PREQUALIFICATION DOCUMENT

PREQUALIFICATION OF FCR-N AND FCR-D

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Definitions

Activated capacity	Part of the active power output caused by FCR activation
AEM	Alert state Energy Management mode
aFRR	Automatic Frequency Restoration Reserve
Backlash	General denotation of mechanical dead-band / insensitivities
Baseline	Part of the active power output that does not include FCR activation
Connection Point	The interface at which the providing entity is connected to a transmission system, or distribution system, as identified in the connection agreement
Controller parameter set	A set of preselected parameter values, selectable with a single signal, e.g. a certain parameter set for island operation and another one for FCR-N
Droop	The ratio of a steady-state change of frequency to the resulting steady-state change in active power output, expressed in percentage terms. The change in frequency is expressed as a ratio to nominal frequency and the change in active power expressed as a ratio to maximum power. Low droop: Highest regulating strength/gain. Very “aggressive” power output change to frequency change. High droop is vice versa.
ENTSO-E	European Network of Transmission System Operators for Electricity
FCP	Frequency Containment Process
FCR	Frequency Containment Reserve
FCR-D	Frequency Containment Reserve for Disturbances
FCR-N	Frequency Containment Reserve for Normal operation
FCR-X	FCR-X is used in common term and can be read as FCR-N, FCR-D upwards or FCR-D downwards
FCR provider	Legal entity providing FCR services from at least one FCR providing unit or group
LER	Limited Energy Reservoir, FCR providing entity with limited activation endurance
Maintained capacity	The amount of prequalified reserve in MW that will be utilized at full activation, FCR-N 50±0.1Hz, at 49.5 Hz for FCR-D upwards, and at 50.5 Hz for FCR-D downwards
Nadir frequency	Low frequency event
NEM	Normal state Energy Management mode
Prequalification	Prequalification means the process to verify the compliance of an FCR providing unit or an FCR providing group with the requirements set by the *Technical Requirements for Frequency Containment Reserve Provision in the Nordic Synchronous Area* and national terms and conditions.
Providing entity	FCR Providing Unit or FCR Providing Group
Providing group	FCR Providing Group means an aggregation of Power Generating Modules, Demand Entities and/or Reserve Providing Units and/or Energy storages connected to more than one Connection Point fulfilling the requirements for FCR

Providing unit	FCR Providing Unit means a single or an aggregation of Power Generating Modules and/or Demand Entities and/or Energy storages connected to a common Connection Point fulfilling the requirements for FCR
SOC	State of Charge (of e.g. a battery)
TSO	Transmission System Operator
Zenit frequency	High frequency event

1. Introduction and purpose of the document

In this document, requirements, and mandatory test for frequency containment reserves in DK2, FCR-N and FCR-D, are presented. The technical requirements for FCR-N and FCR-D have been revised and updated as the Nordic TSOs identified a need to secure the stability of the Nordic electricity system, as the green transition has accelerated in the last decade. This document is based on the Nordic proposal on *additional properties for FCR*, which was approved on the 3rd of April 2023. The document must be seen as the national counterpart to the common Nordic prequalification document, *Technical Requirements for Frequency Containment Reserve Provision in the Nordic Synchronous Area*. The requirements will enter into force in Denmark on the 1st of September 2023. Until then, it is on a voluntary ground to be prequalified on the new requirements.

As the technical requirements explained in this document will not enter into force before the 1st of September 2023, they are kept in a separate document. When the requirements enter into force, they will be included in the original prequalification document.

This document does not only state the new technical requirements, but also the needed tests to prove that a unit fulfills the requirements. The Nordic TSOs have in collaboration developed an IT-tool, which are to be used during the prequalification process, to evaluate the capabilities of the units. The IT-tool ensures Nordic harmonization of the requirements and the prequalification. The IT-tool is still under development and the Nordic TSOs reserves the right to make updates when it is seen fit. The TSOs welcome any inputs from the providers to further develop the IT-tool during the implementation phase.

In addition, Energinet has developed an Excel file that helps the applicants create the required test sequences explained in this document.

2. Test of FCR-D in DK2

This section describes the fundamental requirements for FCR-D and required ancillary services tests to be done before the unit can be used in the market.

FCR-D is split into two distinct subtypes, namely FCR-D dynamic and FCR-D static. Table 1 designates what tests to perform (and read more about), dependent on the specific FCR-D product type.

The FCR-D Dynamic is a product that is able to activate FCR-D in a droop based manner, and the entity is tested that their response has a high stability. For the entities that have difficulties to comply with the dynamic requirements, e.g., activation/deactivation performance and dynamic stability can provide a variant of FCR-D called *Static FCR-D*. The main difference from dynamic FCR-D is a grace period of maximum 15 minutes where the entities must be deactivated and ready to perform another activation within. Non-continuous FCR is where the response is step based and continuous has no steps.

