date of entry into force until its application (see also paragraph 2.1 above) allows for such a national implementation procedure.

Typically additional information or parameters are to be provided by the Relevant Network Operator or the Relevant TSO[5]. In many cases these specifications can be brought forward through an already established process at national level, e.g. grid code review panel, user group, public consultation, regulator or ministry approval. A Network Code itself does not prescribe these national processes, but merely stipulates that they shall be in accordance with the implementation of Directive 2009/72/EC and the principles of transparency, proportionality and non-discrimination, with the mandatory involvement of the National Regulatory Authorities. This framework safeguards against unilateral or non-motivated decisions and often gives a specific frame of how to involve the wider industry. Furthermore it allows Member States to continue using most established processes, which often are acknowledged by all involved parties and have proven to be successful.

Even as the NC RfG explicitly allows for a three year transition period from its entry into force, initial discussions on national choices are picking up in some countries already before adoption of the code as EURegulation, with the motivation to provide clarity to the wider industry (grid users, manufacturers and network operators) as soon as possible. These discussions can however not pre-empt the formal national implementation which is referred to in the Network Code and which can only be commissioned once the code enters into force.

[4] http://www.energy-community.org

[5] The Relevant Network Operator is the operator of the network the user is directly connected to. The Relevant TSO is the TSO in whose control area the user is connected.

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2.4. Why is there room for national choices in a European Network Code?

Non-exhaustive requirements have a valid role in an EU Network Code because of their impact on security of supply, the integration of renewables or market development. Even as specifications depend on local system conditions, clear benefits exist when the code:

a) ensures that these requirements are specified by the Relevant Network Operator or TSO in all Member States;
b) enforces a similar terminology and gives the minimum list of parameters and conditions to specify at the national level; and
c) covers compliance and derogations procedures across Europe in a transparent and non-discriminatory manner.

In many cases the Network Codes constrain national provisions from either very loose or extremely onerous implementations. An EU Network Code pulls all national codes in the same direction.

Non-exhaustive requirements can be broken into two distinct categories.

a) The first category covers project specific non-exhaustive requirements. These requirements cannot be written exhaustively at either a European, synchronous system or national level and need to be considered on a case by case basis.

   Example: Article 9(5) of the NC RfG requires the Relevant Network Operator and the Power Generating Facility Owner to agree on protection and control schemes and settings. Inadequate protection specifications could see wide spread loss of generation and hence impact on security of supply to the European network. Typically this category of non-exhaustive requirements is of purely descriptive nature by simply defining ñwhatò has to be further specified without any prescription on ñhowò the result shall look like. Therefore this category is not subject to the strong stakeholder opposition.

b) The second category covers non-exhaustive requirements that should be specified at either a synchronous system or national level. For these requirements, much greater commonality is expected in the information and/or parameters to be applied. However, characteristics of networks like design and topography, as well as inherent physical conditions determining dynamic system response and stability (e.g. system inertia) differ across Europe. For technical reasons, as well as resulting financial impact, the use of single European settings is not always sound.

   Example 1: The capability of generators to provide reactive power depends on the network characteristics and is needed either more in the lagging or leading range. A uniform requirement covering all of Europe would consequently need to cover both areas simultaneously and would consequently result in massively oversized generators and supplementary components, which are not needed at each location.
   Example 2: Requiring Fault-Ride-Through capability is undisputedly essential for system security. Nevertheless the further details of this capability depend significantly on the dynamic system response during and after the fault, driven by whether frequency stability or voltage stability is the imminent threat.

The requirements of EU Network Codes will also have impact on industry standards, which amongst others provide manufacturers with default parameters for equipment design. Due to the legally binding nature of EU Network Codes, their provisions prevail over any industrial standard- which are in principle non-binding. With regard to exhaustive requirements provided in these codes, affected standards may need to be amended to become compliant with this legislative framework. Existing standards, as well as other technical regulation (e.g. national grid codes) may serve as a reference for further specifications of values and ranges of parameters in non-exhaustive requirements. With continuing evolutions in the integration of

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renewable energy sources and the further strengthening of the European electricity system and markets, modifications to existing standards may also be essential. A much complementary and crucial role for standards lies in its use to give a complete set of specifications for compliance testing with the EU code and other relevant connection conditions[6].

[6] Memorandum of Understanding between ENTSO-E and CEN/CENELEC

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3. Guidelines for Network Code „Requirements for Generators“

The following tables give an overview of the requirements covered under the NC RfG, and to which type of user they apply. The requirements indicated in orange are further described in this document. These requirements have been selected for the scope of this document based on known questions and concerns and in the past development of the code, and are clarified further.

Requirement	type	Type A	Type B	Type C	Type D
FREQUENCY RANGES	Frequency stability	X	X	X	X
LIMITED FREQUENCY SENSITIVE MODE (OVERFREQUENCY)	Frequency stability	X	X	X	X
RATE OF CHANGE OF FREQUENCY WITHSTAND CAPABILITY	Frequency stability	X	X	X	X
CONSTANT OUTPUT AT TARGET ACTIVE POWER	Frequency stability	X	X	X	X
MAXIMUM Active POWER REDUCTION AT UNDERFREQUENCY	Frequency stability	X	X	X	X
AUTOMATIC CONNECTION	Frequency stability	X	X	X	X
REMOTE SWITCH ON/OFF	Frequency stability	X	X		
ACTIVE POWER REDUCTION	Frequency stability		X		
ACTIVE POWER CONTROLLABILITY AND CONTROL RANGE	Frequency stability			X	X
DISCONNECTION OF LOAD DUE TO UNDERFREQUENCY	Frequency stability			X	X
FREQUENCY RESTORATION CONTROL	Frequency stability			X	X
FREQUENCY SENSITIVE MODE	Frequency stability			X	X
LIMITED FREQUENCY SENSITIVE MODE (UNDERFREQUENCY)	Frequency stability			X	X
MONITORING OF FREQUENCY RESPONSE	Frequency stability			X	X
FAULT RIDE THROUGH CAPABILITY OF GENERATORS CONNECTED BELOW 110 kV	Robustness of Generating Units		X	X	
CONTROL SCHEMES AND SETTINGS	General system management		X	X	X
INFORMATION EXCHANGE	General system management		X	X	X
PRIORITY RANKING OF PROTECTION AND CONTROL	General system management		X	X	X
TRANSFORMER NEUTRL-POINT TREATMENT	General system management			X	X
CHANGES TO/MODERNISATION OR REPLACEMENT OF EQUIPMENT OF GENERATING UNITS	General system management			X	X
ELECTRICAL PROTECTION SCHEMES AND SETTINGS	General system management		X	X	X
INSTALLATION OF DEVICES FOR SYSTEM OPERATION AND/ OR SECURITY	General system management			X	X
INSTRUMENTATION FOR FAULT AND DYNAMIC BEHAVIOUR RECORDING	General system management			X	X
LOSS OF STABILITY	General system management			X	X
RATE OF CHANGE OF ACTIVE POWER	General system management			X	X
SIMULATION MODELS	General system management			X	X
SYNCHRONISATION	General system management				X
AUTO RECLOSURES	Robustness of Generating Units			X	X
STEADY-STATE STABILITY	Robustness of Generating Units			X	X
RECONNECTION AFTER AN INCIDENTAL DISCONNECTION DUE TO A NETWORK DISTURBANCE	System restoration		X	X	X
BLACK START	System restoration			X	X
CAPABILITY TO TAKE PART IN ISOLATED NETWORK OPERATION	System restoration			X	X
QUICK RE-SYNCHRONISATION	System restoration			X	X
HIGH/LOW VOLTAGE DISCONNECTION	Voltage stability			X	
FAULT RIDE THROUGH CAPABILITY OF GENERATORS CONNECTED AT 110 kV OR ABOVE	Robustness of Generating Units				X
VOLTAGE RANGES	Voltage stability				X

Table 1 - Requirements applicable to all Power Generating Modules

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Requirement	type	Type A	Type B	Type C	Type D
POST FAULT ACTIVE POWER RECOVERY	Robustness of Generating Units		X	X	X
VOLTAGE CONTROL SYSTEM (SIMPLE)	Voltage stability		X	X	
REACTIVE POWER CAPABILITY (SIMPLE)	Voltage stability		X		
REACTIVE POWER CAPABILITY AT MAXIMUM ACTIVE POWER	Voltage stability			X	X
REACTIVE POWER CAPABILITY BELOW MAXIMUM ACTIVE POWER	Voltage stability			X	X
VOLTAGE CONTROL SYSTEM	Voltage stability				X

Table 2 - Requirements applicable to Synchronous Power Generating Modules

Requirement	type	Type A	Type B	Type C	Type D
SYNTHETIC INERTIA CAPABILITY	Frequency stability			X	X
POST FAULT ACTIVE POWER RECOVERY	Robustness of Generating Units		X	X	X
REACTIVE CURRENT INJECTION	Voltage stability		X	X	X
REACTIVE POWER CAPABILITY (SIMPLE)	Voltage stability		X		
PRIORITY TO ACTIVE OR REACTIVE POWER CONTRIBUTION	Voltage stability			X	X
REACTIVE POWER CAPABILITY AT MAXIMUM ACTIVE POWER	Voltage stability			X	X
REACTIVE POWER CAPABILITY BELOW MAXIMUM ACTIVE POWER	Voltage stability			X	X
REACTIVE POWER CONTROL MODES	Voltage stability			X	X
POWER OSCILLATIONS DAMPING CONTROL	Voltage stability			X	X

Table 3 - Requirements applicable to Power park Modules

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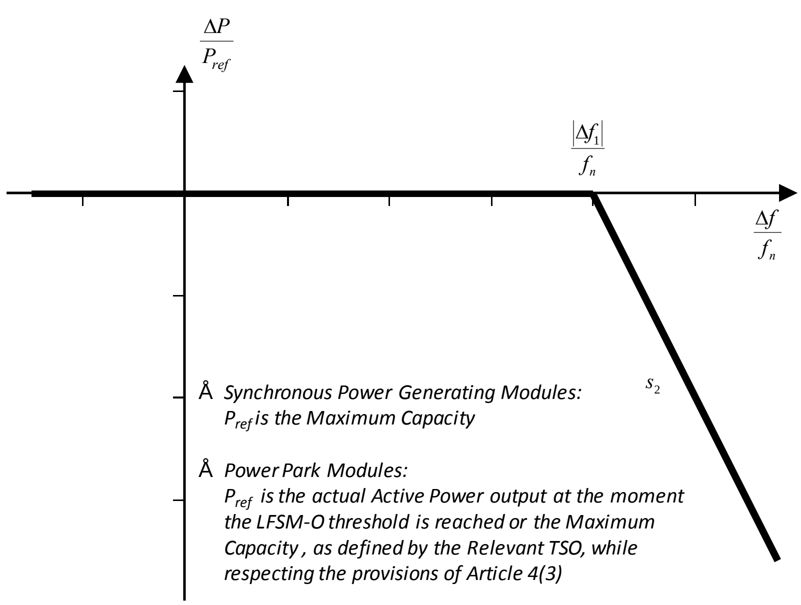
3.1. Limited Frequency Sensitive Mode (Overfrequency)

DESCRIPTION	
Article	Article 8 (1) (c)
Objective	The objective of the requirement is to automatically reduce Active Power output of Power Generating Modules (Synchronous Generators and Power Park Modules) in case of over frequency to reduce the frequency back towards its target value (normally 50.0 Hz) for cases of severe imbalance (excess generation), resulting in significant frequency deviations. This may occur in cases of major disturbances to the system such as large loss of demand (e.g. loss of exporting HVDC link) or in more extreme cases from a system split. Sudden increase of production could also be the cause of the imbalance The requirements aims to reduce Active Power output proportionally to the frequency deviation to restore the generation / demand balance. The capability to reduce active power output is needed in emergency situations in order to stabilise the system.
NC frame	The NC requires from each TSO the specification of the actual Frequency threshold (between and including 50.2 and 50.5 Hz) and Droop settings (in a range of 2 ï 12 %), in order to provide the Active Power Frequency Response according to the following figure. The Power Generating Module shall be capable of activating Active Power Frequency Response as fast as technically feasible with an initial delay that shall be as short as possible and reasonably justified by the Power Generating Facility Owner to the Relevant TSO if greater than 2 seconds. The Power Generating Module shall be capable of either continuing operation at Minimum Regulating Level when reaching it or alternatively further decreasing Active Power output, the choice to be defined by the relevant TSO. This choice should be informed by system characteristics (including needs of the synchronous area / defence plan) and also the capability of the generating technology



Further info	• Supporting documentation of RfG network code:
	  ○ Network Code for requirements for grid connection applicable to all generators ï Justification outlines (26. June 2012)
	  ○ Network Code for requirements for grid connection applicable to all generators ï Requirements in the context of present practices (26 June 2012)
	• External documents:
	  ○ ENTSO-E October 2009 ñTechnical Background and Recommendations for Defence Plans in Continental Europeò [7]

INTERDEPENDENCIES	
In this NC	Frequency ranges (Article 8 (1) (a)) Frequency Sensitive Mode (Article (10) (2) (c))
In other NCs	NC HVDC is expected to have a similar requirement for Limited Frequency Sensitive Mode (overfrequency).
System characteristics	The droop and time of activation can be different for different power generating units in order to reach the necessary overall droop of the system.
Technology characteristics	The individual setting on Power Generating Module has to be made taking into account each technology constraints. E.g. many types of hydro generators often have a minimum delay in excess of the 2 seconds (up to 4seconds), due to an initial movement in the opposite direction of what is needed. Speed of Active power activation can be different depending on technology, but it is important that time of activation is as short as possible, otherwise this requirement cannot contribute to system stability.
COORDINATION	
TSO – TSO	TSO-TSO coordination to agreed droop and threshold (in the range 50.2 to 50.5Hz) within one synchronous area is not required under this NC, but threshold coordination is strongly recommended, to minimise unplanned power flow between the countries, after activation of LFSM. In addition cooperation with representatives of manufacturers is recommended to elaborate time of activation for typical existing technology (reference active power activation) - taking into account real system needs and each technology constraints which are the same irrespective of place of installation. Size of synchronous area will influence the choice of frequency threshold, with high frequency value for smaller synchronous areas and lower frequency for very large synchronous areas.
TSO – DSO	N/A
RNO – Grid User	TSO ï Grid User coordination is implicitly established by the network code (not on a case-by-case basis, but on generation technology level), because the selection of the full set of parameters to exhaustively define LFSM-O should take into consideration technology-specific characteristics and constraints.

