European Network of
Transmission System Operators
for Electricity

Frequency Sensitive Mode

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

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DESCRIPTION

Code(s) & Article(s)	• RfG, Article 15(2)(d) – Frequency Sensitive Mode • RfG, Article 15(2)(e) – Frequency Restoration
Introduction	Frequency Sensitive Mode (or 'FSM') means the operating mode of a power-generating module or HVDC system in which the active power output changes in response to a change in system frequency, in such a way that it assists with the recovery to target frequency. The objective of this guidance document is to help to determine the main criteria/motivation for the specifications of the FSM capabilities of power generating modules at national level. For adequate specifications of the relevant parameters it is essential to be aware of the objective of the FSM functions and to understand how it interacts with other frequency stability requirements. For each synchronous area, proposals for national choices for the non-exhaustive FSM parameters are provided through this IGD.
NC frame	The 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". Despite choices need to be made at national level, frequency-related issues require a similar response within the same synchronous area and therefore strict collaboration between TSOs of the same synchronous area is necessary. See also the general IGD on parameters related to frequency stability.
Further info	IGD on parameters related to frequency stability IGD on frequency ranges IGD on limited frequency sensitive mode (LFSM-O/U) IGD on admissible power reduction at low frequencies IGD on demand response system frequency control (DR SFC)

INTERDEPENDENCIES

Between the CNCs	Frequency variations require a coordinated response at synchronous area level and by all system users who provide frequency response. Therefore there must be a coordinated frequency response across the network extending to not only the different interconnected countries horizontally, but also vertically across the interconnected network within a 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, DR SFC) even to small frequency variation to, • a response (i.e. LFSM, DR SFC) to larger frequency variation, and;

	• finally a last response by low frequency demand disconnection (LFDD) to avoid network collapse
In other NCs	The System Operation Guidelines[1] (SOGL, Title 5 – esp. Article 154 and 156 and Title 6) needs to be taken into account when defining the application of FSM and frequency restoration control capabilities in system operation. Implementation of RfG requirements at national level shall ensure that technical capabilities and, where applicable, initial settings of parameters are available to cover operational needs defined through these operational guidelines.
System characteristics	A frequency deviation away from the nominal frequency results from an imbalance between generation and demand that occurs continuously during normal system operation or after an incident like a loss of generation. System frequency increases in case generation is higher than demand and decreases in case generation is lower than demand. The objective of frequency containment is to maintain the balance between generation and demand within a synchronous area. By the joint action of all interconnected parties/TSOs, it aims to stabilise the system frequency at a stationary value after such disturbance or incident in the time-frame of seconds. It depends on generation or load resources made available to the TSOs, which are called frequency containment reserves (FCR) and are in fact deployed by generators or demand units running in frequency sensitive mode (FSM). HVDC systems connecting different synchronous areas can also contribute to FCR. The objective of frequency restoration control is to restore system frequency to its nominal value and the power exchanges between control areas to their reference values. It is provided by frequency restoration reserve (FRR), deployed by generators or demand units with frequency restoration capabilities. Within a synchronous area FCR and FRR are dimensioned to cover a reference imbalance. For example, the relevant design criteria for defining the FCR amount within the Continental Europe (CE) is a load imbalance of ±3.000 MW. FCR shall be completely deployed at a deviation of ±200 mHz. According to NC RfG, FSM and frequency restoration capabilities could be provided by type C and D power generating modules (PGM) and relevant non-exhaustive parameters (NC RfG Article 15.2.d) shall be defined at national level.