PRODUCT \ TESTS	**FAST RAMP TEST**	**SINE RESPONSE TEST**	**RAMP STATIC TEST**	**LINEARITY TEST**
FCR-D DYNAMIC *CONTINUOUS*	√	√		
FCR-D DYNAMIC *NON-CONTINUOUS*	√	√		√
FCR-D STATIC *CONTINUOUS/NON-CONTINUOUS*			√	√
SPECIFIC SECTION FOR CLARIFICATION	Section 2.1	Section 2.2	Section 2.3	Section 2.4

Table 1 *Tests to perform for each FCR-D product. An "√" indicates a match between a specific product and test.*

To initialize the prequalification process for approval of FCR-D delivery, several tests must be performed. FCR-D dynamic and FCR-D static require different tests and incorporate different requirements to fulfill. The subsequent sections outline describe the necessary tests to perform.

2.1 Fast ramp test sequence

The fast ramp test shall be performed for all FCR-D dynamic providing entities. The purpose of the test is to investigate the steady state response, endurance and time domain dynamic performance of the FCR-D providing entity. The test is executed by performing a series of frequency input ramp signals at specific time instances, as outlined in Table 2. The fast ramp test shall be performed at four operational conditions, thus high load & low droop, high load & high droop, low load & low droop and low load & high droop, unless the provider can prove that the unit is not affected by this change. The endurance testing for non-LER units is performed at the most challenging operational condition. Endurance and energy management of entities with LER is unfolded in Section 5. Figure 1 and Figure 2 illustrate the test sequence for downregulation and upregulation, respectively.

RAMP NUMBER	FREQUENCY FCR-D UP/DOWN [HZ]	START TIME [S]	END TIME, RAMP [S]	END TIME [S]	TEST DURATION [S]	COMMENTS
0	49.9/50.1	0	0	30	30	No activation for the first 30 seconds. Thus, ΔP_{ss} should be equal to 0 MW.
1	49.45/50.55	30	33.1	34.9	4.9	Activation performance test 1.
2	49.9/50.1	34.9	39.9	90	55.1	Deactivation test 1.
3	49.5/50.5	90	91.7	390	300/900*	The steady-state response is fully activated ($\Delta P_{ss} = \max[kW]$). *For non-LER units, the test duration is 900 seconds when testing the endurance.
4	49.9/50.1	390	391.7	690	Minimum 300	The steady-state response must be at zero activation ($\Delta P_{ss} = 0\ [kW]$)
5	49/51	690	693.8	750	60	Activation performance test 2. Frequency deviation of +/- 1000 [mHz] induce a full activation.
6	50/50	750	754.2	1050	300	Deactivation test 2.
7	49.8/50.2	1050	1050.8	1350	300	Shall only be performed if FCR-N and FCR-D co-delivery is desired.
8	49.89/50.11	1350	1350.4	1650	300	Shall only be performed if FCR-N and FCR-D co-delivery is desired.