[7] https://www.entsoe.eu/publications/system-operations-reports/continental-europe/

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3.2. Rate of Change of Frequency withstand capability

DESCRIPTION	
Article	Article 8 (1) (b)
Objective	The requirement aims at ensuring that Generation modules that are connected to the network will remain connected when a rate of change of frequency (df/dt) occurs after severe system incidents (e.g. system splits or loss of large generator in a smaller system) and therefore allow control responses from devices notably generation to stabilize and restore the network to normal operating states.
NC frame	The NC requires that the Relevant TSO provides the df/dt (rate of change of frequency). The selected value should be coordinated for each synchronous area.
Further info	• Supporting documentation of RfG network code: o Network Code for requirements for grid connection applicable to all generators ï Justification outlines (26. June 2012) • External documents: o All Island TSO Facilitation of Renewables Studies[8] o Summary of Studies on Rate of Change of Frequency events on the All-Island System (Aug 2012)[9] o Chapter 4 of GB ETYS 2012 diagram on severe reduction in total system inertia 2012 to 2030. [10] o UK ENA report from 2009 on LOM (including RoCoF) settings [11]
INTERDEPENDENCIES	
In this NC	• Frequency Range Article 8 (1) (a) • Frequency Sensitive Mode 8 (1) (c) • Protection settings coordination 9 (5) (b) regarding RoCoF
In other NCs	• OS / LFCR link to requirement to calculate and manage total system inertia. • NC DCC Article 22 (p) • NC HVDC will have a similar requirement for HVDC Converter Units and DC-connected PPMs.
System characteristics	The df/dt withstand capability should be based on analysis of the largest scale credible range of system incidents for that network i.e. loss of largest generating stations or HVDC link. This df/dt capability should be provided as a change in frequency over a time period which negates short term electro-mechanical effects and therefore reflect the actual change in synchronous network frequency. Notably changes in protection for example Loss of Mains protection using RoCoF driven by other needs, for example RES integration should be considered. The df/dt withstand capability should be assessed on not only the present network but also account for the expected df/dt capability that will be required over the asset life of the generator accounting for future changes in the network and its demand and generation

[8] http://www.eirgrid.com/media/FacilitationRenewablesFinalStudyReport.pdf
[9] http://www.eirgrid.com/media/Summary%20of%20Studies%20on%20Rate%20of%20Change%20of%20Frequency%20events%20on%20the%20All-Island%20System.pdf
[10] http://www.nationalgrid.com/NR/rdonlyres/DF56DC3B-13D7-4B19-9DFB-6E1B971C43F6/57770/10761_NG_ElectricityTenYearStatement_LR.pdf
[11] Electricity Network Association, UK. Report ENA ET ETR 139:2009 ñRecommendation for the Setting of Loss Of Mains (LOM) Protection Relays. http://infostore.saiglobal.com/EMEA/Details.aspx?ProductID=1392413

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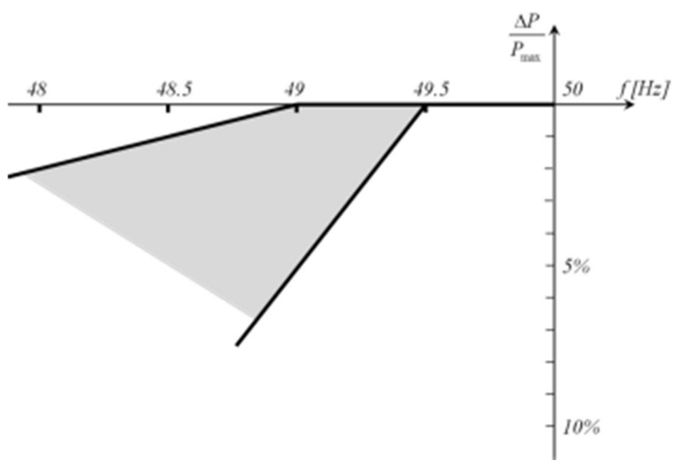
Technology characteristics	portfolio, e.g. see [10]. As the df/dt capability is defined by the entire synchronous systems characteristics this means that the entire synchronous system must be considered. In addition "islanding" requirements where a portion of the synchronous network can be reasonably assumed by the TSO to become disconnected and operate stably from the wider synchronous network must also be considered. Given the uncertainty on system characteristics and their future evolution, power generating modules need to be robust against changes to the system and shall provide df/dt capability which accounts for these varying system conditions. Hence, it is an important that the df/dt capability accounts for reduced network strength due to higher DC components, HVDC, PPMs, Soft start Demand and Pan-European (very remote) generation when defining these scenarios. The identified minimum df/dt requirement is therefore applied to all users regardless of technology, but the scenarios which define the minimum df/dt requirements have to reflect technological changes (e.g. proportion of generation in operation contributing substantial inertia) on the network. [GB ref 2012 ETYS] Therefore although the natural capability of the technology types of generation may vary, a single minimum df/dt withstand capability should be required to ensure stability of the network accounting for the future system requirements. This single national value of df/dt withstand capability does not inhibit TSOs asking for further inherent withstand capabilities not to be unreasonably withheld. Loss of Mains RoCoF type protection & settings, although not explicitly part of Article 8 (1) b, are covered in Article 9 (5) b on Protection Coordination. These requirements should be carefully coordinated.
COORDINATION	
TSO – TSO	TSO – TSO coordination within the same control area is necessary to ensure that a coordinated df/dt withstand requirement is placed on all plant and equipment. This coordination will ensure that the network df/dt capability is adequate to continue to provide network stability. As generation and demand on a synchronous network basis mostly covers more than one TSO, TSOs must determine the df/dt withstand capabilities accounting for other TSOs in their synchronous network.
TSO – DSO	TSO – DSO consideration via other connection codes for their network and their Users df/dt capability similar to TSO-TSO must be coordinated to ensure that the network remains stable.
RNO – Grid User	RNO – Grid User coordination of their df/dt capability similar to TSO-TSO must be coordinated to ensure that the network remains stable.

3.3. Maximum Active Power Reduction at Underfrequency

DESCRIPTION	
Article	Article 8 (1) (e)
Objective	This requirement is primarily focused on technologies not able to provide full active power during under frequency. The power generating units without technology constraints should not reduce active power output if technically possible. The purpose of the requirements is to maintain the capability of power generating modules to generate highest possible level of active power during periods of reduced system frequency, taking into account technology constraints and ambient conditions. The requirement aims at preventing power generating modules from reduction of the active power with falling frequency in the synchronous area. The objective is to limit the potential reduction of active power generation after the disturbances in the system and therefore avoiding experiencing more severe disturbances, i.e. frequency collapse in a synchronous area possibly leading to cascade tripping, system splitting, load shedding, and even total black out.
NC frame	The NC requires from each TSO the specification of admissible level of active power reduction from maximum output with falling frequency within the boundaries, given by the full lines in figure shown below.  • Below 49 Hz falling by a reduction rate of 2 % of the Maximum Capacity at 50 Hz per 1 Hz Frequency drop; • Below 49.5 Hz by a reduction rate of 10 % of the Maximum Capacity at 50 Hz per 1 Hz Frequency drop. The ability to maintain maximum active power output with falling frequency is different for different generation technologies. The permitted power reduction is therefore limited to a selection of affected generation technologies and may be subject to further conditions defined by each TSO It should be emphasised that this requirement does not force power generating modules to

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	reduce the active power according to the falling frequency but allow them to reduce power if the technology makes it impossible to keep maximum power at frequency below 49.5Hz. It can be consider as relaxation rather than requirement. This requirement does not determine the parameters of ambient conditions (esp. ambient temperature) at which the generator is to be able to generate maximum power. Ambient temperature (esp. for gas turbines) affects the capability to produce maximum power regardless of the falling frequency. In principle maximum power generation can be generated at nominal ambient conditions as one of the design conditions. These ambient conditions can be subject to coding in national Grid Codes or further agreement between the Relevant Network Operator and PGF Owner, irrespective of maximum power capability at under frequency.
Further info	• Supporting documentation of RfG network code: o Network Code for requirements for grid connection applicable to all generators ï Justification outlines (26. June 2012) o Network Code for requirements for grid connection applicable to all generators ï Requirements in the context of present practices (26. June 2012)
INTERDEPENDENCIES	
In this NC	Required frequency ranges (Article 8 (1) (a)) LFSM ï Under frequency (Article 10 (2) (b))
In other NCs	• No direct equivalent in other connection codes • To be considered in Emergency Procedures
System characteristics	Physical phenomena of power generating output reduction with falling frequency is contrary to grid stability needs. Active power reduction at low frequencies aggravates a situation where already a lack of generation persists and shall be limited as far as possible. Loss of a large generating units from the grid may have caused the initial drop of frequency and this would be aggravated by the further decrease the power output or even loss of other generators. There is a strong dependency between maximum power reduction at underfrequency and Low Frequency Demand Disconnection (LFDD in NC DCC). When setting parameters of power reduction at underfrequency each TSO has to consider behaviour of the whole system taking into account active power reduction at falling frequency. The potential active power output reduction should be lower than the volume of LFDD, otherwise the unbalance of the system can lead to onerous system disturbance. This requirement is more significant for small synchronous areas with high share of this kind of power generating units which are characterized by high power dependence on frequency (see below).
Technology characteristics	Maximum Active Power Output Reduction at underfrequency needs to be addressed in order to mitigate frequency drop. This requirement needs to cover all generators. The relationship between frequency and active power output is different depending on generation technology. These requirements especially affect the CCGT design. Gas turbines commonly operated in the power system include a shaft driven air compressor at the turbine inlet. When CCGT is synchronously connected to the grid any disturbance in the system resulting in decrease of frequency will cause the compressor to slow down. This results in reduction of the mass flow of air through the turbine and reduction of the active power output of the CCGT. This effect is much stronger at high ambient temperatures. Thus due to this physical phenomenon, gas turbine output drops significantly with falling frequency. To mitigate active power reduction, depending on the machine type and plant configuration different measures can be used e.g.: - Increasing the gas turbine flame temperature - Increasing the air mass flow (by opening fully the compressor vanes or by injection of water mist into air intake of compressor) This phenomenon of decreasing the capability to produce the maximum power at underfrequency can be observed as well for other technologies used in power sector

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	especially if the reduction of the frequency is combined with the decreasing of voltage. Due to reduction in efficiency of auxiliaries, the power generating units loose the capability to produce maximum power. The solution of this problem is the appropriate choice of the auxiliary devices at the design stage.
COORDINATION	
TSO – TSO	TSO-TSO coordination within one synchronous area is recommended. Such coordination with cooperation with representatives of manufactures should help to elaborate - taking into account real system needs and each technology constraints which are the same irrespective of location of installation.
TSO – DSO	N/A
RNO – Grid User	TSO ï Grid User coordination is implicitly established by the network code (not on a case-by-case basis, but on generation technology level), because the selection of the characteristics within the predefined boundaries should take into consideration technology-specific characteristics and constraints.

