European Network of
Transmission System Operators
for Electricity

Parameters related to frequency stability

ENTSO-E guidance document for national implementation for network codes on grid connection

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DESCRIPTION	
Code(s) & Article(s)	NCs RfG, DCC and HVDC All articles with non exhaustive requirements for which a national choice is requested for frequency (see tables per code below)
Introduction	The objective of this guidance document is provide general but more detailed guidance on a cluster of parameters related to frequency stability issues and to give a framework to define the related non-exhaustive technical requirements . This guidance also seeks to ensure consistency between the requirements for generators, HVDC links and demand facilities in order to ensure voltage stability or recovery. As such this guidance document should be viewed in conjunction with the general guidance on non-exhaustive requirements and more specific IGDs on these issues. This guidance should help to determine the main criteria/motivation for the definition at national level of these non-exhaustive requirements. For each NC, the precise lists of the non-exhaustive frequency parameters which will need a national choice are provided. Frequency parameters set out both the withstand capability range of the equipment and the frequency response capabilities for all grid users (generators, DR) and the network (HVDC converters). The withstand capabilities ensure the range of frequencies that can be expected, both in normal (only continuous range) and abnormal (time bounded frequencies, and the rate of change) situations. The frequency response requirements and parameters provide a range of interlocking response capabilities in power production, absorption or transfer from the users and HVDC circuits, to a change in frequency on the network. These are designed to provide corrective responses to these variations to attempt to limit the frequency deviation from the nominal value.
NC frame	These non-exhaustive topics are those for which the European level CNCs do not contain all the information or parameters necessary to apply the requirements immediately. These requirements are typically described in the CNC as “TSO / relevant system operator shall define” or “defined by / determined by / in coordination with the TSO / relevant TSO”. Some of them need a choice at national level, but for frequency this normally requires a system wide response and therefore collaboration will be necessary. See tables below.

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Further info	IGD ROCOF withstand IGD Active power recovery IGD Need for synthetic Inertia IGD Special issues for type A

INTERDEPENDENCIES

Between the CNCs	Response to frequency variations requires a coordinated response from all parts of a synchronous network and all users who provide frequency response. These responses may be time bounded based, due to the time period that the user can continue to provide their response to a frequency variation. Therefore in order to restore the frequency to nominal a number of users providing frequency response may be required sequentially over time to provide response until nominal frequency is restored. Therefore there must be a coordinated frequency response across the network extending to not only the different interconnected countries, but across the interconnected network within the country i.e. DSOs, CDSOs and the users themselves. Also there must be collaboration between all of these parties as we move typically from: • an early response (i.e. FSM, DSR SFC) even to small frequency variation to, • a response (i.e. LFSM, APC, RPC) to larger frequency variation, and; • Finally a last response (LFDD) as last response to avoid network collapse Additionally, for larger frequency deviations an Inertial Response (typically (0-2 sec) may also be required. As each type of user, generator, demand and HVDC circuits can provide these responses all the codes have some frequency response requirements, which have been determined reflecting consultation with manufacturers on their equipment's capabilities. It should be noted that these frequency response capabilities are only possible if the user remains connected post an incident on the network. In this context the non-exhaustive parameter selection for ROCOF withstand capability, frequency ranges generally, and notably fault ride through capability and maximum power capability with falling frequency for generators all need to be aligned. Failure to do so risks the frequency response strategy for the network failing to work.
In other NCs	There are many links nationally to the implementation of the codes applying the connection capabilities in both system and market operation (SOC and MC topics). In some cases these topics will need to be contained in combined documents at a national level (e.g. broader content Grid Codes). Consistency needs to be maintained in these cases, i.e. it needs to be ensured that national connection code frequency capabilities are actually defined so that the settings that need to be applied can be developed through system and market operation codes.