[1] COMMISSION REGULATION (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation

According to NC RfG Article 15.2.d, non-exhaustive FSM parameters to be defined at national level are the following:

Active power range $\|\Delta P1\| / P_{max}$	Between 1.5 – 10%
Droop	Between 2-12%
Frequency response insensitivity $\|\Delta f_i\|$ $\|\Delta f_i\| / f_n$	Between 10 – 30 mHz Between 0.02 – 0.06%
Frequency response deadband	Between 0 – 500 mHz
Maximum initial delay of FSM activation (t_1)	SPGM : 2s (to be justified if > 2s) PPM : to be specified by the relevant TSO
Maximum delay of FSM full activation (t_2)	30 s

TABLE 1 : PARAMETERS FOR ACTIVE POWER RESPONSE IN FSM

RfG requirements shall ensure, that technical capabilities and, where applicable, initial settings of parameters are available to cover operational needs, such as FCR minimal technical requirements (SOGL Art 154).

Regarding Active power range related to maximum capacity $|\Delta P1|$ / Pref and droop :

This requirement is applicable to type C & D PGMs. There is a need to ensure that overall FCR is covered at synchronous area level (cf. synchronous area operational agreements concerning dimensioning of FCR, and SOGL Article 153). This shall not be understood as setting the same parameters for each power generating module within a synchronous area, but that each TSO defines those parameters in its control area to cover its required level of FCR.

It is recommended that each TSO shall identify and quantify critical future scenarios with low instantaneous penetration of C & D units and then defines the following **minimal requirements** to cover its required level of FCR :

- $|\Delta P1| / P_{max}$ value within the range to ensure that its FCR obligation will be mainly covered by C & D PGMs in its country (a power generating module could choose to do more than this minimal requirement).
- Droop should be calculated to be able to increase/decrease power from $|\Delta P1| / P_{max}$ for FCR full activation at a defined frequency deviation, e.g. 200 mHz for PGMs within the Continental Europe synchronous area. This is important to calculate the droop to make sure the reserve ($|\Delta P1| / P_{max}$) could be fully deployed for the synchronous area reference frequency deviation (i.e 200 mHz for CE, 500 mHz for GB)

Compliance testing shall validate that this minimal requirement is met for a FCR full activation frequency deviation.

Note : SOGL Art 156.6 states that a single power generation unit is not allowed to cover more than 5% of the FCR of a synchronous area.

At operational timescales a PGM can provide a lower/higher volume of reserve (based on market needs) with an adjustable droop to achieve full activation at the defined frequency deviation.

According to NC RfG, the FSM droop is defined as

$$s[\%] = 100 \cdot \frac{|\Delta f|}{f_n} \cdot \frac{P_{ref}}{|\Delta P|}$$

P_{ref} is the reference active power to which ΔP is related and may be specified differently for synchronous power generating modules and power park modules. ΔP is the change in active power output from the power-generating module. f_n is the nominal frequency (50 Hz) in the network, Δf is the frequency deviation in the network. At a change of frequency, the power generating module has to provide an active power output change according to the droop.

NC RfG allows for two options for defining P_{ref} for power park modules, either P_{max} or the actual active power output at the moment the FSM threshold is reached.

Regarding activation of FSM:

In the event of a frequency step response, the PGM controller should carefully manage overshoot and damping of the response aiming at avoiding unnecessary active power oscillations.

Regarding maximum admissible delay t1, Article 15(2)(d)(iv) shall be respected: "the initial activation of active power frequency response required shall not be unduly delayed. If the delay in initial activation of active power frequency response is greater than two seconds, the power- generating facility owner shall provide technical evidence demonstrating why a longer time is needed. For power-generating modules without inertia, the relevant TSO may specify a shorter time than two seconds. If the power-generating facility owner cannot meet this requirement they shall provide technical evidence demonstrating why a longer time is needed for the initial activation of active power frequency response".
It is proposed to use the widest possible technical capability of the power-generating module.

Regarding maximum full activation time t_2, default value can be proposed refering to normal operating conditions across a synchronous area. In case of forming local islands accidentally, a faster t_2 could be requested by the TSO with the purpose of facilitating an appropriate system restoration. Therefore, the generator FSM control must be designed to allow a faster response in case of local needs, taking into consideration technology specifics.