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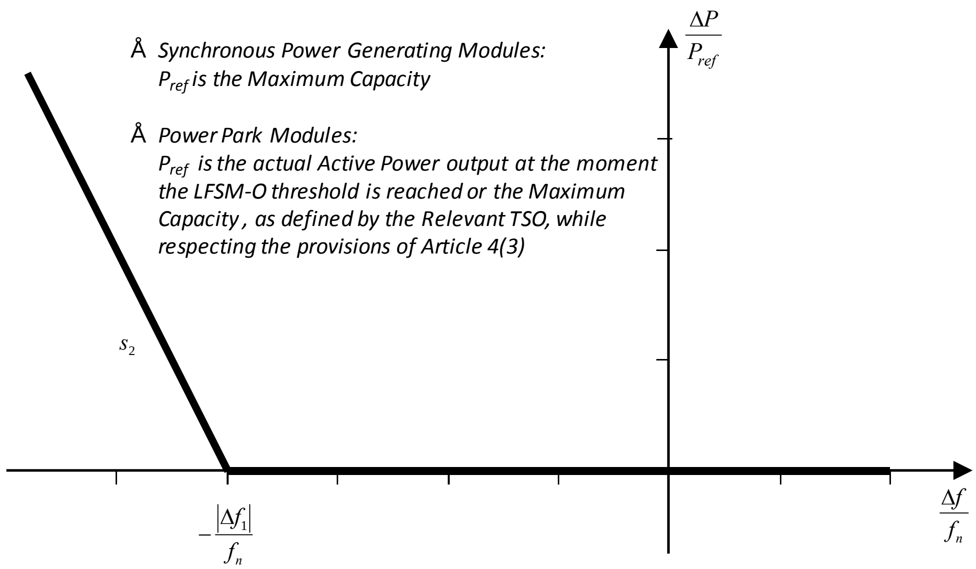
3.4. Limited Frequency Sensitive Mode (Underfrequency)

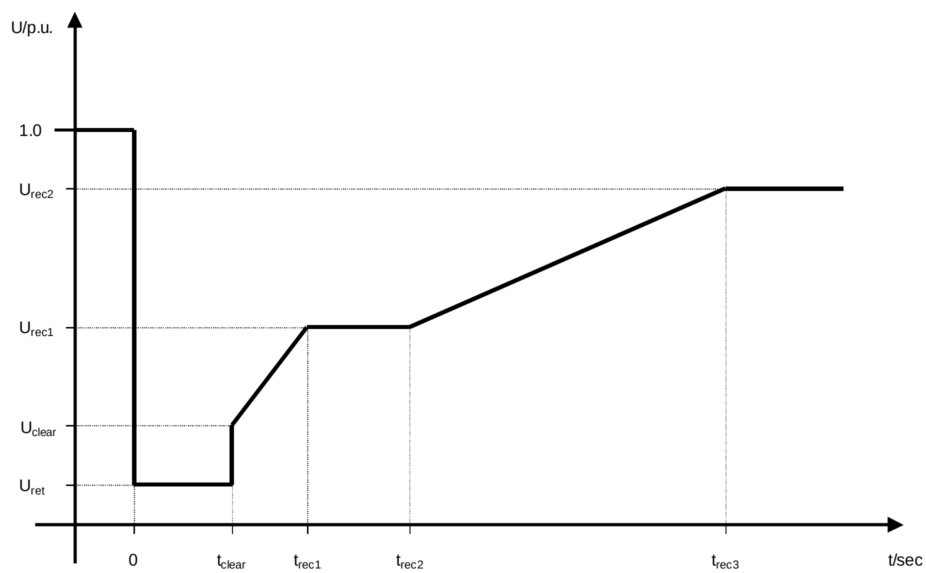
DESCRIPTION	
Article	Article 10 (2) (b) (1)
Objective	The objective of the requirement is to automatically increase Active Power output of Power Generating Modules (Synchronous Generators and Power Park Modules) in case of under frequency, to inrease the frequency back towards its target value (normally 50.0 Hz) for cases of severe imbalance (shortfall of generation), increasing the power output in case of severe deviation. This may occur in cases of major disturbances to the system such as loss of a large generation or in more extreme cases from a system split. The requirements aims to increase Active Power output proportionally to the frequency deviation to restore the generation / demand balance. The capability to increase active power output is needed in emergency situations in order to stabilize the system and avoid further decrease of frequency and more severe disturbances, i.e. frequency collapse in a synchronous area possibly leading to cascade tripping, system splitting, load shedding, major faults and even black outs.
NC frame	The NC requires from each TSO the specification of the actual frequency threshold (between and including 49.8 and 49.5 Hz) and Droop settings (in a range of 2 ï 12 %), in order to provide the Active Power Frequency Response according to the following figure.  The Active Power Frequency Response shall be activated as fast as technically feasible with an initial delay that shall be as short as possible and reasonably justified by the Power Generating Facility Owner to the Relevant TSO if greater than 2 seconds.

Further info	• Supporting documentation of RfG network code:
	    ○ Network Code for requirements for grid connection applicable to all generators ï Justification outlines (26. June 2012)
	    ○ Network Code for requirements for grid connection applicable to all generators ï Requirements in the context of present practices (26 June 2012)

INTERDEPENDENCIES	

In this NC	• Frequency ranges (Article 8 (1) (a)) • Frequency Sensitive Mode (Article (10) (2) (c)) • Maximum Power Reduction at Underfrequency (Article 8 (1) (e))
In other NCs	NC HVDC is expected to have a similar requirement for Limited Frequency Sensitive Mode (under frequency) for HVDC Converter Units and DC-Connected PPMs.
System characteristics	The droop and time of activation can be different for different power generating units in order to reach the necessary overall droop of the system, in order to maintain system security and avoid unnecessary loss of load due to protection schemes.
Technology characteristics	The actual delivery of Active Power Frequency Response in LFSM-U mode depends on the operating and ambient conditions of the Power Generating Module when this response is triggered, in particular limitations on operation near Maximum Capacity at low frequencies according to Article 8(1) (e) and available primary energy sources.
COORDINATION	
TSO – TSO	TSO-TSO coordination to agreed droop and threshold (in the range 49.8 to 49.5Hz) within one synchronous area is not required under this NC, but it is recommended, to minimise unplanned power flow between the countries, after activation of LFSM. In addition cooperation with representatives of manufactures is recommended to elaborate time of activation for typical existing technology (reference active power activation) - taking into account real system needs and each technology constraints which are the same irrespective of place of installation.
TSO – DSO	./.
RNO – Grid User	TSO ï Grid User coordination is implicitly established by the network code (not on a case-by-case basis, but on generation technology level), because the selection of the full set of parameters to exhaustively define LFSM-U should take into consideration technology-specific characteristics and constraints.

3.5. Fault Ride Through Capability of Generators Connected Below 110 kV

DESCRIPTION	
Article	Article 9 (3) (a)
Objective	The requirements aims at preventing power generating modules connected to networks below 110 kV from disconnection after a secured fault on the higher transmission level. The objective is to limit the potential loss of generation after a fault on the distribution or transmission system at voltage levels of 110 kV or above in order to avoid more severe disturbances, i.e. frequency collapse in a synchronous area causing demand tripping and unexpected power flows resulting in overloads both on internal transmission lines and tie lines with neighbouring systems possibly leading to cascading tripping, system splitting, load shedding, major faults, brown outs and even black outs. In the case of a fault on the transmission system level a voltage drop will propagate across large geographical areas around the point of the fault during the period of the fault. The increased levels of distributed generation will need to be tolerant to such faults, especially where the total installed volume of embedded generation possibly affected by a transmission system fault exceeds the maximum designed generation loss. It is also possible that a large generator may have been tripped depending upon the exact fault location. Unless this capability is established, the total loss would then be the sum of this large generator plus any lower level distributed generation tripping.
NC frame	The NC requires from each TSO the specification of a voltage-against-time-profile which expresses the lower limit of the course of the phase-to-phase Voltages on the Network Voltage level at the Connection Point during a symmetrical fault, as a function of time before, during and after the fault. This profile represents the worst voltage variation during a fault and after its clearance (retained voltage during a fault and post-fault voltage recovery). Power Generating Modules shall stay connected to the grid and continue stable operation for voltages above these worst-case conditions. The specification of the profile comprises of a set of parameters for times and voltages within ranges defined by the network code. 

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	Synchronous Power Generating Modules				Power Park Modules			
	Voltage parameters [pu]		Time parameters [sec]		Voltage parameters [pu]		Time parameters [sec]	
Type B/C	U_{ret}:	0.05 ï 0.3	t_{clear}:	0.14 ï 0.25	U_{ret}:	0.05 ï 0.15	t_{clear}:	0.14 ï 0.25
	U_{clear}:	0.7 ï 0.9	t_{rec1}:	t_{clear}	U_{clear}:	U_{ret} ï 0.15	t_{rec1}:	t_{clear}
	U_{rec1}:	U_{clear}	t_{rec2}:	t_{rec1} ï 0.7	U_{rec1}:	U_{clear}	t_{rec2}:	t_{rec1}
	U_{rec2}:	0.85 ï 0.9 and ÓU_{clear}	t_{rec3}:	t_{rec2} ï 1.5	U_{rec2}:	0.85	t_{rec3}:	1.5 ï 3.0

The fault-ride-through requirement does not require the actual voltage recovery curve to be of the shape of the voltage-against-time-profile, but represents a lower limit of it. Successful fault-ride-through performance is required only in cases in which the actual voltage profile remains above this limit.

Successful fault-ride-through performance is subject to further pre- and post-fault conditions of the system and operation of the power generating module (pre- and post-fault short circuit capacity at the connection point, pre-fault operating point of the power generating module in terms of apparent power and voltage), which shall be specified by the relevant network operator based on conditions for calculation as defined by each TSO.

Further info

- Supporting documentation of RfG network code:
  - Network Code for requirements for grid connection applicable to all generators ï Frequently asked questions (19. June 2012 ï FAQ 24)
  - Network Code for requirements for grid connection applicable to all generators ï Justification outlines (26. June 2012)
  - Network Code for requirements for grid connection applicable to all generators ï Requirements in the context of present practices (26. June 2012)

INTERDEPENDENCIES

In this NC

- Post-fault active power recovery of synchronous power generating modules (Article 12 (3) (a))
- Reactive current injection during a fault by power park modules (Article 15 (2) (b) and (c))
- Post-fault active power recovery of power park modules (Article 15 (3) (a))

In other NCs

- NC HVDC will have a similar requirement for fault-ride-through capability.
- Network Codes OS and LFCR address the limit of maximum secured losses.

System characteristics

System characteristics like network topology and generation mix have significant impact on the relevant parameters of the fault-ride-through requirement and should be taken into account reasonably by the relevant network operator when selecting them:

- *Retained voltage*

  The retained voltage at or near a fault location on transmission level will be zero for the phases affected by the fault. However, the transformers between the transmission system (above 110 kV) and the lower voltage levels of transmission or distribution systems will limit the voltage drop seen at those levels in case of a transmission system fault. Hence, a zero retained voltage is unrealistic to be sustained on a distribution level for transmission system faults. Further aspects will have impact on the magnitude of the retained voltage are the topology of the distribution system and the distribution connected generation portfolio. Higher levels of retained voltage can be expected in meshed distribution systems with several connection points to the transmission system and in systems with a high penetration of embedded generation in operation, either synchronous power generating modules, which will deliver short-circuit currents to support voltage inherently or power park modules, which can provide the relevant performance as of Article 15 (2) (b) and (c) of this network code. The voltage drop in distribution system resulting from transmission level faults can best be examined by recordings of real events in the past and by respective calculations for existing and estimated network topology and generation portfolio, but nevertheless for future-proof fault-ride-through performance a tendency towards lower retained voltage should be taken into consideration due to a trend towards converter-connected generation, which, despite the requirements of reactive current injection, will provide less voltage support compared to traditional synchronous generators.