System characteristics	With regard to frequency response the speed and scale of the change in power production/absorption or power transfer will be highly dependent on the size of the synchronous system and the largest loss of either power production/absorption that can occur. Therefore in the context of small synchronous area, such as Ireland or GB, a single loss of a generator or HVDC interconnector can result in a change in system frequency that is markedly greater than what could be in CE synchronous network. This leads naturally to the need for a faster response and/or larger response to a frequency change in smaller Synchronous Areas than in Continental Europe to arrest a change in frequency and restore the nominal frequency. In alignment with this, if the frequency response cannot be sufficiently fast or scaled then a wider withstand capability will be required i.e. frequency ranges and ROCOF capability. Similarly the generation, DR and HVDC circuit portfolio has a major contributory impact as newer renewable generators provide lower inertia. Therefore for higher renewable levels the greater the need for frequency response and/or synthetic inertia. This will also have a significant influence on the capability set by system operators for these requirements. As each system operator may influence the choices of another within a synchronous area there must be collaboration within a synchronous area in terms of criteria to be considered at national level. Notably the already planned introduction of over 20,000km of HVDC links principally as additional interconnection in the Ten Year Network Development Plan will make interaction between synchronous areas vitally important. These links will predominately be compliant with the network code HVDC. Hence selection of frequency response parameters should reflect not only their immediate use but also their in future use. In future it can reasonably be expected that as a primary source of frequency regulation the full rated capability of HVDC circuits will be used and therefore any future HVDC links should be carefully considered to ensure they have the capability to do so. As interconnection increases towards European Union targets so will the effective links between synchronous areas acting increasingly as one synchronous area. Therefore the frequency response capability specified for HVDC links should also consider all forms of response across all time periods from very fast responses, i.e. system inertia, to restoration reserves.
Technology characteristics	Frequency response capabilities, and withstand capabilities requirements will vary between technologies.

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All plant and equipment that is controllable, has a limitation imposed by its ability to respond to a frequency variation. However the specified speed for operation of these control systems could normally be standardized independent of technology.

Although a technological limitation will need to be reflective on requirements for inverter connected generators/demand on the period they can alter their power production/transfer/consumption behind the inverter, the frequency range and ROCOF can be standardized.

As frequency response of synchronous rotating plant is dictated by the physical ability to change either the shaft speed or the electrical fields within the plant, there is a limitation on the ability to make these changes post a controlled actioned has been initiated.

As many of the networks code requirements are effectively interacting on the stresses placed on machines (i.e. from the loss of functionality of ancillary pumps, compressors, etc due to falling frequency) the selected non-exhaustive frequency response parameters must also consider the combined impact on users.

Manufacturers have responded in consultation that their plant and equipment is being challenged by some of the requirements or their combined effect in the codes including frequency response capabilities. There are real and costly changes that can occur following parameter selection that must be considered but experience has also shown that often real and manageable concerns from users can be overcome.

Consultation around non-exhaustive parameter selection is therefore essential with stakeholders. Industry concerns expressed at the time and since with regard to the loss of control stability and hence GT/CCGT units has proven not to be the case for more than 10 years.

COLLABORATION

TSO – TSO	Frequency non-exhaustive requirements as defined in RfG Art. 13(2)(a) and 15(2)(e), in DCC Art. 29(2)(e) (g) and 37(5) and in HVDC Art. 13(3) and 17(2) require co-ordination while collaboration and information sharing is recommended between TSOs in terms of criteria to be considered for the national implementation
TSO – DSO	Frequency non-exhaustive requirements require co-ordination between the TSO and DSO to ensure they meet the functional requirements in the Connection Network Codes. These are identifed in the Tables 1 to 3.
RSO – Grid User	Frequency non-exhaustive requirements require co-ordination between the RSO and end user to ensure they meet the functional requirements in the Connection Network Codes. These are identifed in the Tables 1 to 3.