Initial delay t1	≤ 2s for SPGM ≤ 500 ms for PPM	
Response activation (full activation) t_2 default value	CE, Nordic :	30s
	GB	10s
	IE/NI	15s

TABLE 2 : DELAYS FOR ACTIVATION OF ACTIVE POWER RESPONSE IN FSM

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Regarding frequency response dead band and insensitivity:

'frequency response insensitivity' means the inherent feature of the control system specified as the minimum magnitude of change in the frequency or input signal that results in a change of output power or output signal (NC RfG, art 2 (40).
Originally, insensitivity or backlash is a lost motion in a mechanism caused by gaps between the parts (see figure below).

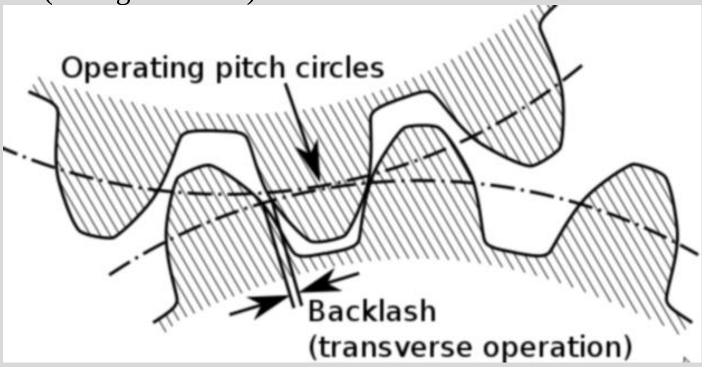

FIGURE 1 : INSENSITIVITY OR BACKLASH REPRESENTATION

It can be defined as "the maximum distance or angle through which any part of a mechanical system may be moved in one direction without applying appreciable force or motion to the next part in mechanical sequence"[2], and is a mechanical form of dead band. Today, this concept is not totally applicable because power generation modules are mainly connected through power electronics devices to the network. This process is equivalent to filter small variations of frequency and can be modelled as an active dead-band which follows frequency values (see figure below);

[2] *Bagad, V.S. (2009). Mechatronics (4th revised ed.). Pune: Technical Publications.*