***Table 2** FCR-D dynamic up- and downwards fast ramp test. Ramp speed must maximum be 0.24 Hz/s.*

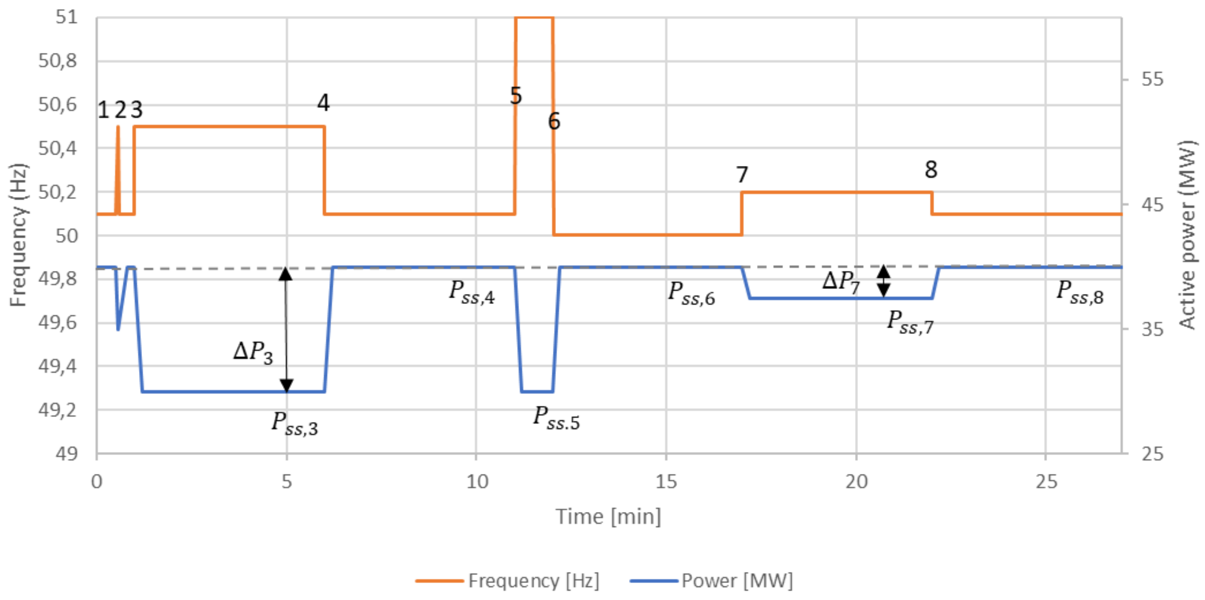


***Figure 1** FCR-D dynamic downwards fast ramp test. FCR-N is omitted in this illustration.*

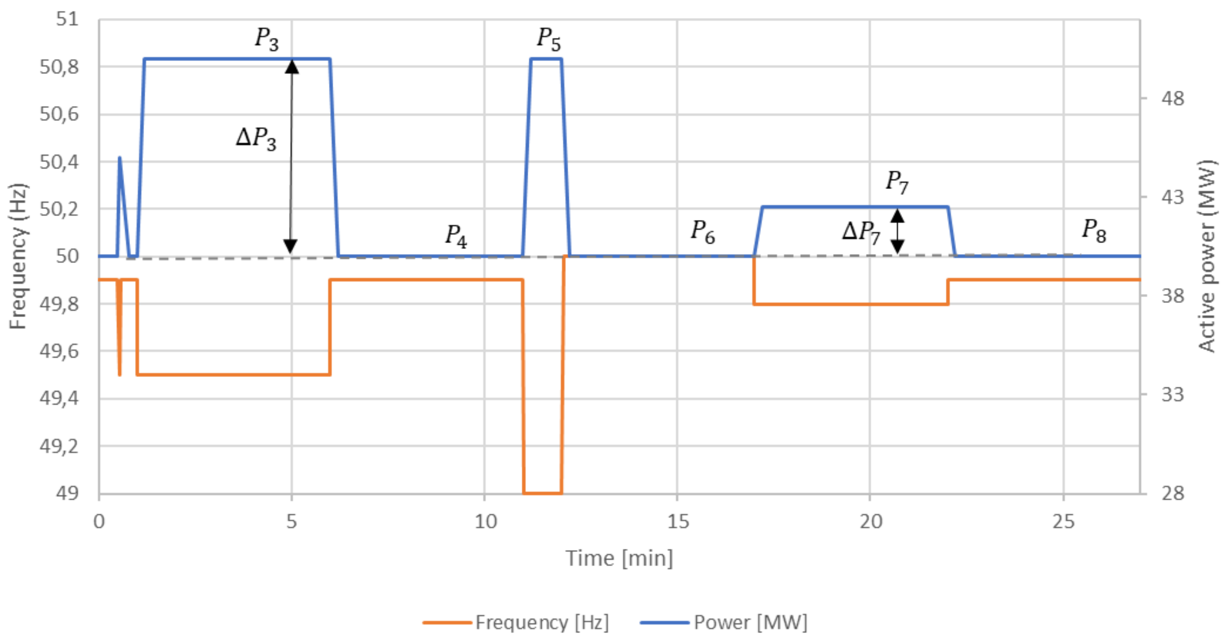


***Figure 2** FCR-D dynamic upwards fast ramp test. FCR-N is omitted in this illustration.*

Table 3 shows the necessary requirements to fulfill during the fast ramp test sequence. It is designated in the table for which ramps the specific requirements are valid for.