Abbreviations			
APC	Active Power Control	**LFDD**	Low Frequency Demand Disconnection

CDSO	Closed Distribution System Operator	**LFSM**	Limited Frequency Sensitivity Mode
CDS	Closed Distribution System	**PGFO**	Power Generating Facility Owner
DCC	Demand Connection Code	**PGM**	Power Generating Module
DF	Demand Facility	**PPM**	Power Park Module
DR	Demand Response	**RfG**	Requirements for Generators
DU	Demand Unit	**ROCOF**	Rate Of Change Of Frequency
DSO	Distribution System Operator	**RPC**	Reactive Power Control
FSM	Frequency Sensitivity Mode	**RSO**	Regional System Operator
HVDC	High Voltage Direct Current	**SFC**	System Frequency Control
IGD	Implementation Guidance Document	**TSO**	Transmission System Operator

Table 1 – RfG Non-Exhaustive Requirements

Non-Exhaustive Requirement	Non-Mandatory Requirement	Article	Applicability	Parameters to be defined	Definition
FREQUENCY RANGES		13.1.a.(i)	A, B, C, D	Time period for operation in the frequency ranges **Continental Europe** 47.5 - 48.5 Hz and 48.5 - 49 Hz **Nordic**:48.5 - 49 Hz **GB:**48.5 - 49 Hz **Ireland:**48.5 - 49 Hz **Baltic:** 47.5 - 48.5 Hz and 48.5 - 49 Hz and 51 - 51,5 Hz	TSO
	X	13.1.a.(ii)	A, B, C, D	Agreement on wider frequency ranges, longer minimum times for operation or specific requirements for combined frequency and voltage deviations	agreement between the RSO (DSO or TSO), in coordination with the TSO, and the PGFO
ROCOF WITHSTAND CAPABILITY		13.1.(b)	A, B, C, D	- Maximum ROCOF for which the PGM shall stay connected	TSO
				specify ROCOF of the loss of main protection	RSO in coordination with the TSO
LFSM-O		13.2.(a)	A, B, C, D	Frequency threshold and droop settings	TSO
					TSO
	X			Requirements in case of expected compliance on an aggregate level	TSO
	X	13.2(b)	A	Use of automatic disconnection and reconnection	TSO
	X	13.2.e	A, B, C, D	Expected behaviour of the PGM once the minimum regulating level is reached	TSO
ADMISSIBLE ACTIVE POWER REDUCTION FROM MAXIMUM OUTPUT WITH FALLING FREQUENCY		13.4	A, B, C, D	Admissible active power reduction from maximum output with falling frequency	TSO
		13.5	A, B, C, D	definition of the ambient conditions applicable when defining the admissible active power reduction and take account of the technical capabilities of power-generating modules	TSO
LOGIC INTERFACE	X	13.6	A, B, C, D	Requirements for the additional equipment necessary to allow active power output to be remotely operable	RSO
AUTOMATIC CONNECTION TO THE NETWORK		13.7	A, B, C, D	Conditions for automatic connection to the network, including: - frequency ranges and corresponding delay time - Maximum admissible gradient of increase in active power output	TSO
LOGIC INTERFACE	X	14.2.b	B, C, D	Requirements for the equipment necessary to make the logic interface (to cease active power output) remotely operable	RSO