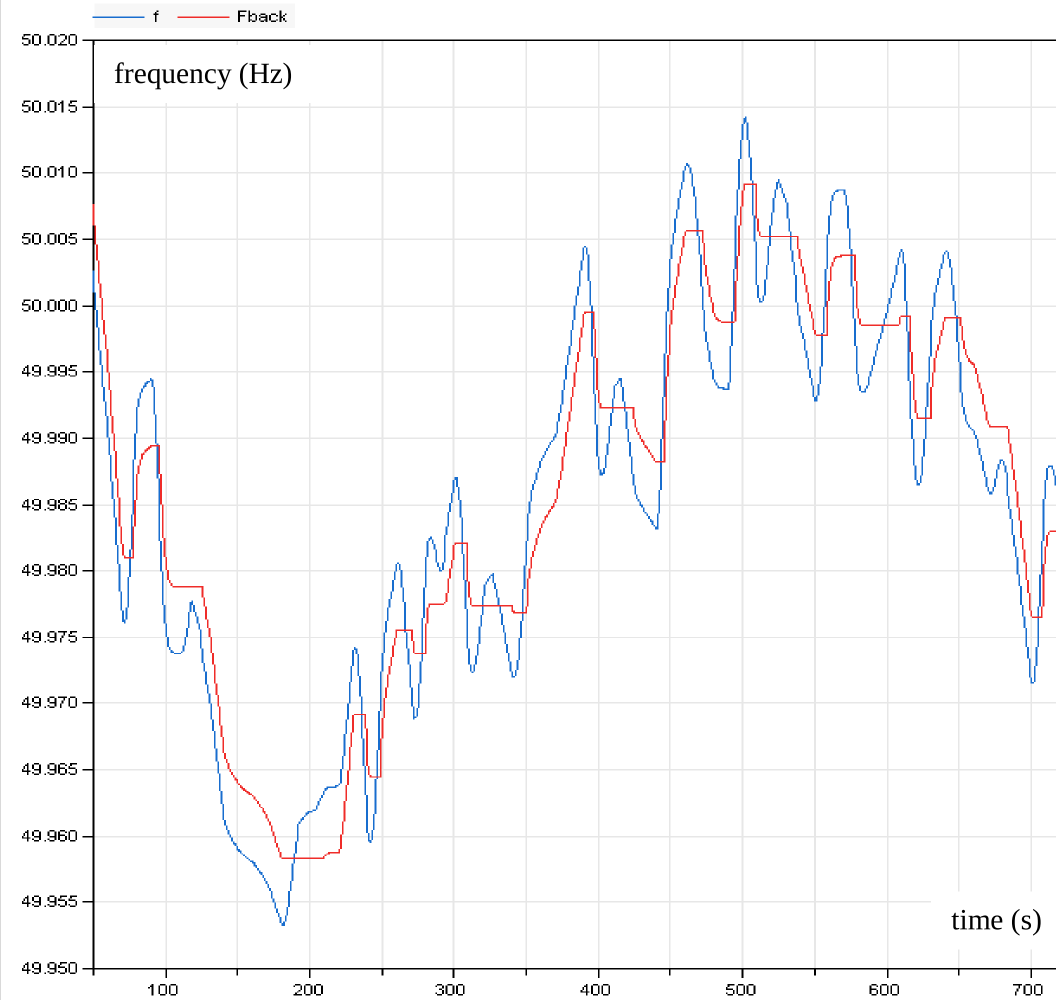

FIGURE 2 : FREQUENCY PROFILE OBSERVED WITH AN INSENSITIVITY MODELLED AS AN ACTIVE DEAD-BAND (RED CURVE)

Based on the network model of a unique generator connected to a load (self-regulation of the load assumed to be 1 %/Hz), different simulations have been performed assuming that the percentage of power generating modules having an ±10mHz-insensitivity varies from 0% to 100% to evaluate the impact of this parameter on frequency distribution. An imbalance (between supply and demand) profile is applied to the system. This profile comes from real measurement of frequency (two days of September 2016) multiplied by the minimum network power frequency characteristic of primary control for CE synchronous area (15000 MW/Hz).