REQ. NUMBER	RAMP NUMBER	REQUIREMENT SPECIFICATION (DESCRIPTIVE)	REQUIREMENT SPECIFICATION (MATHEMATICALLY)
1	At any ramp	The steady state response of FCR-D is calculated as the difference between the steady state response of ramp 3 (ending at 49.5 Hz for FCR-D upwards and 50.5 Hz for FCR-D downwards) and ramp 4 (ending at 49.9 Hz for FCR-D upwards and 50.1 Hz for FCR-D downwards). The steady state response must not differ more than 5 % from the theoretical steady state response in the direction of under-delivery and 20 % in the direction of over-delivery.	Upwards direction: $-0.05 \le \frac{P_{ss,3} - P_{ss,4} - \lvert\Delta P_{ss,theoretical}\rvert}{\lvert\Delta P_{ss,theoretical}\rvert} \le 0.2$ Downwards direction: $-0.2 \le \frac{P_{ss,3} - P_{ss,4} + \lvert\Delta P_{ss,theoretical}\rvert}{\lvert\Delta P_{ss,theoretical}\rvert} \le 0.05$
2	Ramp 5 (see Figure 3)	The actual steady-state power response ($\lvert\Delta P_{7.5s}\rvert$) shall 7.5 seconds after initialization of the activation (due to frequency drop/increase to 49.0/51.0 [Hz]), being able to deliver minimum 86% of the theoretical steady state response ($\lvert\Delta P_{ss,theoretical}\rvert$). The activated power shall not be decreased below the power at 7.5 seconds at any point in time until start of ramp 6 (back to 50.0 Hz).	$\lvert\Delta P_{7.5s}\rvert \ge 0.86 * \lvert\Delta P_{ss,theoretical}\rvert$ $\lvert\Delta P_{7.5s\to 60s}\rvert \ge \lvert\Delta P_{7.5s}\rvert$
3	Ramp 5	The supplied energy must from the start of the ramp to 7.5 seconds after the start of the ramp, be equivalent to minimum 3.2 seconds multiplied with the theoretical steady state response.	$\lvert E_{7.5s}\rvert \ge 3.2\text{s} * \lvert\Delta P_{ss,theoretical}\rvert$
4	Ramp 1 & 2 (see Figure 4)	A low (nadir)/high (zenit) frequency event occurs 4.4 seconds after the start of ramp 1. The requirement for deactivation in ramp 2 is that the energy exceeding the power delivered at the time of nadir or half of the steady state response for full activation must not exceed 1.7	Upwards direction: $\max_{k=t_{nadir}\to t_{nadir+40}} \int_{t_{nadir}}^{t=k} \left(\Delta P(t) - \min\left(\lvert\Delta P_{nadir}\rvert, 0.5 \cdot \lvert\Delta P_{ss,theo}\rvert\right)\right) dt \le 1.7 \cdot \lvert\Delta P_{ss,theo}\rvert$

	times the steady state response for full activation at any time after the nadir (evaluated for at least 40 seconds). Thus, this requirement is implemented to ensure that the energy overshoot is limited in the event of a significant frequency deviation.	Downwards direction: $\max_{k=t_{zenith}\to t_{zenith+40}} \int_{t_{zenith}}^{t=k} \left(-\Delta P(t) - \min\left(\lvert\Delta P_{zenith}\rvert, 0.5\cdot \lvert\Delta P_{ss,theo}\rvert\right)\right) dt \le 1.7 \cdot \lvert\Delta P_{ss,theo}\rvert$

Table 3 *Requirements associated to the conduction of the fast ramp test for dynamic FCR-D, as outlined in Table 2.*

Figure 3 unfolds requirement number 2 and 3, and Figure 4 visually describes requirement number 4. Table 4 contains explanations for each of the utilized variable/parameter names.

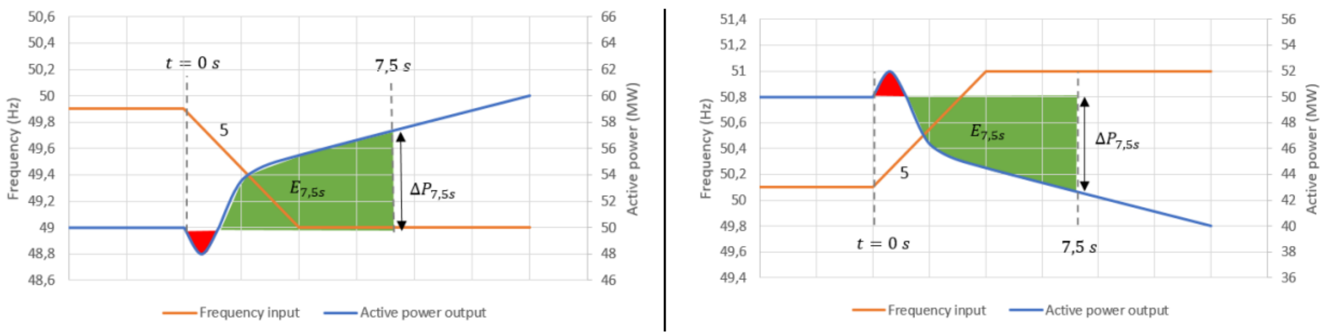


Figure 3 *Dynamic performance requirements on ramp 5 (as seen in Figure 1 and Figure 2) for FCR-D dynamic upwards (left) and downwards (right). $E_{7.5s}$ is equal to the green area subtracted with the red area.*