- *Fault clearance time*
  The specification of the relevant fault clearance time depends on the applied protection schemes and technologies. On the transmission system level of 110 kV and above (which is the relevant

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	domain of faults for FRT requirements), fault clearance in 150 msec by primary protection can be considered reasonable for covering even unfavourable fault locations. If failure of a circuit breaker is included a fault clearance time of 250 msec seems to be an appropriate choice. When specifying the requested fault clearance time parameter underlying assumptions with regard to protection schemes and settings should be explained for transparency reasons, in particular whether fault clearance by primary protection or backup protection is implied (e. g. coverage of circuit breaker failures will result in longer fault clearance times to be considered). • *Pre- and post-fault short-circuit capacity at the connection point* Short-circuit capacity at the connection point also influences the stability of synchronous power generation modules. It represents an equivalent for robustness of the network against disturbances. Though this value will change permanently as a consequence of changes to network topology and generation portfolio the underlying assumptions for its calculations and the corresponding pre- and post-fault values should be determined by calculation of the initial symmetrical short-circuit current to give guidance for the power generating module design. The above mentioned system characteristics have significant impact on fault-ride-through performance and should be taken into account properly when further specifying the required capabilities. They have in common, that they cannot be described by long-term fixed values, but will vary as a result of changes to the system, both to topology and network and user technologies. Hence, assumptions of future developments need to be made and the parameters selected for exhaustively specifying fault-ride-through capability need to have margins to allow for maintaining the capability on a long-term basis.
Technology characteristics	Given the uncertainty on system characteristics and their future evolution, power generating modules need to be robust against changes to the system and shall provide fault-ride-through capability also under varying system conditions. Hence, it is an important aspect that best use of the different technical capabilities of the generation technologies is made. Consequently, different voltage-against-time-profiles for synchronous power generating modules and power park modules are applied in this network code taking into consideration technical limits and cost implications. The most debated parameters are the retained voltage during a fault (U_{ret}) and the fault clearance time (t_{clear}), because they both have a significant impact in particular on the design of synchronous generators and control strategy of power park modules during a fault. Fault clearance time is critical for the rotor angle stability of a synchronous generator, because it accelerates during a fault and longer fault clearance times would require more rotational masses in a generator to increase its inertia and limit the acceleration. However, the stability is not only influenced by the fault clearance time, but as well by the generatorôs pre-fault operating point in terms of apparent power and voltage. In general terms fault-ride-through capability with a fault clearance time of 150 msec can typically be requested from any admissible operating point of a generator, while the same capability at the long end of 250 msec can be applied only for pre-fault operating points in a limited area of the generator P-Q-diagram. It is therefore insufficient to specify the fault clearance time to be withstood without specifying the operating conditions of the generator under which the successful performance is required. The TSO needs to decide whether priority is given to generality with regard to pre-fault operating conditions of power generating modules (which sets constraints on fault clearance time for successful fault-ride-through performance) or to longer fault clearance times when taking into account circuit breaker failure (which sets constraints on pre-fault operating conditions for successful fault-ride-through performance).
COORDINATION	
TSO – TSO	TSO ï TSO coordination is recommended on protection schemes and settings for transmission system faults in an interconnected synchronous area with regard to faults near to control area boundaries. Such coordination should aim at ensuring that nearby faults in the control area of the adjacent TSO have similar impact on the distribution system.
TSO – DSO	Coordination is requested when determining the pre- and post-fault short-circuit capacities at the connection points of power generating modules. The network code stipulates that the conditions for calculating these parameters by the relevant network operator shall be determined by the TSO. Furthermore coordination will include compatibility of fault-ride-through requirements with operational strategies of distribution systems.

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RNO – Grid User	Coordination is implicitly established by the network code (not on a case-by-case basis, but on generation technology level), because the selection of the full set of parameters to exhaustively define fault-ride-through capability should take into consideration technology-specific characteristics and constraints.

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3.6. Rate of Change of Active Power Output

DESCRIPTION	
Article	Article 10 (6) (e)
Objective	The requirement aims at ensuring that generation modules that are connected to the network can regulate their active output to respond to changes in scheduled output. The rates of change of active power are valid under normal operation . A minimum rate of change of active power may depend on prime mover characteristics while a maximum rate may be instructed by the network operator to limit the impact of step changes in schedules.
NC frame	The NC requires that the minimum and maximum acceptable ramping limits for power generation modules are specified by the Relevant Network Operator.
Further info	• Supporting documentation of RfG network code: o Network Code for requirements for grid connection applicable to all generators ï Justification outlines (26. June 2012)
INTERDEPENDENCIES	
In this NC	./.
In other NCs	• NC LFC&R : Article 26-28 (Ramping periods and restrictions)
System characteristics	The rate of change of active power capability should be based on the need to deliver scheduled changes in output to follow demand and scheduled cross-border power exchanges. Given the uncertainty on system characteristics and their future evolution, power generating modules need to be robust against changes to the system and shall provide their active power capability also under varying system conditions. Hence, it is an important aspect that best use of the different technical capabilities of the generation technologies is made. Notably the rate of change of active power capability should be assessed on not only the present network but also account for the expected capability that will be required over the asset life of the power generating module accounting for future changes in the network and its demand and generation portfolio.
Technology characteristics	The minimum rate of change of active power is not only a function of system needs but also of prime mover characteristics. Many prime mover characteristics have a number of technological choices to provide improved response times, and these should be examined when a rate of change of active power system need exceeds those inherent in the Power Generating Modules design, to determine the most effective approach. For example the design of the penstock for a hydro power plant. However there are physical limits to prime mover characteristics, which vary with technologies and these must be respected, for example the gravitational effect on the fall rate of water.
COORDINATION	

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TSO – TSO	TSO ï TSO coordination within the same control area is necessary since frequency and system stability are shared concerns.
TSO – DSO	TSO ï DSO coordination within the same control area is necessary since frequency and system stability are shared concerns.
RNO – Grid User	RNO ï Grid User coordination within the same control area is necessary since frequency and system stability are shared concerns.

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3.7. Black Start

DESCRIPTION	
Article	Article 10 (5) (a)
Objective	The objective of the requirement is to guarantee that there is a sufficient amount of generation capable of black start for the power system restoration process after major disturbance or a blackout. The Black Start Capability is a critical functionality that is required in all power systems, but it Is not mandatory, because it is only necessary for the generation units which initiate the restoration process. After the connection of these generation units, the system will be back to stable conditions and the other generation units that will reconnect subsequently do not require Black Start Capability. The number of generation plants needed for the initiation of the restoration process is a function of the local electric system topology and characteristics. Therefore, the specific details must be defined locally by the Relevant Network Operator.
NC frame	The NC requires from each TSO to check if the system security is at risk due to a lack of Black Start Capability in a Control Area. If the Relevant TSO deems system security to be at risk, the Relevant TSO shall have the right to obtain a quote for Black Start Capability from Power Generating Facility Owners. A Power Generating Module with a Black Start Capability shall be able to: - Start from shut down within a timeframe decided by the Relevant Network Operator in coordination with the Relevant TSO while respecting the provisions of Article 4(3), without any external electricity supply. - Synchronize within the Frequency limits defined in Article 8(1) and Voltage limits defined by the Relevant Network Operator or defined by Article 11(2) where applicable. - Regulating load connections causing voltage dips automatically. - Regulating load connections in block load - Control Frequency in case of over-frequency and under-frequency within the whole Active Power output range between Minimum Regulating Level and Maximum Capacity as well as at houseload level. - Parallel operation of a few Power Generating Modules within one island. - Control Voltage automatically during the system restoration phase
Further info	• Supporting documentation of RfG network code: o Network Code for requirements for grid connection applicable to all generators ï Justification outlines (26. June 2012) • External documents: o NERC Standard EOP-005-2 ñSystem Restoration from Blackstart Resourcesò
INTERDEPENDENCIES	
In this NC	• Voltage stability (Article 11 (2)) • Frequency stability (Article 8 (1))

In other NCs	• NC HVDC will have a similar requirement for Black Start Capability. • NC OS: Restoration • Could be addressed in scope of future NC on Emergency Procedures
System characteristics	System characteristics like network topology, demands and generation mix have significant impact on the need of Black Start Capability of a particular Power Generating Module and should be taken into account reasonably by the relevant TSO when deciding to ask for a quote. The main system characteristics are: • System Topology. After a blackout it is necessary to proceed with the restoration process as soon as possible. Restoration processes are very complex and depend on the topology and circumstances of the electrical system at the moment of the blackout. The use of a far located Power Generation Module to restore an area is often not possible due to overvoltages and electrical connections transients. The need of a Black Start Capability from Power Generations Modules is more related to a specific area than a whole system need. • Loads situation and characteristics. The final purpose of a restoration process is to supply all system loads but during the restoration process the loads are used to stabilize the island, reduce overvoltages and maintain the island frequency. The characteristics of the loads (power factor, connection peak etc.) must be taken into account when deciding the needs of a Black Start Capability from a particular Power Generation Facility. • Electrical protection system. The electrical protection system must be capable to trip an element in case of an electrical fault. Sometimes it is necessary to connect a Power Generating Module to have the Short Circuit Power needed by the electrical protection system.
Technology characteristics	It is acknowledged that Black Start Capability is much linked to the Power Generating Module technology. As an example hydro plants are traditionally used for this service when available in the power system. If applied to power generation modules based on renewable energy sources it will only help during the restoration process when the primary energy (wind, sun, etc.) is available. TSOs must analyze the different generation plants existing in their systems or to be connected to it, to obtain a quote for Black Start Capability from the Power Generating Facility Owners whose plants are the most suitable for this service.
COORDINATION	
TSO – TSO	TSO ï TSO coordination is recommended when defining the Black Start Capability needs of their electrical power systems. The collaboration between the different TSOs can reduce the Black Start Capability needs in both systems improving at the same time the restoration process.
TSO – DSO	Coordination is requested when the Power Generation Facility that has Black Start Capability is connected to the distribution network.
RNO – Grid User	Coordination is implicitly established by the network code not on a case-by-case basis, but on generation technology level), because the need for Black Start Capability is assessed regarding the technological capability of the Power Generation Facility.

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3.8. Capability to take part in isolated network operation

DESCRIPTION	
Article	Article 10 (5) (b)
Objective	This provision of NC RfG aims at setting requirements for power generating modules in order to enable them to operate in an isolated network after its disconnection from the interconnected system and control frequency and voltage in this isolated network. The objective is to guarantee the availability of such generating units which are able to operate in these specific conditions. The defined requirements consider frequency and voltage ranges and control features, e.g. the plant shall be able to operate in specific frequency and voltage ranges, and adjust its active power output automatically according to the actual frequency in the isolated network. The objective is to maintain supply in the isolated network and to be able to reconnect it to the interconnected system quickly.
NC frame	NC RfG entitles the Relevant Network Operator in coordination with the Relevant TSO to require the capability to take part in isolated network operation in the context of system defence and restoration while respecting the provisions of Article 4(3). In general, the Power Generating Module controls should be tuned and coordinated in a way that they are able to operate in isolated operation and control frequency and voltage after disconnection from the interconnected system. The network code requires that operation in isolated network shall be possible within the Frequency limits defined in Article 8(1) and Voltage limits according to Article 10(3) or Article 11(2) where applicable. If required, the plant shall be able to operate in FSM mode as defined in Article 10(2) (b). The Power Generating module shall be able to reduce the Active Power Output in case of power surplus from its previous operating point to any new operating point within the P-Q-Capability Diagram as much as inherently technically feasible, but at least a Active Power Output reduction to 55% of its Maximum Capacity shall be possible. Specific methods how the Power Generating Module identifies the isolated network operation shall be coordinated between the Power Generating Facility Owner and the Relevant Network Operator in coordination with the Relevant TSO while respecting the provisions of Article 4(3). The detection of change from interconnected system operation to island operation shall not rely solely on the Network Operatorôs switchgear position signals.
Further info	• Supporting documentation of RfG network code: ○ Network Code for requirements for grid connection applicable to all generators ï Justification outlines (26. June 2012)
INTERDEPENDENCIES	
In this NC	• Frequency limits (Article 8 (1)). • Voltage limits (Article 10 (3) or Article 11 (2)) • Frequency stability (Article 10 (2)) • Reactive power capability ((Article 13 (2)) • FSM and LFSM (Article 10(2) (c), Article 10(2)(b), Article 8(1) (c)
In other NCs	• NC OS: System Defence Plan