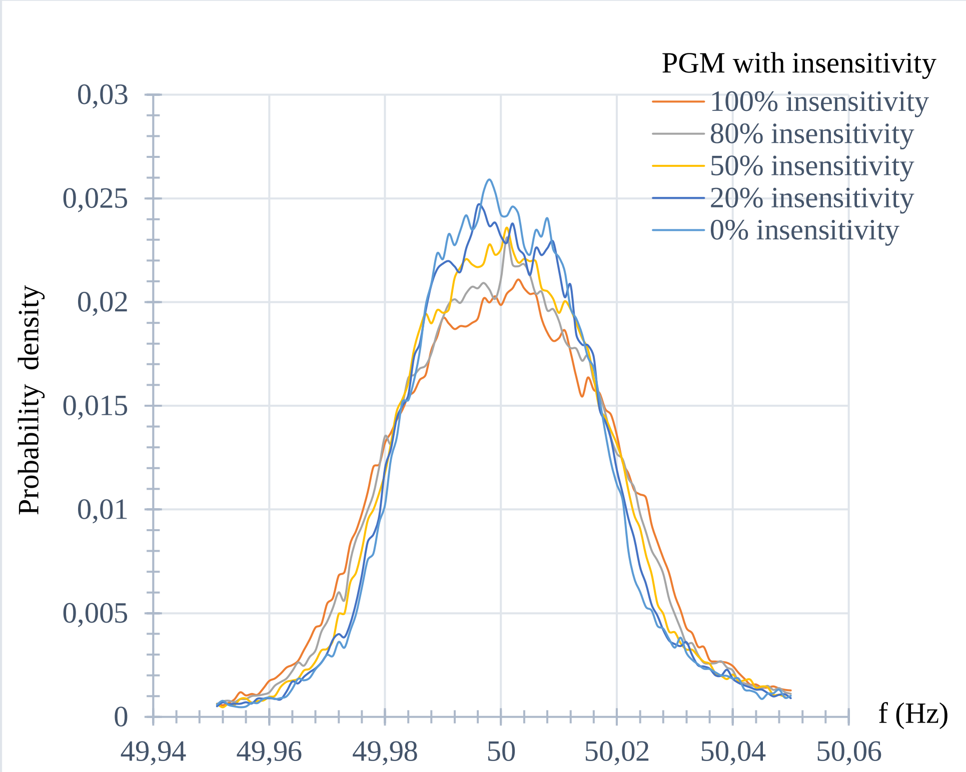

Figure 3: Probability density function of frequency as a function of share of units with +/- 10mHz insensitivity

Insensitivity allows power generating units not to react to small variations of frequency, but following the trend of frequency variation, thus there is a negligible impact on the frequency distribution, even if a large number of power generating units are concerned.

'frequency response deadband' centered at nominal frequency is adopted in governor designs to reduce excessive controller activities and turbine mechanical wear for normal power system frequency variations. Until the preset intentional deadband is reached, the turbine governor would not respond to system frequency excursion. In this paper, only the no-step-function implementation is considered because a step-function deadband implementation results in a step change in mechanical set-point and excessive stress on mechanical parts.