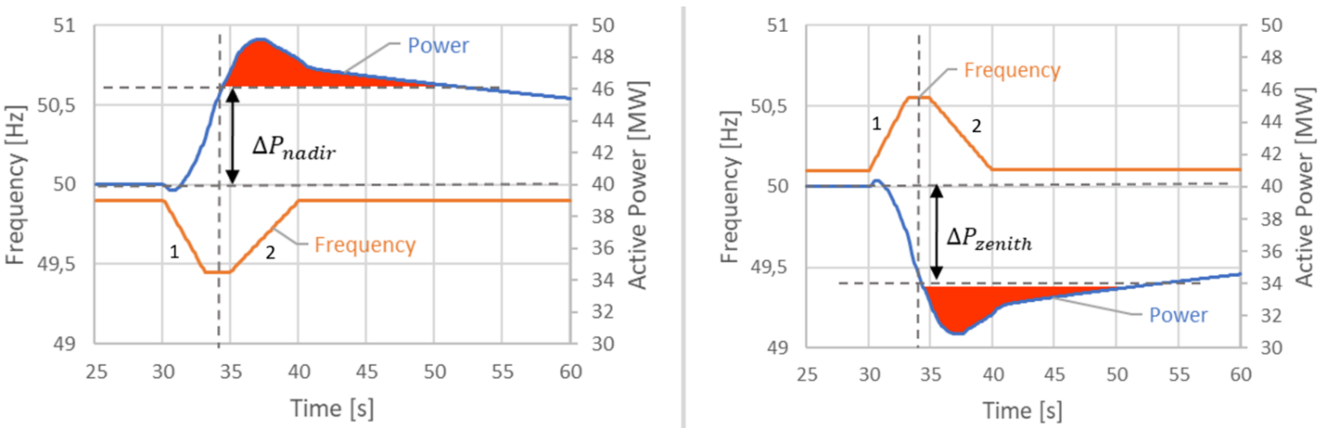


Figure 4 *Deactivation test on ramp 1 and 2 for FCR-D dynamic upwards (left) and FCR-D dynamic downwards (right).*

PARAMETER	EXPLANATION
$\lvert\boldsymbol{\Delta P_{ss,theo.}}\rvert$	The theoretical steady state response is measured in [MW] for a frequency change from 49.9 [Hz] to 49.5 [Hz] for FCR-D upregulation.
$\boldsymbol{P_{ss,x}}$	The actual steady-state response from the unit after ramp number x.
$\lvert\boldsymbol{\Delta P_{7.5s}}\rvert$	It is the activated power 7.5 seconds after the start of the ramp.
$\boldsymbol{\Delta P(t)}$	The active power response at time instant t.
$\lvert\boldsymbol{E_{7.5s}}\rvert$	It is the accumulated amount of energy from the start of the ramp to 7.5 seconds after the start of the ramp, which is calculated as: $$E_{7.5s} = \int_{t}^{t+7.5s} \Delta P(t)dt$$
$\boldsymbol{P_0}$	Baseline power consumption/production.
$\boldsymbol{C_{FCR}}$	FCR capacity measured in [MW].

Table 4 *Explanation of variables/parameters utilized in Table 3.*

Combination of FCR-D and FCR-N

In steady state, an entity desiring to provide both FCR-N and FCR-D shall activate the sum of FCR-N and FCR-D at any frequency deviation, as depicted in Figure 5. It is recommended that the controller structure is implemented such that the FCR products are individually controllable, i.e., delivered from separate controllers for each product.

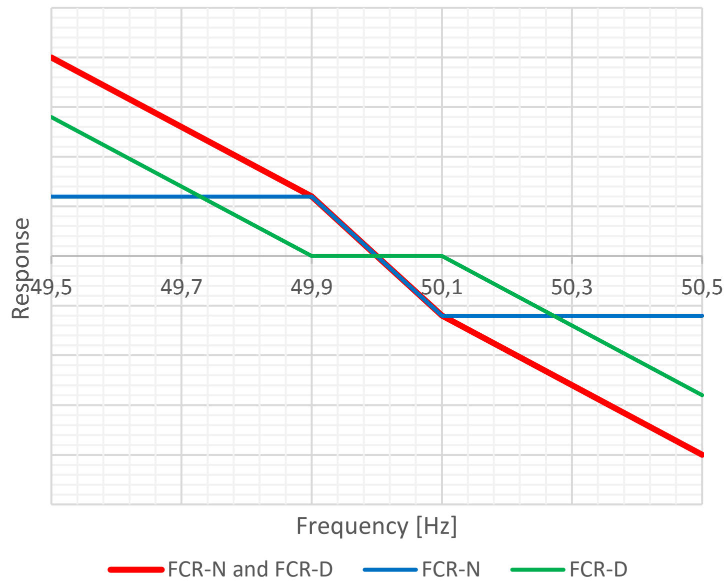


***Figure 5** Steady state active power activation as a function of frequency, droop profile of FCR-N (blue), FCR-D (green) and both combined (red).*