Non-Exhaustive Requirement	Non-Mandatory Requirement	Article	Applicability	Parameters to be defined	Definition
FREQUENCY STABILITY		15.2.(a)	B, C, D	Time period for reaching x% of the target output	TSO
LFSM-U		15.2.c	C, D	Definition of the frequency threshold and droop	TSO
			C, D	Definition of Pref	TSO
FREQUENCY SENSITIVE MODE		15.2.d.(i)	C, D	Parameters of the FSM: - Active power range related to maximum capacity - Frequency response insensitivity - Frequency response dead band - Droop	TSO
		15.2.d.(iii)	C, D	Maximum admissible full activation time	TSO
		15.2.d.(iv)	C, D	Maximum admissible initial delay for power generating modules with inertia	TSO
	X	15.2.d.(iv)	C, D	Maximum admissible initial delay for power generating modules without inertia	TSO
		15.2.d.(v)	C, D	time period for the provision of full active power frequency response	TSO
FREQUENCY RESTORATION CONTROL		15.2.e	C, D	Specifications of the Frequency Restoration Control	TSO
REAL-TIME MONITORING OF FSM		15.2.g	C, D	List of the necessary data which will be sent in real time	RSO (DSO or TSO) or TSO
	X			definition of additional signals	RSO (DSO or TSO) or TSO
RATES OF CHANGE OF ACTIVE POWER OUTPUT		15.6.e	C, D	Definition of the minimum and maximum limits on rates of change of active power output (ramping limits) in both an up and down direction, taking into consideration the specific characteristics of the prime mover technology	RSO in coordination with the TSO
SYNTHETIC INERTIA CAPABILITY FOR PPM	X	21.2	PPM: C, D	- Definition of the operating principle of control systems to provide synthetic inertia and the related performance parameters	TSO

Table 2 – DCC Non-Exhaustive Requirements

Non-Exhaustive Requirement	Non-Mandatory Requirement	Article	Applicability	Parameters to be defined	Definition
FREQUENCY RANGES		12.1	Transmission Connected DF and DSO	Time period for operation in the frequency ranges **Continental Europe** 47.5 - 48.5 Hz and 48.5 - 49 Hz **Nordic**:48.5 - 49 Hz **GB:**48.5 - 49 Hz **Ireland:**48.5 - 49 Hz **Baltic:** 47.5 - 48.5 Hz and 48.5 - 49 Hz and 51 - 51,5 Hz	TSO
	X	12.2	Transmission Connected DF and DSO	Agreement on wider frequency ranges, longer minimum times for operation	agreement between the DSO, TCDF and the TSO
	X	29.2 (a)	DF and CDS offering DR	definition of a extended frequency range	agreement between TSO and TC DSO or TC DF
DEMAND RESPONSE SFC	**X**	29.2 (c)	DU offering DR	for DU connected below 110 kV: definition of the normal operating range	RSO
	X	29.2 (c)	DU offering DR	definition of the allowed frequency dead band	TSO, in consultation with the TSO of the synchronous area
	X	29.2 (e)	DU offering DR	definition of the frequency range for DR SFC and definition of the maximum frequency deviation to respond	TSO, in consultation with the TSO of the synchronous area
	X	21.2 (g)	DU offering DR	definition of the rapid detection and response to frequency system changes	TSO, in consultation with the TSO of the synchronous area

Table 3 – HVDC Non-Exhaustive Requirements

Non-Exhaustive Requirement	Non-Mandatory Requirement	Article	Applicability	Parameters to be defined	Definition
FREQUENCY RANGES		11.1	HVDC System	Time period for operation in the frequency ranges **Continental Europe** 47.5 - 48.5 Hz and 48.5 - 49 Hz **Nordic**:48.5 - 49 Hz **GB:**48.5 - 49 Hz **Ireland:**48.5 - 49 Hz **Baltic:** 47.5 - 48.5 Hz and 48.5 - 49 Hz and 51 - 51,5 Hz	RSO
WIDER FREQUENCY RANGES	**X**	11.2	HVDC System	Agreement on wider frequency ranges, longer minimum times for operation	Agreement between TSO and HVDC System Operator
AUTOMATIC DISCONNECTION		11.3	HVDC System	Frequencies to disconnect	TSO
MAXIMUM ADMISSABLE POWER OUTPUT	**X**	11.4	HVDC System	Maximum admissible power output below 49Hz	TSO
ACTIVE POWER CONTROLLABILITY	**X**	13.1.(a)i	HVDC system	Maximum and minimum power step	TSO
ACTIVE POWER CONTROLLABILITY	**X**	13.1.(a)ii	HVDC System	Minimum active power transmission capacity	TSO
	X	13.1.(a)ii	HVDC System	Maximum delay	TSO
		13.1.(b)	HVDC System	Modification of transmitted active power	TSO
FAST ACTIVE POWER REVERSAL	**X**	13.1.(c)	HVDC System	Capability or not	TSO
AUTOMATIC REMEDIAL ACTIONS	**X**	13.3	HVDC system	If required, and triggering and blocking criteria	TSO
SYNTHETIC INERTIA	**X**	14.1	HVDC System	If required, and functionality	TSO
	X	14.2	HVDC System	Principle of control and performance parameters	Agreement between TSO and HVDC System Operator
FREQUENCY SENSITIVE MODE		Annex II. 3.(e)	HVDC System	Frequency threshold and droop settings	TSO
		Annex II. 3.(h)(ii)	HVDC System	Active power response capability	TSO
LFSM-O		Annex II. 4.(m)	HVDC System	Time for full activation	TSO
		Annex II. 5.	HVDC System	Frequency threshold and droop settings	TSO
LFSM-U		Annex II. 6.(q)	HVDC System	Time for full activation	TSO
		Annex II. 7.	HVDC System	Frequency threshold and droop settings	TSO
FREQUENCY CONTROL MODE	**X**	16.1	HVDC System	Need for independent control mode to modulate active power output	TSO
	X	16.1	HVDC System	Specify operating principle	TSO