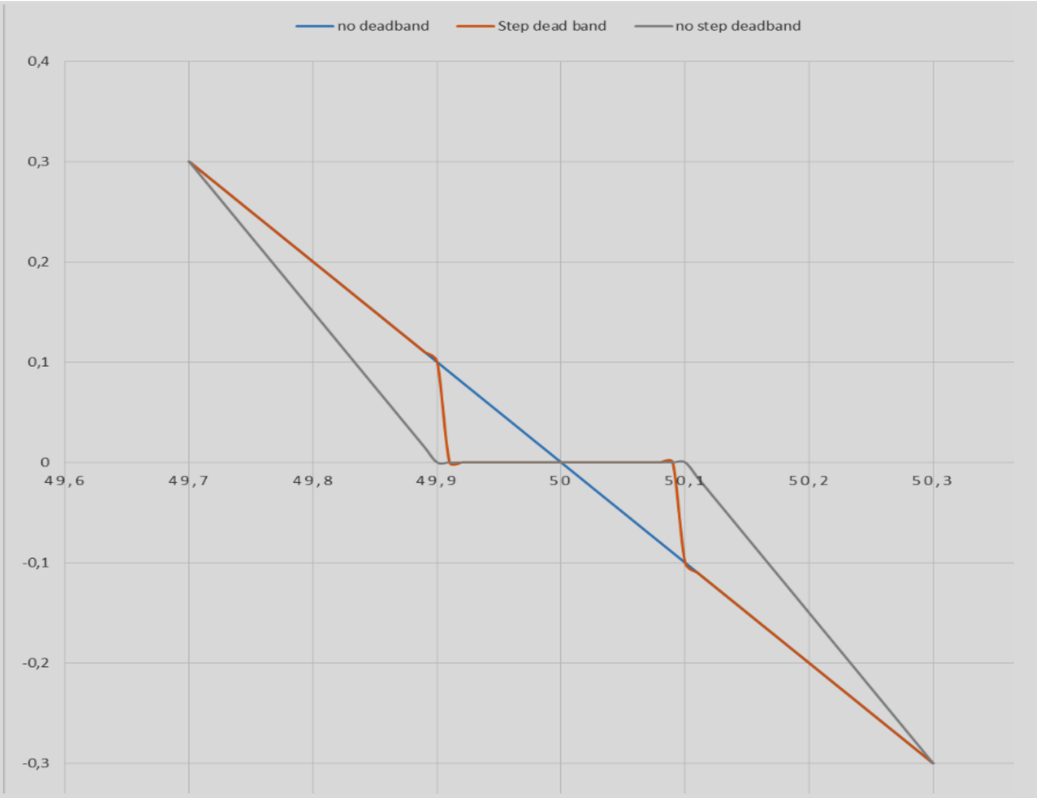

FIGURE 4 : FREQUENCY RESPONSE WITH STEP DEADBAND (ORANGE), NO-STEP DEADBAND (GREY) OR WITHOUT DEADBAND (BLUE)

Based on the same modelling, different simulations have been performed assuming that the number of power generating modules having a ±10mHz deadband varies from 0% to 100% to evaluate the impact of this parameter on frequency distribution. An imbalance (between generation and demand) profile is applied to the system. This profile comes from real measurement of frequency (two days of September 2016) multiplied by the minimum network power frequency characteristic of primary control for CE synchronous area (15000 MW/Hz).

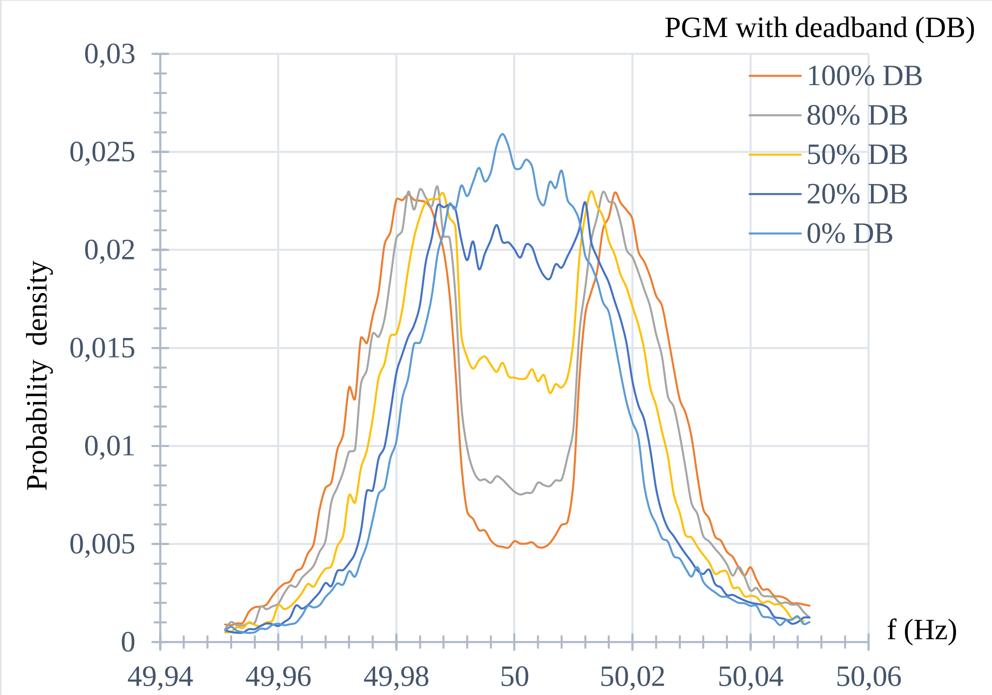

FIGURE 5 : Probability density function of frequency as a function of share of units with +/- 10mHz deadband

A deadband around nominal frequency results in power generating modules being less-sensitive to small frequency deviations centered around 50Hz. Modules with a deadband around nominal frequency do not perceive any frequency deviation within this deadband, and thus not change their active power output. As shown by the figure above, the number of power generating with a deadband should be limited to reduce the impact on the frequency distribution.