If the entity will at times provide both FCR-N and FCR-D, the fast ramp test with high droop should be carried out with both FCR-N and FCR-D active, while the ramp test with low droop should be carried out with only FCR-D active. The over- and under delivery requirements for co-delivery of FCR-N and FCR, is shown in Table 5. The utilized variables are explained in Table 6.

REQ. NUMBER	RAMP NUMBER	REQUIREMENT SPECIFICATION (DESCRIPTIVE)	REQUIREMENT SPECIFICATION (MATHEMATICALLY)
1	Ramp 6 and 8	For the test sequence when FCR-N is active, the difference between the steady state response after ramp 6 and ramp 8 (as illustrated in Figure 1 and Figure 2) should fulfil the steady state response requirement for FCR-N with a small correction.	Combination upwards direction: $-0.05 \leq \frac{(P_{ss,8} - P_{ss,6}) - \lvert\Delta P_{FCR-N,ss,theoretical}\rvert - 0.01/0.4\lvert\Delta P_{FCR-D,up,ss,theoretical}\rvert}{\lvert\Delta P_{FCR-N,ss,theoretical}\rvert} \leq 0.2$ Combination downwards direction: $-0.2 \leq \frac{P_{ss,8} - P_{ss,6} + \lvert\Delta P_{FCR-N,ss,theoretical}\rvert + 0.01/0.4\lvert\Delta P_{FCR-D,down,ss,theoretical}\rvert}{\lvert\Delta P_{FCR-N,ss,theoretical}\rvert} \leq 0.05$

***Table 5** Requirements associated to the conduction of the fast ramp test for co-delivery of dynamic FCR-D and FCR-N, as outlined in with ramp number 7 and 8 in Table 2.*

PARAMETER	EXPLANATION
$\lvert \Delta P_{FCR-D,\mathrm{up},ss,theo.} \rvert$	The theoretical steady state response is measured in [MW] for a frequency change from 49.9 [Hz] to 49.5 [Hz] for FCR-D upregulation.
$\lvert \Delta P_{FCR-N,ss,theo.} \rvert$	The theoretical steady state response is measured in [MW] for a frequency change from 50 to 50.1/49.9 [Hz] for FCR-N.
$P_{ss,6}$	Steady state power response after ramp 6.
$P_{ss,8}$	Steady state power response after ramp 8.

Table 6 *Explanation of variables/parameters utilized in Table 5.*

2.2 Sine response test sequence

The sine response test shall be performed for all FCR-D providing entities. The test is executed by performing a sine response testing as shown in Figure 6. A sinusoidal frequency disturbance shall be injected, oscillating around 49.7 Hz for FCR-D Up and 50.3 for FCR-D Down with an amplitude of $\pm$ 100 mHz. If the applicant applies for both FCR-D Up and Down, then only one is required.

The sine response test is to be performed for a range of different periods, listed in Table 7 along with required stationary periods (*T*).

The sine test is only required for the most challenging operational condition (High/low droop and load) and thus the sine test is only performed once. The applicant shall describe the reasoning behind choosing the operational condition for the test - e.g., low load is the most challenging due to limited ramping.

When set on the operational condition, the applicant can design the test sequence via the Energinet Excel File.

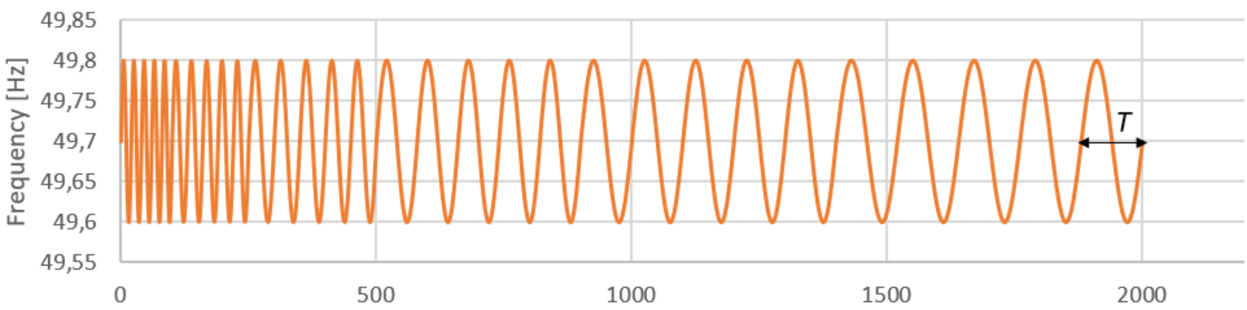


Figure 6 *illustrates the full FCR-D sine test for upregulation. Down regulation is equal in amplitude but centered at 50.3 Hz.*

Between each change in periods, it is possible to pause the test for a duration, however coherence time sampling is needed.