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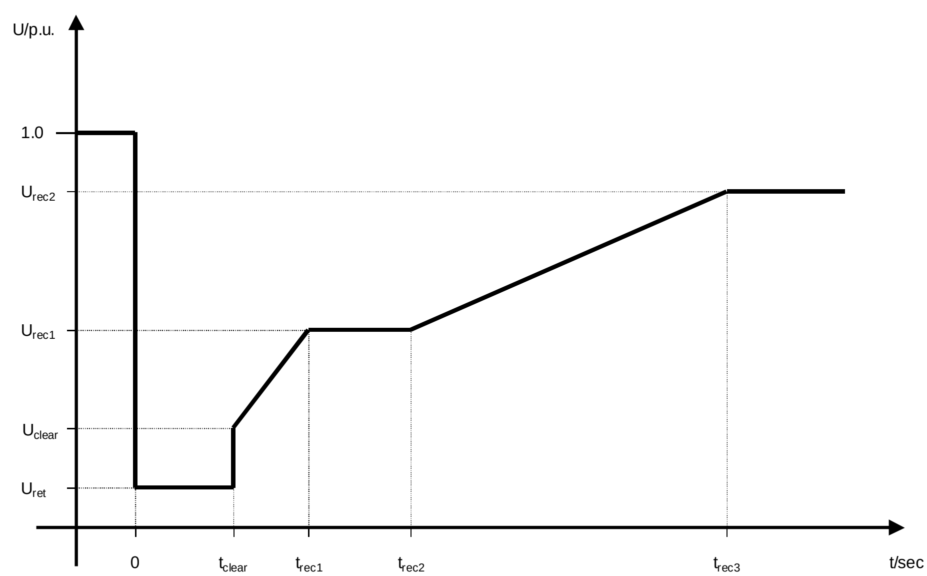
System characteristics	The functionality to take part in isolated network operation depends on system characteristics. Network topology, allocation of loads and generation structure and technology should be considered, to determine which power generating modules shall be capable of isolated network operation. The relevant network operator in cooperation with the relevant TSO shall analyse the network operation and security based on different conditions and coordinate the system defence and restoration process. As far as system defence and restoration is concerned, it is hardly possible to predict where the interconnected system will split in case of large disturbances. Such consequences often represent the final stage of complex processes resulting from a sequence of multiple events, which are difficult to assess in advance. The detailed procedures of restoration of the power system in each TSO's control area are the subject of national restoration plans, which are developed by individual TSOs on national level. Therefore the responsibility of the relevant network operator in coordination with the relevant TSO is to determine the detection methods of island operation and how many and which power generating modules have to be capable of isolated network capability when setting up a defense plan to preserve and restore system security. Load characteristics and their allocation in the system together with the network topology and the availability of generating units have impact on the networkôs ability to be operated when isolated from the interconnected system. When specifying system restoration plans the relevant network operator shall consider different contingencies and analyse the system considering different system stability (frequency, voltage) aspects.
Technology characteristics	When selecting the appropriate power generating modules to take part in island operation for system restoration the Relevant Network Operator should consider the flexibility of different generation technologies and demand this functionality respecting the provisions of Article 4(3). For example, hydro units are more manoeuvrable than thermal units, the regulation speed and the range of active power output between the minimum regulating level and maximum capacity is different. It should be emphasized that the speed/frequency regulation (i.e. (L)FSM) of the units determines their availability and functionality for isolated network operation. Thus FSM and accumulatively LFSM with high quality performance should be ensured by power generating modules to increase probability of operating an isolated network stably. Active power frequency response within LFSM should be as fast as possible. Therefore the generation technology with inherent high speed active power activation is favourable. Another important function of the power generating modules to be considered is its ability of house load operation, which further supports the operation of an isolated network.
COORDINATION	
TSO – TSO	TSO ï TSO coordination is recommended in order to adopt similar control philosophies inside one synchronous area or within control area and in that way guarantee system security and most optimal allocation of available generating options. This coordination should enable to operate the power system even as smaller islands after separation or after system start-up, and afterwards reconnect different parts to interconnected power system.
TSO – DSO	Coordination between TSO and DSO is requested in order to guarantee system security and ensure appropriate action in case of a system split.. Nevertheless, TSO shall coordinate the need for this functionality and if a relevant plant is connected to the DSO network then full coordination with the TSO shall be done.
RNO – Grid User	Coordination is implicitly established by the network code (not on a case-by-case basis, but on generation technology level), because the requirements set to define the capability to take part in isolated network operation should take into consideration technology-specific characteristics and constraints.

3.9. Fault Ride Through Capability of Generators Connected at 110 kV or above

DESCRIPTION	
Article	Article 11 (3) (a)
Objective	The requirements aims at preventing power generating modules connected to networks at 110 kV or above from disconnection after a secured fault on transmission or distribution networks of these voltage levels. The objective is to limit the potential loss of generation after a fault on the transmission or distribution system of these voltage levels in order to avoid more severe disturbances, i.e. frequency collapse in a synchronous area causing demand tripping and unexpected power flows resulting in overloads both on internal transmission lines and tie lines with neighbouring systems possibly leading to cascading tripping, system splitting, load shedding, major faults, brown outs and even black outs. In the case of a fault on the transmission system level a voltage drop will propagate across large geographical areas around the point of the fault during the period of the fault. A number of bulk power generating modules connected at 110 kV or above will need to be tolerant to such faults, especially where the total installed volume of generation possibly affected by a transmission system fault exceeds the maximum designed generation loss.
NC frame	The NC requires from each TSO the specification of a voltage-against-time-profile which expresses the lower limit of the course of the phase-to-phase Voltages on the Network Voltage level at the Connection Point during a symmetrical fault, as a function of time before, during and after the fault. This profile represents the worst voltage variation during a fault and after its clearance (retained voltage during a fault and post-fault voltage recovery). Power Generating Modules shall stay connected to the grid and continue stable operation for voltages above these worst-case conditions. The specification of the profile comprises of a set of parameters for times and voltages within ranges defined by the network code. 

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Type	Synchronous Power Generating Modules: Voltage parameters [pu]		Synchronous Power Generating Modules: Time parameters [sec]		Power Park Modules: Voltage parameters [pu]		Power Park Modules: Time parameters [sec]	
Type D	U_{ret}:	0	t_{clear}:	0.14 ï 0.25	U_{ret}:	0	t_{clear}:	0.14 ï 0.25
	U_{clear}:	0.25	t_{rec1}:	t_{clear} ï 0.45	U_{clear}:	U_{ret}	t_{rec1}:	t_{clear}
	U_{rec1}:	0.5 ï 0.7	t_{rec2}:	t_{rec1} ï 0.7	U_{rec1}:	U_{clear}	t_{rec2}:	t_{rec1}
	U_{rec2}:	0.85 ï 0.9	t_{rec3}:	t_{rec2} ï 1.5	U_{rec2}:	0.85	t_{rec3}:	1.5 ï 3.0

The fault-ride-through requirement does not require the actual voltage recovery curve to be of the shape of the voltage-against-time-profile, but represents a lower limit of it. Successful fault-ride-through performance is required only in cases in which the actual voltage profile remains above this limit.

Successful fault-ride-through performance is subject to further pre- and post-fault conditions of the system and operation of the power generating module (pre- and post-fault short circuit capacity at the connection point, pre-fault operating point of the power generating module in terms of apparent power and voltage), which shall be specified by the relevant network operator based on conditions for calculation as defined by each TSO.

Further info

- Supporting documentation of RfG network code:
  - Network Code for requirements for grid connection applicable to all generators ï Frequently asked questions (19. June 2012 ï FAQ 24)
  - Network Code for requirements for grid connection applicable to all generators ï Justification outlines (26. June 2012)
  - Network Code for requirements for grid connection applicable to all generators ï Requirements in the context of present practices (26. June 2012)

INTERDEPENDENCIES

In this NC

- Post-fault active power recovery of synchronous power generating modules (Article 12 (3) (a))
- Reactive current injection during a fault by power park modules (Article 15 (2) (b) and (c))
- Post-fault active power recovery of power park modules (Article 15 (3) (a))

In other NCs

- NC HVDC will have a similar requirement for fault-ride-through capability.
- Network Codes OS and LFCR address the limits of maximum secured losses.

System characteristics

System characteristics like network topology and generation mix have significant impact on the relevant parameters of the fault-ride-through requirement and should be taken into account reasonably by the relevant network operator when selecting them:

- *Retained voltage*
  The retained voltage at or near a fault location will be zero for the phases affected by the fault. Hence, it is important that power generating modules, which are connected at voltage levels, where the faults that shall be withstood originate from, are capable of sustaining a zero retained voltage. At voltage levels of 110 kV or above it is possible, that a considerable amount of generation is located close to a fault location, e. g. in case of a power generating facilities with several generating units, which are connected to the network in the same substation.

- *Fault clearance time*
  The specification of the relevant fault clearance time depends on the applied protection schemes and technologies. On the transmission system level of 110 kV and above (which is the relevant domain of faults for FRT requirements), fault clearance in 150 msec by primary protection can be considered reasonable for covering even unfavourable fault locations. If failure of a circuit breaker is included a fault clearance time of 250 msec seems to be an appropriate choice. When specifying the requested fault clearance time parameter underlying assumptions with regard to protection schemes and settings should be explained for transparency reasons, in particular whether fault clearance by primary protection or backup protection is implied (e. g. coverage of circuit breaker failures will result in longer fault clearance times to be considered).

- *Pre- and post-fault short-circuit capacity at the connection point*
  Short-circuit capacity at the connection point also influences the stability of synchronous power

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	generation modules. It represents an equivalent for robustness of the network against disturbances. Though this value will change permanently as a consequence of changes to network topology and generation portfolio the underlying assumptions for its calculations and the corresponding pre- and post-fault values should be determined by calculation of the initial symmetrical short-circuit current to give guidance for the power generating module design. The abovementioned system characteristics have significant impact on fault-ride-through performance and should be taken into account properly when further specifying the required capabilities. They have in common, that they cannot be described by long-term fixed values, but will vary as a result of changes to the system, both to topology and network and user technologies. Hence, assumptions of future developments need to be made and the parameters selected for exhaustively specifying fault-ride-through capability need to have margins to allow for maintaining the capability on a long-term basis.
Technology characteristics	Given the uncertainty on system characteristics and their future evolution, power generating modules need to be robust against changes to the system and shall provide fault-ride-through capability also under varying system conditions. Hence, it is an important aspect that best use of the different technical capabilities of the generation technologies is made. Consequently, different voltage-against-time-profiles for synchronous power generating modules and power park modules are applied in this network code taking into consideration technical limits and cost implications. The most debated parameters are the retained voltage during a fault (U_{ret}) and the fault clearance time (t_{clear}), because they both have a significant impact in particular on the design of synchronous generators and control strategy of power park modules during a fault. Fault clearance time is critical for the rotor angle stability of a synchronous generator, because it accelerates during a fault and longer fault clearance times would require more rotational masses in a generator to increase its inertia and limit the acceleration. However, the stability is not only influenced by the fault clearance time, but as well by the generatorǿs pre-fault operating point in terms of apparent power and voltage. In general terms fault-ride-through capability with a fault clearance time of 150 msec can typically be requested from any admissible operating point of a generator, while the same capability at the long end of 250 msec can be applied only for pre-fault operating points in a limited area of the generator P-Q-diagram. It is therefore insufficient to specify the fault clearance time to be withstood without specifying the operating conditions of the generator under which the successful performance is required. The TSO needs to decide whether priority is given to generality with regard to pre-fault operating conditions of power generating modules (which sets constraints on fault clearance time for successful fault-ride-through performance) or to longer fault clearance times when taking into account circuit breaker failure (which sets constraints on pre-fault operating conditions for successful fault-ride-through performance).
COORDINATION	
TSO – TSO	TSO ï TSO coordination is recommended on protection schemes and settings for transmission system faults in an interconnected synchronous area with regard to faults near to control area boundaries. Such coordination should aim at ensuring that nearby faults in the control area of the adjacent TSO have similar impact on the distribution system.
TSO – DSO	Coordination is requested when determining the pre- and post-fault short-circuit capacities at the connection points of power generating modules. The network code stipulates that the conditions for calculating these parameters by the relevant network operator shall be determined by the TSO. Furthermore coordination will include compatibility of fault-ride-through requirements with operational strategies of distribution systems.
RNO – Grid User	Coordination is implicitly established by the network code (not on a case-by-case basis, but on generation technology level), because the selection of the full set of parameters to exhaustively define fault-ride-through capability should take into consideration technology-specific characteristics and constraints.

3.10. Post Fault Active Power Recovery (Synchronous Generators)

DESCRIPTION	
Article	Article 12 (3) (a)
Objective	The requirement for synchronous power generating modules connected to distribution or transmission networks to deliver active power infeed after the clearance of a secured fault on the transmission level within a certain time. The objective of this requirement is to limit the short term loss of active power infeed and to stabilize the frequency after secured faults on transmission level in order to prevent frequency collapse within a synchronous area. As in case of a fault on the transmission system level a voltage drop will propagate across large geographical areas around the point of the fault during the period of the fault, the increased levels of distributed generation (including Type B generators) will need to be tolerant to such post fault conditions. The post fault conditions vary between synchronous areas. In synchronous areas with strong frequency sensitivity a very fast active power recovery is needed in order to stabilize the transmission system, in other areas a moderate active power recovery is sufficient.
NC frame	The network code requires from each TSO the specification of a value and gradient for the active power recovery which expresses the required active power infeed at the Connection Point after the clearance of a symmetrical fault. Power Generating Modules have to stay connected and shall continue stable operation during active power recovery with regards to the operating point before fault incidence. The specification of the active power recovery comprises of a value or range and gradient within the range defined by the network code.