Nota : In case of a large number of power generating modules with a deadband, some power plants technologies could be impacted by mechanical constraints due to the action of switching from one side to the other side of a deadband.

Therefore, the number of power generating modules providing FCR with a deadband around nominal frequency shall be limited to not impair the objective of equal FCR provision over frequency deviation. Notwithstanding this, a deadband around nominal frequency may be used to deactivate FCR by setting it equal to the LFSM frequency thresholds.

To ensure that frequency containment is provided by all TSOs through an *equality principle*, it's recommended to harmonize those two parameters at synchronous area level.

In addition, RfG requirements should be consistent to FCR minimal technical requirements (SOGL Art 154): the maximum combined effect of inherent frequency response insensitivity and possible intentional frequency response dead band of the governor of the FCR providing units or FCR providing groups shall be 10 mHz (for Continental Europe area).

Therefore the following settings are recommended:

- Frequency response deadband: selectable value between 0 and LFSM threshold (default value, if PGM provides FCR: 0, needed to comply with SOGL FCR

	technical requirements). Setting the deadband width equal to the LFSM-O/-U thresholds is equivalent to disable the FSM mode. • Frequency response insensitivity: ≤ 10 mHz. Compliance testing shall validate that the maximum combined effect of inherent frequency response insensitivity and possible intentional frequency response dead band is ≤ 10 mHz (SOGL requirement regarding FCR providers). RfG requirements (relevant for plant design) to FRR providers RfG Art 15(2)(e) let the TSO define requirements (relevant for plant design) regarding FRR. The TSO should ensure that SOGL FRR requirements are covered.
Technology characteristics	Frequency step response can be provided by power generating modules from any active power operating point between minimum regulating level and maximum capacity, the actual delivery of active power frequency response depends on the operating and ambient conditions (see RfG, article 15.2.d.i). Wind turbines minimum regulating level shall be 10% of maximum capacity to avoid mechanical constraints or damages. On-site frequency measurement for FCR provision under FSM mode is technology-dependant. For synchronous power generating modules the rotational speed of the shaft is signaled to the speed controller, which adapts the active power output accordingly. However, power park modules (connected to the network through power electronics) need an external frequency measurement from electrical quantities (typically voltage). The performance criteria of this external frequency measurement need to be defined in particular by speed and accuracy, and a critically damped frequency measurement (e.g. as harmonic oscillator) should be the objective.
COLLABORATION	
TSO – TSO	FSM settings shall by coordinated between the control areas of a synchronous area. The main motivation is to set a coordinated activation of frequency response in case of frequency deviation, through a principle of equality and efficiency.
TSO – DSO	DSOs shall make sure, that power generating modules connected to their network will meet the FSM requirements as defined by the Relevant TSO.
RSO – Grid User	The parameter settings and the relevant rationales behind shall be presented to power generating facility owners. It shall aim at better mutual understanding of system needs vs. technical limitations of power generating modules. New power generating modules (types C and D) shall be capable of activating FSM according to the recommended ranges to establish an equitable response to frequency excursions across a synchronous area.

Abbreviations			
APC	Active Power Control	**PGM**	Power Generating Module
CDSO	Closed Distribution System Operator	**PPM**	Power Park Module
CDS	Closed Distribution System	**RfG**	Requirements for Generators
DSO	Distribution System Operator	**ROCOF**	Rate Of Change Of Frequency
FSM	Frequency Sensitivity Mode	**RPC**	Reactive Power Control
FCR	Frequency Containment Reserve	**RSO**	Relevant System Operator
FRR	Frequency Restoration Reserve	**SFC**	System Frequency Control
IGD	Implementation Guidance Document	**SOGL**	System Operation Guidelines
LFDD	Low Frequency Demand Disconnection	**SPGM**	Synchronous Power Generating Module
LFSM	Limited Frequency Sensitivity Mode (-O: Overfrequency, -U: underfrequency)	**TSO**	Transmission System Operator