PERIOD, *T* [S]	10	15	25	40	50	60	70
NO. OF STATIONARY PERIODS	5	5	5	5	5	5	5

Table 7 *shows the different sine frequency and iterations.*

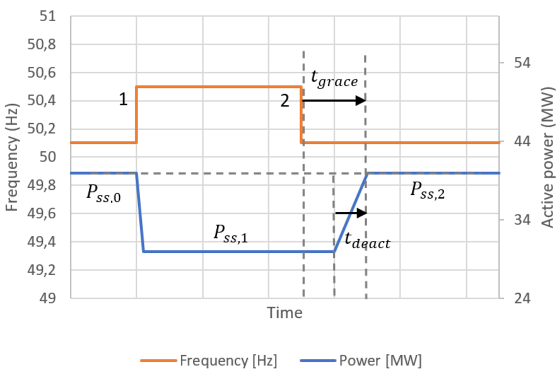
The sine test yields information about the stability of the FCR applying entity and its performance to the stability requirements (Nyquist stability criteria and transfer function requirements).

2.3 Ramp static test sequence

The ramp static test shall be performed for all FCR-D static providing entities. The purpose of the test is to investigate the steady state response capabilities of the providing entity. The test is executed by performing a series of frequency input ramp signals at specific time instances, as outlined in Table 8. The ramps shall be effectuated at a rate of maximum 0.24 [Hz/s]. Figure 7 illustrates the test sequence for downregulation (left figure) and upregulation (right figure).

RAMP NUMBER	FREQUENCY FOR FCR-D UP/DOWN [HZ]	START TIME [S]	START TIME (ENDURANCE TEST) [S]		DURATION [S]	COMMENT
			Non-LER	LER		
	49.9/50.1	0	0	0	180	Wait until the power is stable before starting the test.
1	49.5/50.5	180	180	180	900 / 1800 (non-LER / LER)	Activation performance test 1. Note, for LER units, the full activation must be delivered for 1800 seconds (30 minutes) when testing for endurance. Non-LER units must prove the endurance in 900 seconds.
2	49.9/50.1	240	1080	1980	1200	Deactivation test 1.
		1440	2280	3180		End of test.

Table 8 *FCR-D static up- and downwards ramp static test.*



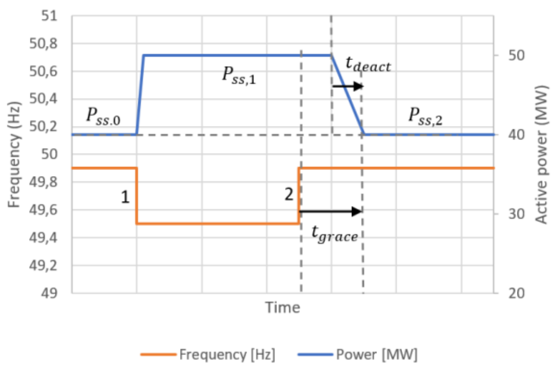


Figure 7 *FCR-D static downwards (left) and upwards (right) ramp test. FCR-N is omitted in this illustration.*

Table 9 shows the necessary requirements to fulfill during the ramp static test sequence. It is designated in the table for which ramps the specific requirements are valid for. Table 10 contains explanations for the utilized variables.