Further info	• Supporting documentation of RfG network code:
	  ○ Network Code for requirements for grid connection applicable to all generators ï Frequently asked questions (19. June 2012 ï FAQ 24)
	  ○ Network Code for requirements for grid connection applicable to all generators ï Justification outlines (26. June 2012)
	  ○ Network Code for requirements for grid connection applicable to all generators ï Requirements in the context of present practices (26. June 2012)

INTERDEPENDENCIES	
In this NC	• Fault Ride Through Type B Power Generating Modules (Article 9) • Reactive current injection during a fault by power park modules (Article 15 (2) (b) and (c)) • Post-fault active power recovery of power park modules (Article 15 (3) (a))
In other NCs	NC HVDC will have a similar requirement for fault-ride-through capability.
System characteristics	System characteristics like network topology and generation mix have significant impact on voltage recovery after fault clearance which in turn affects the ability of active power recovery and should be taken into account reasonably by the relevant network operator when selecting the parameters: • *Active Power Recovery Range and Gradient* Power recovery after a fault is important in order to restore the pre-fault operation after fault clearance. The relative priority of restoring the reactive power and voltage versus restoring real power and frequency depends upon the system size, predominantly of the synchronous area. For smaller synchronous areas (with less

INTERDEPENDENCIES

Technology characteristics	system inertia than larger areas) the active power restoration is particular time critical, in order to avoid reaching a system frequency following a large sudden power imbalance which results in demand disconnection. Similarly total system power balance following a fault (particularly for smaller synchronous areas) should be considered prior to deciding if deliberate power reductions (fast valving) can be allowed. It is insufficient to specify the active power recovery time without specifying voltage conditions after fault clearance (e. g. return to normal operating voltage range) under which the successful performance is required. Based on the specific system needs within a synchronous area (number of generation and load, generation mix, regional distribution of generation, etc.) the TSO needs to decide whether priority is given to fast active power recovery or fast voltage restoration. The TSO shall take into account technical limitations of generation technologies when defining capabilities to restore active power.
COORDINATION	
TSO – TSO	TSO ï TSO coordination is recommended on active power recovery after transmission system faults in an interconnected synchronous area with regard to faults near to control area boundaries. Such coordination should aim at ensuring that nearby faults in the control area of the adjacent TSO shall obtain equal active power infeed in all distribution systems affected by the fault in order not to shift power flows causing overloadings and/or cascading events.
TSO – DSO	./.
RNO – Grid User	Coordination is implicitly established by the network code (not on a case-by-case basis, but on generation technology level), because the selection of the full set of parameters to exhaustively define active power recovery should take into consideration technology-specific characteristics and constraints.

3.11. Reactive Power Capability at Maximum Capacity (Synchronous Generators)

DESCRIPTION	
Article	Article 13 (2) (b)
Objective	Reactive power is a key component in terms of voltage stability, which in turn is the foundation for cross-border trading. The influence on overall system voltage stability is essential for type C and D Power Generating Modules and will vary with location. This requirement is focused on the provision of reactive power from Synchronous Power Generating Modules in the steady state to allow the Relevant Network Operator having a sufficient reactive power reserve when the Synchronous Power Generating Module is operating at maximum capacity to keep voltages within the admissible limits. This requirement is completed by a provision of reactive power when the Power Generating Module operates below maximum capacity (Article 13(2)(c)). A similar requirement is defined for Power Park Modules (Article 16(3)(b)). The importance of a wide reactive power capability range is defined by the constantly increasing necessity of effective voltage regulation in the whole network. Voltage regulation becomes more complex because of the continuous change of network topology and characteristics, in particular driven by increasing long-distance power flows due to changes in the generation portfolio. Each Power Generating Module Type C and D shall be capable to participate in system voltage regulation.
NC frame	The NC requires from the Relevant Network Operator in coordination with the Relevant TSO the definition of the reactive power provision capability in the context of varying voltage. This requirement is defined by the U-Q/Pmax-profile expected at the connection point, and it has to be represented through a diagram (see below) expressed by the voltage at the connection point (ratio of actual value and its nominal value, i.e. per unit), against the ratio of the reactive power (Q) and the maximum capacity (Pmax). The NC defines several boundaries within which the U-Q/Pmax-profile will have to be defined. These boundaries are: • A fixed outer envelope, exhaustively defined in the NC • An inner envelope, which maximum dimensions (Q/Pmax range and Voltage range) are defined for each synchronous area in the NC. Note: The position, size and shape of the inner envelope in the diagram below are indicative.

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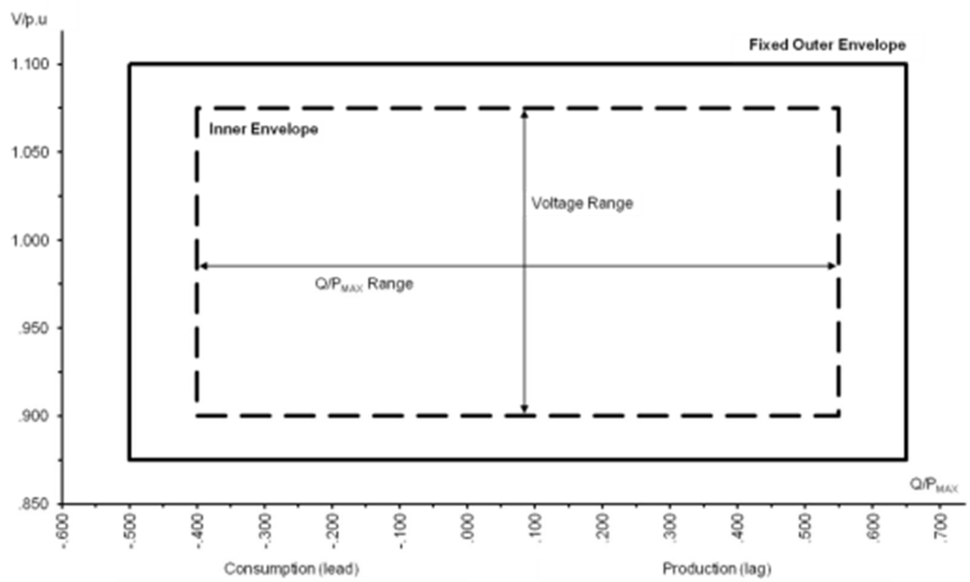

Each Relevant Network Operator in coordination with the Relevant TSO shall locate the inner envelope within the fixed outer envelope and define its own U-Q/Pmax-profile within the inner envelope. Regional needs regarding reactive power capability shall be taken into (depending on the degree of network meshing, the ratio of infeed and consumption,é) and as a consequence more than one profile is appropriate when regional system characteristics vary significantly within the area of responsibility of a network operator. This U-Q/Pmax profile shall take any shape that does not need to be rectangular. However it shall be taken into account that reactive power production (lagging mode) at high voltages and reactive power consumption (leading mode) at low voltages may not be necessary, which also may put constraints onto power generation design and operation and therefore it should be investigated what capability is actually required.

The Synchronous Power Generating Module shall be capable of moving to any operating point within its U-Q/Pmax profile in appropriate timescales to target values requested by the Relevant Network Operator.

Further info

- Supporting documentation of RfG network code:
  - Network Code for requirements for grid connection applicable to all generators ï Frequently asked questions (19. June 2012 ï FAQ 22)
  - Network Code for requirements for grid connection applicable to all generators ï Justification outlines (26. June 2012)
  - Network Code for requirements for grid connection applicable to all generators ï Requirements in the context of present practices (26. June 2012)
- Other relevant documentation:
  - ñReactive Power Interconnection Requirements for PV and Wind Plants ï Recommendations to NERCò, Sandia National Laboratories; Feb.2012.

INTERDEPENDENCIES

In this NC

- Reactive Power Capability at Maximum Capacity (PPM, Type C and D) (Article 16(3)(b))

In other NCs

- NC HVDC will have requirements related to reactive power capability for HVDC Converter Units, óremote endô (often offshore) Converter Units, and DC-connected PPMs. A similar framework is proposed with an option to optimize between the DC link and the PPM, as well as to reflect long-term development of the network
- Demand connection Code contains requirements referring to Reactive Power exchange and control for all Transmission Connected Demand Facilities and all Transmission Connected Distribution Networks,

	deemed significant pursuant to the provisions of this Network Code • Network Code Operational Security: Reactive Power Management and Voltage Control • Network Code Operational Planning Scheduling: Reactive Power Ancillary Services
System characteristics	System characteristics like network topology (e.g. degree of network meshing, the use of overhead power lines or cables, etc.), network loading (ratio of infeed and consumption) and the generation mix, have significant impact on the relevant parameters of the reactive power capability at maximum capacity requirement and should be taken into account reasonably by the relevant network operator when selecting them. For instance, highly meshed and/or heavily loaded networks need more lagging Reactive Power (production), whereas remote networks with modest power flows and low consumption need more leading Reactive Power (consumption) in order to keep the network voltage within the permitted range. The abovementioned system characteristics should be taken into account properly when further specifying the reactive power capability. They have in common, that they cannot be described by long-term fixed values, but could vary as a result of changes to the system, both to topology and network and user technologies. Hence, assumptions of future developments need to be made and the parameters selected for exhaustively specifying reactive power capability at maximum capacity profile, need to have margins to allow for maintaining the capability on a long-term basis.
Technology characteristics	Given the expected evolution of the generation mix and the increasing complexity of voltage regulation, it is crucial that every kind of Power Generating Modules (type C and D) contribute to voltage support, based on the best use of the reactive power capabilities of the two different technologies. Consequently, different reactive power capability requirements at maximum Capacity for synchronous power generating modules and for power park modules have been defined in the code, taking into consideration technical limits and cost implications.
COORDINATION	
TSO – TSO	TSO ï TSO coordination is recommended on the definition of the U-Q/Pmax profile concerning adjacent power generating modules in different control areas and within the same interconnected synchronous area. Such coordination should aim at ensuring that voltage regulation in the control area of the adjacent TSO is balanced and not only achieved by the power generating modules of one TSO. Although the voltage is a local variable, normally this coordination between adjacent TSOs is not critical, however, in the case of electrical areas shared by more than one TSO, that are prone to voltage instability, this coordination in the definition of this technical requirement is recommended.
TSO – DSO	Coordination between TSO and DSO is paramount for DSO-connected power generating modules when determining the U-Q/Pmax profile of the power generating modules. This coordination will be executed under article 4(3) provisions.
RNO – Grid User	Coordination is implicitly established by the network code (not on a case-by-case basis, but on generation technology level), because the definition of the U-Q/Pmax profile should take into consideration technology-specific characteristics and constraints.

3.12. Post Fault Active Power Recovery (Power Park modules)

DESCRIPTION	
Article	Article 15 (3) (a)
Objective	The requirement for power park modules connected to distribution or transmission networks defines the active power infeed after the clearance of a fault within a certain time. The objective of this requirement is to limit the short term loss of active power infeed and to stabilize the frequency after cleared faults on transmission level in order to prevent frequency collapse within a synchronous area. As in case of a fault on the transmission system level a voltage drop will propagate across large geographical areas around the point of the fault during the period of the fault, the increased levels of distributed generation (including Type B power plant modules) will need to be tolerant to such post fault conditions. The post fault conditions vary between synchronous areas. In synchronous areas with strong frequency sensitivity a very fast active power recovery is needed in order to stabilize the transmission system, in other areas a moderate active power recovery is sufficient.
NC frame	The network code requires from each TSO the specification of a value and gradient for the active power recovery which expresses the required active power infeed at the Connection Point after the clearance of a symmetrical fault. Power Park Modules have to stay connected and shall continue stable operation during active power recovery with regards to the operating point before fault incidence. The specification of the active power recovery comprises of a value or range and gradient within the range defined by the network code.