Non-Exhaustive Requirement	Non-Mandatory Requirement	Article	Applicability	Parameters to be defined	Definition
MAX. LOSS OF ACTIVE POWER		17.1	HVDC System	specify limit for loss of active power injection	TSO
		17.2	HVDC System	Coordinate specified limit of active power injection	TSOs
FREQUENCY STABILITY REQUIREMENTS		39.1	HVDC System	Specify coordinated frequency control capabilities	TSO
FREQUENCY RANGES		39.2.(a)	DC-Connected Power Park Module	Nominal frequencies other than 50Hz will be provided	TSO
WIDER FREQUENCY RANGES	**X**	39.2(b)	DC-Connected Power Park Module	Agreement on wider frequency ranges, longer minimum times for operation	Agreement between TSO and HVDC System Operator
AUTOMATIC DISCONNECTION		39.2©	DC-Connected Power Park Module	Frequencies to disconnect	TSO
LFSM-O		39.4	DC connected Power Park Modules	Frequency threshold and droop settings	TSO
				For PPM: Definition of Pref	TSO
	X			Requirements in case of expected compliance on an aggregate level	TSO
	X			Expected behaviour of the PGM once the minimum regulating level is reached	TSO
CONSTANT POWER		39.5	DC-Connected Power Park Module	Specify parameters in accordance with Network Code RfG Article 13(3)	See RfG
ACTIVE POWER CONTROLLABILITY		39.6	DC-Connected Power Park Module	Specify parameters in accordance with Network Code RfG Article 15(2)(a)	See RfG
LFSM-U		39.7	DC-Connected Power Park Module	Specify parameters in accordance with Network Code RfG Article 15(2)(c)	See RfG
FSM WITH SUBJECT TO A FAST SIGNAL RESPONSE		39.8	DC-Connected Power Park Module	Specify parameters in accordance with Network Code RfG Article 15(2)(d)	See RfG
FREQUENCY RESTORATION		39.9	DC-Connected Power Park Module	Specify parameters in accordance with Network Code RfG Article 15(2)(e)	See RfG
3-9 FOR FREQUENCIES OTHER THAN 50HZ		39.10	DC connected Power Park Modules	Define the parameters capabilities in Article 39.3-39.9 for frequencies other than 50Hz	TSO
FREQUENCY RANGES		47.1	Remote-end HVDC converter stations	Nominal frequencies other than 50Hz will be provided accounting for Annex I requirements	TSO
SCOPE		38	DC connected Power Park Modules	Non-exhaustive requirements of Articles 11 to 22 of the Network Code RfG will apply	-
SCOPE		46	Remote-end HVDC converter stations	Non-exhaustive requirements of Articles 11 to 39 will apply	-

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