Further info	• Supporting documentation of RfG network code:
	  o Network Code for requirements for grid connection applicable to all generators ï Frequently asked questions (19. June 2012 ï FAQ 24)
	  o Network Code for requirements for grid connection applicable to all generators ï Justification outlines (26. June 2012)
	  o Network Code for requirements for grid connection applicable to all generators ï Requirements in the context of present practices (26. June 2012)

INTERDEPENDENCIES	
In this NC	• Fault Ride Through Type B Power Park Modules (Article 9) • Reactive current injection during a fault by power park modules (Article 15 (2) (b) and (c)) • Post-fault active power recovery of power park modules (Article 15 (3) (a))
In other NCs	NC HVDC will have a similar requirement for fault-ride-through capability.
System characteristics	System characteristics like network topology and generation mix have significant impact on voltage recovery after fault clearance which in turn affects the ability of active power recovery and should be taken into account reasonably by the relevant network operator when selecting the parameters: • *Active Power Recovery Range and Gradient* Power recovery after a fault is important in order to restore the pre-fault operation after fault clearance. The relative priority of restoring the reactive power and voltage versus restoring real power and frequency depends upon the system size, predominantly of the synchronous area. For smaller synchronous areas (with less system inertia than larger areas) the active power restoration is particular time

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Technology characteristics	critical, in order to avoid reaching a system frequency following a large sudden power imbalance which results in demand disconnection. For larger synchronous areas, a moderate active power recovery after a cleared fault may be sufficient, and the emphasis may be laid on the post fault reactive power support. It is insufficient to specify the active power recovery time without specifying voltage conditions after fault clearance (e. g. return to normal operating voltage range) under which the successful performance is required. Based on the specific system needs within a synchronous area (number of generation and load, generation mix, regional distribution of generation, etc.) the TSO needs to decide whether priority is given to fast active power recovery or fast voltage restoration. The TSO shall take into account technical limitations of power park module technologies when defining capabilities to restore active power.
COORDINATION	
TSO – TSO	TSO ï TSO coordination is recommended on active power recovery after transmission system faults in an interconnected synchronous area with regard to faults near to control area boundaries. Such coordination should aim at ensuring that nearby faults in the control area of the adjacent TSO shall obtain equal active power infeed in all distribution systems affected by the fault in order not to shift power flows causing overloadings and/or cascading events.
TSO – DSO	./.
RNO – Grid User	Coordination is implicitly established by the network code (not on a case-by-case basis, but on generation technology level), because the selection of the full set of parameters to exhaustively define active power recovery should take into consideration technology-specific characteristics and constraints.

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3.13. Reactive Current Injection (Power Park Modules)

<table>
<tr><td colspan="2">DESCRIPTION</td></tr>
<tr><td>Article</td><td>Article 15 (2) (b) and (c)</td></tr>
<tr><td>Objective</td><td> The non-mandatory requirement aims to providing fast acting additional reactive current injection at the connection point to the pre-fault reactive current injection during the period of faults in the case of (b) symmetrical faults and (c) asymmetrical (1-phase or 2-phase). The key issue at a national level is to determine if there is a need for such fault current support. The main consideration relates to analysis of ñhealthò of fault current contribution delivering adequate system strength. </td></tr>
<tr><td>NC frame</td><td> This national review should consider the most challenging future operating conditions in this respect, e.g. operating at the highest instantaneous level of non-synchronous generation foreseen say by 2030. Will the fault current from sources other than power park modules provide adequate system strength: Transmission protection operation?
Stable commutation of LCC type HVDC on the system?
Quality of supply quantities moving outside limits from extreme low fault levels, e.g. impact on harmonics and voltage steps from routine switching?
Voltage stability, low system strength resulting in low retained voltage during the fault and poor recovery of the system voltage after the fault? If these aspects are deemed OK, say out to 2030, then the national choice should be not to apply this requirement. Otherwise relevant parameters should be determined. Current contribution can be considered in terms of: Very fast component The initial contribution delivered while the modern transmission protections are identifying the fault, are needed very fast and then sustained. Key parameters are speed and magnitude of instantaneous current. The magnitude should be chosen to make best use of the capability without requiring additional rating of the converters. Measurement does not need to be based on sequence components. A criterion for initiating delivery of this capability should be stated. This ought to be as simple as possible to measure, e.g. voltage instantaneously below a simple threshold (e.g. outside normal operating range) locally at the individual unit (e.g. at the individual WTG) avoiding delays from communications between poer park module central control point and individual units. The volume to be delivered needs not be a controlled amount as long as it ceases when the voltage returns above the threshold. Fast component The purpose is to contribute to boost retained voltage during the fault to aid voltage and angular stability and deliver improved starting point for voltage recovery. This can be delivered a bit slower than the initial contribution, but with a defined accuracy. Post fault cleared component Support is needed to recover the system voltage. This is not part of this requirement, which is explicitly about delivery during the fault duration. </td></tr>
<tr><td>Further info</td><td>Supporting documentation of RfG network code:
Network Code for requirements for grid connection applicable to all generators ï Justification outlines (26. June 2012)</td></tr>
</table>

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INTERDEPENDENCIES	
In this NC	• Capability of providing synthetic inertia (Article 16 (2) (a))
In other NCs	NC HVDC will cover a similar requirement, based on the same three components of current injection.
System characteristics	System strength is the key characteristic involved. This may reduce very significant in systems which can at times (e.g. during high RES production and low demand) experience > 50% non-synchronous generation. Particular care should be taken if there are even prospects of operating conditions >75% non-synchronous generation within the control area.
Technology characteristics	There is a significant difference in the inherent behaviour of Full Converters (FC) and Doubly Fed Induction Generators (DFIG) in case of a sudden voltage drop. DFIGs will deliver an inherent very fast current spike, while the FC has to deliver everything through measurement and control action. Prior to requiring FCs to deliver a very fast (within 20ms) contribution, further info should be obtained with regard to its technical feasibility. For VSC technology using transistors (e.g. IGBTs) there may not be any short term (dynamic) rating beyond the continuous rating.
COORDINATION	
TSO – TSO	Adjacent AC-connected TSOs should take a coordinated approach, although they do not have to be the same, as there is a location component to system strength.
TSO – DSO	Specifications by the Relevant Network Operator should be made in coordination with the Relevant TSO.
RNO – Grid User	Grid Users and their suppliers should be consulted in particular with respect to capability of FC technology to deliver a reactive current very fast.

3.14. Reactive Power Capability at Maximum Capacity (Power Park Modules)

DESCRIPTION	
Article	Article 16 (3) (b)
Objective	Reactive power is a key component in terms of voltage stability, which in turn is the foundation for cross-border trading. The influence on overall system voltage stability is essential for type C and D Power Generating Modules and will vary with location. This requirement is focused on the provision of reactive power from Power Park Modules in the steady state to allow the Relevant Network Operator having a sufficient reactive power reserve when the Power Park Module is operating at maximum capacity to keep voltages within the admissible limits in the power system operation. This requirement is completed by a provision of reactive power when the Power Park Module operates below maximum capacity (Article 16(3)(c)). A similar requirement is defined for Synchronous Power Generating Modules (Article 13(2)(b). The importance of a wide reactive power capability range is defined by the constantly increasing necessity of effective voltage regulation in the whole network. Voltage regulation becomes more complex because of the continuous change of network topology and characteristics, in particular driven by increasing long-distance power flows due to changes in the generation portfolio. Each Power generating Module Type C and D shall be capable to participate in system voltage regulation. Moreover, the growing level of penetration of distributed generation (majority of Power Park Modules) in many European countries requires the future Power Park Modules to participate in bulk system voltage regulation as well as it traditionally has been done by the synchronous generating units.
NC frame	The NC requires from the Relevant Network Operator in coordination with the Relevant TSO the definition of the reactive power provision capability requirements in the context of varying voltage. This requirement is defined by the U-Q/Pmax-profile expected at the connection point, and it has to be represented through a diagram (see below) expressed by the voltage at the connection point (ratio of actual value and its nominal value, i.e. per unit) against the ratio of the reactive power (Q) and the maximum capacity (Pmax). The NC defines several boundaries within which the U-Q/Pmax-profile will have to be defined. These boundaries are: • A fixed outer envelope, exhaustively defined in the NC • An inner envelope, which maximum dimensions (Q/Pmax range and Voltage range) are defined for each synchronous area in the NC. Note: The position, size and shape of the inner envelope in the diagram below are indicative.

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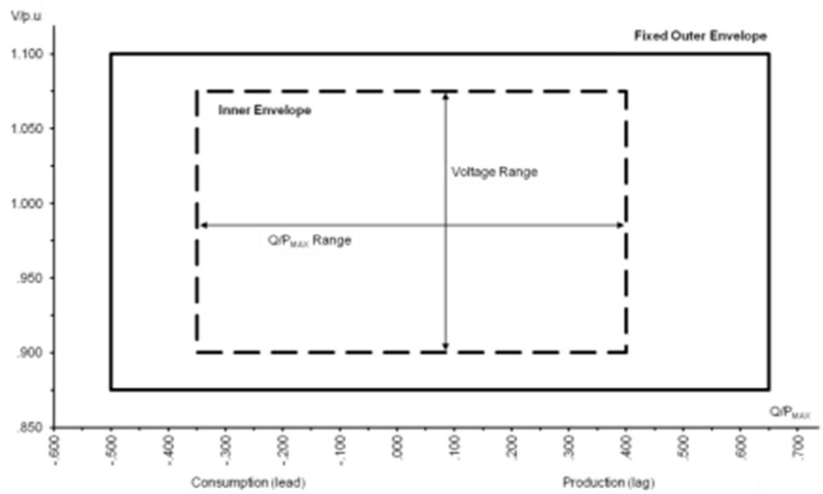

Each Relevant Network Operator in coordination with the Relevant TSO shall locate the inner envelope within the fixed outer envelope and define its own U-Q/Pmax-profile within the inner envelope. Regional needs regarding reactive power capability shall be taken into (depending on the degree of network meshing, the ratio of infeed and consumption,é) and as a consequence more than one profile is appropriate when regional system characteristics vary significantly within the area of responsibility of a network operator. This U-Q/Pmax profile shall take any shape that does not need to be rectangular. However it shall be taken into account that reactive power production (lagging mode) at high voltages and reactive power consumption (leading mode) at low voltages may not be necessary, which also may put constraints onto power generation design and operation and therefore it should be investigated what capability is actually required.

The Power Park Module shall be capable of moving to any operating point within its P-Q/Pmax profile in appropriate timescales to target values requested by the Relevant Network Operator.

Further info

- Supporting documentation of RfG network code:
  - Network Code for requirements for grid connection applicable to all generators ï Frequently asked questions (19. June 2012 ï FAQ 22)
  - Network Code for requirements for grid connection applicable to all generators ï Justification outlines (26. June 2012)
  - Network Code for requirements for grid connection applicable to all generators ï Requirements in the context of present practices (26. June 2012)
- Other relevant documentation:
  - ñReactive Power Capability of Wind Turbines Based on Doubly Fed Induction Generatorsò Stephan Engelhardt, S.; Erlich, I.; Feltes, C.; Kretschmann, J.; Shewarega, F.; IEEE Transactions on Energy Conversion, Vol. 26, no. 1, March 2011.
  - ñReactive Power Interconnection Requirements for PV and Wind Plants ï Recommendations to NERCò, Sandia National Laboratories; Feb.2012.

INTERDEPENDENCIES

In this NC

- Reactive power capability below maximum capacity (PPM, type C) (Article 16 (3) (c))
- Reactive power control modes of type C PPMs (Article 16 (3) (d))
- Voltage stability requirements applicable to offshore power park modules (Article 20

	(3)) • Reactive Power Capability at Maximum Capacity (Synchronous Power generating Modules, Type C) (Article 13(2)(b))
In other NCs	• NC HVDC will have consistent requirements related to reactive power capability • Demand connection Code contains requirements referring to Reactive Power exchange and control for all Transmission Connected Demand Facilities and all Transmission Connected Distribution Networks. In addition it provides for the option for a DSO to deliver an active form of reactive power control, as well the option to all users to provide demand response for reactive power. • Network Code Operational Security: Reactive Power Management and Voltage Control • Network Code Operational Planning and Scheduling: Reactive Power Ancillary Services
System characteristics	System characteristics like network topology (e.g. degree of network meshing, the use of overhead power lines or cables, etc.), network loading (ratio of infeed and consumption) and the generation mix, have significant impact on the relevant parameters of the reactive power capability at maximum capacity requirement and should be taken into account reasonably by the relevant network operator when selecting them. For instance, highly meshed and/or heavily loaded networks need more lagging Reactive Power (production), whereas remote networks with modest power flows and low consumption need more leading Reactive Power (consumption) in order to keep the network voltage within the permitted range. Moreover, distributed generation generates electricity from many small energy sources, commonly Power Park Modules, which could be weakly connected to the grid in remote locations, and consequently the degree of meshing is low. In these cases, the short circuit ratio of these locations might be too low and the voltage regulation in these areas is totally necessary to prevent the voltage collapse and to allow the power flows between areas. Therefore, the provision of a wide reactive power range from Power Park Modules, as reasonable as technically feasible, is absolutely necessary from this point of view to avoid these situations. The rapid increase of renewable energy sources (RES) in many European countries results in displacement of conventional generation, which presently provides active voltage control, both at transmission and distribution network, by Power Park Modules like wind and PV parks. Consequently, the contribution of these RES to voltage control is crucial in cases of high RES penetration. If Power Park Modules do not provide reactive power sufficiently, managing grid voltage would be jeopardized. In this context it needs to be noted, that inverters may provide capabilities of reactive power supply similar to synchronous generators. The abovementioned system characteristics have significant impact on the reactive power requirement definition and should be taken into account properly when further specifying such capability. They have in common, that they cannot be described by long-term fixed values, but could vary as a result of changes to the system, both to topology and network and user technologies. Hence, assumptions of future developments need to be made and the parameters selected for exhaustively specifying reactive power capability at maximum capacity profile need to have margins to allow for maintaining the capability on a long-term basis.
Technology characteristics	Reactive power requirements are specified at the connection point. This means that several technical options can be considered in the Power Park Module design to meet connection requirements. Power Park Modules consisting of wind farms are typically doubly fed induction generators (DFIG) or based on full-converter technology, which have considerable voltage control capability. The reactive power capability of PV and wind plants can be enhanced either by larger sized inverters or by adding of a static var compensator (SVC), static converters (STATCOMS), and other reactive support equipment at the plant level. PV inverters have a similar technological design to full-converter wind generators, and are increasingly being sold with similar reactive power capability. State-of-the-art PV inverters

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	have the capability to absorb or inject reactive power, if needed, provided that current and terminal voltage ratings are not exceeded. This use of reactive power capability may also allow an increase in the maximum installed PV capacity in an existing distribution networks. Given the expected evolution of the generation mix and the increasing complexity of voltage regulation, it is crucial that every kind of Power Generating Modules (type C and D) contribute to voltage support, based on the best use of the reactive power capabilities of the different technologies. Consequently, different reactive power capability requirements at maximum Capacity for synchronous power generating modules and for power park modules have been defined in the code, taking into consideration technical limits and cost implications.
COORDINATION	
TSO – TSO	TSO ï TSO coordination is recommended on the definition of the U-Q/Pmax profile concerning adjacent PPMs in different control areas and within the same interconnected synchronous area. Such coordination should aim at ensuring that voltage regulation in the control area of the adjacent TSO is balanced and not only achieved by the PPMs of one TSO. Although the voltage is a local variable, normally this coordination between adjacent TSOs is not critical, however, in the case of electrical areas shared by more than one TSO, that are prone to voltage instability, this coordination in the definition of this technical requirement is recommended.
TSO – DSO	Coordination between TSO and DSO is paramount for DSO-connected power generating modules when determining the U-Q/Pmax profile of the Power Park Modules. This coordination will be executed under article 4(3) provisions.
RNO – Grid User	Coordination is implicitly established by the network code (not on a case-by-case basis, but on generation technology level), because the definition of the U-Q/Pmax profile should take into consideration technology-specific characteristics and constraints.

3.15. Reactive Power Capability Below Maximum Capacity (Power Park Modules)

DESCRIPTION	
Article	Article 16 (3) (c)
Objective	Reactive power is a key component in terms of voltage stability, which in turn is the foundation for cross-border trading. The influence on overall system voltage stability is essential for type C and D Power Generating Modules and will vary with location. This requirement is focused on the provision of reactive power from Power Park Modules in the steady state to allow the Relevant Network Operator having a sufficient reactive power reserve even when the Power Park Module is operating at low active power output to keep voltages within the admissible limits in the power system operation. This requirement is completed by a provision of reactive power when the Power Park Module operates at maximum capacity (Article 16(3)(b)). A similar requirement is defined for Synchronous Power Generating Modules (Article 13(2)(c). The importance of a reactive power capability range is defined by the constantly increasing necessity of effective voltage regulation in the whole network. Voltage regulation becomes more complex because of the continuous change of network topology and characteristics, in particular driven by increasing long-distance power flows due to changes in the generation portfolio. Each Power generating Module Type C and D shall be capable to participate in system voltage regulation. Moreover, the growing level of penetration of distributed generation (majority of Power Park Modules) in many European countries requires the future Power Park Modules to participate in bulk system voltage regulation as well as it traditionally has been done by the synchronous generating units.
NC frame	The NC requires from the Relevant Network Operator in coordination with the Relevant TSO the definition of the reactive power provision capability requirements in the context of varying the active power. This requirement is defined by the P-Q/Pmax profile expected at the connection point and it has to be represented through a diagram (see below) expressed by the active power (the ratio of its actual value and the maximum capacity in per unit) against the ratio of the reactive power (Q) and the maximum capacity (Pmax). The NC defines several boundaries within which the P-Q/Pmax-profile will have to be defined. These boundaries are: • A fixed outer envelope, exhaustively defined in the NC • An inner envelope, for which the Q/Pmax range is defined for each synchronous area. Note: The position, size and shape of the inner envelope in the diagram are indicative

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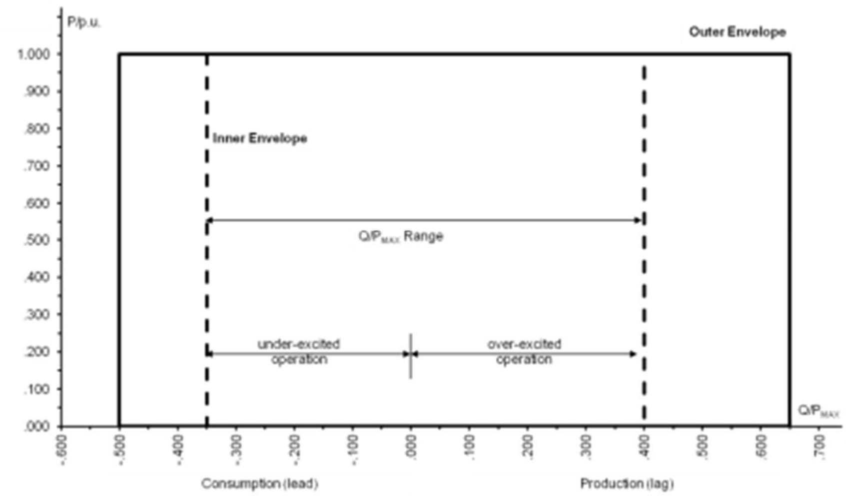

Each relevant Network operator in coordination with the TSO shall locate the inner envelope anywhere within the outer envelope and define its own P-Q/Pmax-profile within the inner envelope. Regional needs regarding reactive power capability shall be taken into (depending on the degree of network meshing, the ratio of infeed and consumption,é) and as a consequence more than one profile is appropriate when regional system characteristics vary significantly within the area of responsibility of a network operator. Moreover:

- the active power range of the P-Q/Pmax profile envelope at zero reactive power shall be 1 pu;
- the P-Q/Pmax profile can be of any shape and shall include conditions for reactive power capability at zero active power; and

When operating at an active power output below the maximum capacity (P<Pmax), the PPM shall be capable of providing reactive power at any operating point inside its P-Q/Pmax-profile, if all units of this Power Park Module, which generate power, are technically available (i.e. not out-of-service due to maintenance or failure). Otherwise the reactive power capability may be less taking into consideration the technical availabilities.

For profile shapes other than rectangular, the voltage range represents the highest and lowest values.

Further info

- Supporting documentation of RfG network code:
  - Network Code for requirements for grid connection applicable to all generators ï Justification outlines (26. June 2012)
  - Network Code for requirements for grid connection applicable to all generators ï Requirements in the context of present practices (26. June 2012)
- Other relevant documentation:
  - ñReactive Power Capability of Wind Turbines Based on Doubly Fed Induction Generatorsò Stephan Engelhardt, S.; Erlich, I.; Feltes, C.; Kretschmann, J.; Shewarega, F.; IEEE Transactions on Energy Conversion, Vol. 26, no. 1, March 2011.
  - ñReactive Power Interconnection Requirements for PV and Wind Plants ï Recommendations to NERCò, Sandia National Laboratories; Feb.2012.

INTERDEPENDENCIES

In this NC

- Reactive power capability at maximum capacity (PPM, type C) (Article 16(3) (c)).
- Reactive power control modes of type C PPMs (Article 16 (3) (d))

	• Voltage stability requirements applicable to offshore power park modules (Article 20 (3))
In other NCs	• NC HVDC will have requirements related to reactive power capability for HVDC Converter Units and DC-connected PPMs • Demand connection Code contains requirements referring to Reactive Power exchange and control for all Transmission Connected Demand Facilities and all Transmission Connected Distribution Networks. In addition it provides for the option for a DSO to deliver an active form of reactive power control, as well the option to all users to provide demand response for reactive power. • Network Code Operational Security: Reactive Power Management and Voltage Control • Network Code Operational Planning and Scheduling: Reactive Power Ancillary Services
System characteristics	System characteristics like network topology (e.g. degree of network meshing, the use of overhead power lines or cables, etc), network loading (ratio of infeed and consumption) and the generation mix, have significant impact on the relevant parameters of the reactive power capability below maximum capacity requirement and should be taken into account reasonably by the relevant network operator when selecting them. For instance, highly meshed and/or heavily loaded networks need more lagging Reactive Power (production), whereas remote networks with modest power flows and low consumption need more leading Reactive Power (consumption) in order to keep the network voltage within the permitted range. Moreover, distributed generation generates electricity from many small energy sources, commonly Power Park Modules, which could be weakly connected to the grid in remote locations, and consequently the degree of meshing is low. In these cases, the short circuit ratio of these locations might be too low and the voltage regulation in these areas is totally necessary to prevent the voltage collapse and to allow the power flows between areas. Therefore, the provision of a wide reactive power range from Power Park Modules, as reasonable as technically feasible, is absolutely necessary from this point of view to avoid these situations. The rapid increase of renewable energy sources (RES) in many European countries results in displacement of conventional generation, which presently provides active voltage control, by Power Park Modules like wind and PV parks. Consequently, the contribution of these RES to voltage control, both at transmission and distribution network, is crucial in cases of high RES penetration. If Power Park Modules do not provide reactive power sufficiently, managing grid voltage would be jeopardized. In this context it needs to be noted, that inverters may provide capabilities of reactive power supply similar to synchronous generators. The abovementioned system characteristics have significant impact on the reactive power requirement definition and should be taken into account properly when further specifying such capability. They have in common, that they cannot be described by long-term fixed values, but could vary as a result of changes to the system, both to topology and network and user technologies. Hence, assumptions of future developments need to be made and the parameters selected for exhaustively specifying reactive power capability below maximum capacity profile need to have margins to allow for maintaining the capability on a long-term basis.
Technology characteristics	It is clear that the area of the inner envelope of the P-Q/Pmax profile allows the selection of different profile shapes, but periods of low wind or solar resource have to be considered, as some generators in the Power Park Module may be disconnected from the grid in these circumstances, and therefore the reactive power capability may be reduced. This should be taken into consideration when specifying reactive power capability for variable generation plants. Below a certain output level, it is possible to specify a reduced power factor range or a permissive MVAr range and this can be implemented in the diagram by means of e.g. a triangular shape. Moreover, if there is a need of reactive power provision at zero active power in a certain area, it can also be taken into account in the shape of the diagram. Reactive power requirements are specified at the connection point. This means that several technical options can be considered in the Power Park Module design to meet connection requirements. Technically, a plant with inverter-based wind or solar generators could rely on the inverters to provide part or all the necessary reactive power range at the connection point. Another option may be the use of external devices at Power Park Module level, such as FACTs. The additional amount of reactive support required depends on the reactive capability of individual wind generators of PV

	inverters and how it is utilized. Doubly fed and full-converter wind generators are often provided by the manufacturers with a ñtriangular,ò ñrectangular,ò or ñD shapeò reactive capability characteristic as the shape of the inner envelope. Machines with a ñrectangularò or ñD-shapedò reactive capability characteristic may be employed to provide voltage regulation service when they are not producing active power (e.g., a low-wind-speed condition for a wind resource or at night for a PV resource, or during a curtailment) by operation as an STATCOM (zero active power mode). However, this capability may not be available or may not be enabled by default. Unlike doubly fed or full-converter wind turbine generators, induction-based wind generators without converters are unable to control reactive power. Under steady-state conditions, they absorb reactive power just like any other induction machine. For this kind of generators, additional reactive power devices (inductors/capacitors, é) will be needed.
COORDINATION	
TSO – TSO	TSO ï TSO coordination is recommended on the definition of the P-Q/Pmax profile concerning adjacent Power Park Modules in different control areas and within the same interconnected synchronous area. Such coordination should aim at ensuring that voltage regulation in the control area of the adjacent TSO is balanced and not only achieved by the Power Park Modules of one TSO. Although the voltage is a local variable, normally this coordination between adjacent TSOs is not critical, however, in the case of electrical areas shared by more than one TSO, that are prone to voltage instability, this coordination in the definition of this technical requirement is recommended.
TSO – DSO	Coordination between TSO and DSO is paramount DSO-connected power generating modules when determining the P-Q/Pmax profile of the Power Park Modules. This coordination will be executed under article 4(3) provisions.
RNO – Grid User	Coordination is implicitly established by the network code (not on a case-by-case basis, but on generation technology level), because the definition of the P-Q/Pmax profile should take into consideration technology-specific characteristics and constraints.

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