REQ. NUMBER	RAMP NUMBER	REQUIREMENT SPECIFICATION (DESCRIPTIVE)	REQUIREMENT SPECIFICATION (MATHEMATICALLY)
1	Ramp 1	The steady state response of Static FCR-D is calculated as the difference between the steady state response of ramp 1 (ending at 49.5 Hz for FCR-D upwards and 50.5 Hz for FCR-D downwards) and before ramp 1, i.e. at 49.9 Hz for FCR-D upwards or 50.1 Hz for FCR-D downwards. The steady state response must not differ more than 5 % from the theoretical steady state response in the direction of under-delivery and 10 % in the direction of over-delivery.	Upwards direction: $-0.05 \leq \frac{P_{ss,1} - P_{ss,0} - \lvert \Delta P_{ss,theo.} \rvert}{\lvert \Delta P_{ss,theo.} \rvert} \leq 0.1$ Downwards direction: $-0.1 \leq \frac{P_{ss,1} - P_{ss,0} + \lvert \Delta P_{ss,theo.} \rvert}{\lvert \Delta P_{ss,theo.} \rvert} \leq 0.05$
2	Ramp 1	The actual steady-state power response ($\lvert \Delta P_{7.5s} \rvert$) shall 7.5 seconds after initialization of the activation (due to frequency drop/increase to 49.5/50.5 [Hz]), being able to deliver minimum 86% of the theoretical steady state response ($\lvert \Delta P_{ss,theoretical} \rvert$). The activated power shall not be decreased below the power at 7.5 seconds at any point in time until start of ramp 2 (back to 50.1 Hz) (in the equation, until 60 seconds is inserted, but can vary depend on i.e., LER).	$\lvert \Delta P_{7.5s} \rvert \geq 0.86 * \lvert \Delta P_{ss,theo.} \rvert$ $\lvert \Delta P_{7.5s \to 60s} \rvert \geq \lvert \Delta P_{7.5s} \rvert$
3	Ramp 1	The supplied energy must from the start of the ramp to 7.5 seconds after the start of the ramp, be equivalent to minimum 3.2 seconds multiplied with the theoretical steady state response.	$\lvert E_{7.5s} \rvert \geq 3.2 * \lvert \Delta P_{ss,theo.} \rvert$
4	Ramp 1	The overshoot in the power response to ramp 1 must not exceed 20%.	$\lvert \Delta P_{max} \rvert \leq 1.2 * \lvert \Delta P_{ss,theo.} \rvert$
5	Ramp 1	The power response must be initialized within 2.5 seconds of the activation.	$\lvert \Delta P_{t>2.5s} \rvert > 0$
6	Ramp 2	Static FCR-D shall be deactivated and prepared for a re-activation within a grace period of maximum 15 minutes, counted from 60 seconds after the return of the frequency into the standard frequency range (49.9 – 50.1 [Hz]).	$t_{deact} \leq 900\ [s]$
7	Ramp 2	Deactivation is only allowed when the frequency is within the standard frequency range. The rate of deactivation is limited to maximum 2.5% of the theoretical steady state response to a full frequency deviation per second, as a moving average with a window of 10 seconds and with no single step larger than 20%. .	$\frac{\lvert P_{ss,1} \rvert - \lvert P_{ss,2} \rvert}{t_{deact}} \leq 0.025 * \lvert \Delta P_{ss,theo.} \rvert$

Table 9 *Requirements associated to the conduction of the ramp static test sequence for static FCR-D, as outlined in Table 8.*

PARAMETER	EXPLANATION
$\boldsymbol{P_{ss,0}}$	The actual steady-state response from the unit, equaling zero, before ramp 1.
$\boldsymbol{\lvert\Delta P_{ss,theo.}\rvert}$	The theoretical steady state response is measured in [MW] for a frequency change from 49.9 [Hz] to 49.5 [Hz] for FCR-D upregulation. It is calculated with the provider's steady state response calculation method.
$\boldsymbol{\lvert\Delta P_{max}\rvert}$	Maximum power response at ramp 1.
$\boldsymbol{P_{ss,x}}$	The actual steady-state response from the unit after ramp number x.
$\boldsymbol{t_{deact}}$	The time from the start of the deactivation to the end of the deactivation for ramp 2.
$\boldsymbol{\lvert\Delta P_{7.5s}\rvert}$	It is the activated power 7.5 seconds after the start of the ramp.
$\boldsymbol{\Delta P(t)}$	The active power response at time instant t.
$\boldsymbol{\lvert E_{7.5s}\rvert}$	It is the accumulated amount of energy from the start of the ramp to 7.5 seconds after the start of the ramp, which is calculated as: $$E_{7.5s} = \int_{t}^{t+7.5s} \Delta P(t)dt$$

Table 10 *Explanation of variables/parameters utilized in Table 9.*

2.4 Linearity test

FCR-D resources have to contribute within the blue area in Figure 8. For stepwise activated resources this means that the number of steps in the controller must be at least 7 in each direction. The black line in the figure indicates the mandatory target response for the controller. The controller shall aim to be as close and centered as possible to the target response. Deviations from the target response are allowed if caused by uncertainties in the response, natural variations in production/consumption, or due to step sizes of the resources connected to the relay.

The coordinates for the corners of the blue areas in Figure 8 are provided in Table 11. The coordinates are given clockwise starting from the minimum activation at 49.88 Hz and 50.12 Hz respectively. The full requirement is calculated via linear interpolation of the provided coordinates.

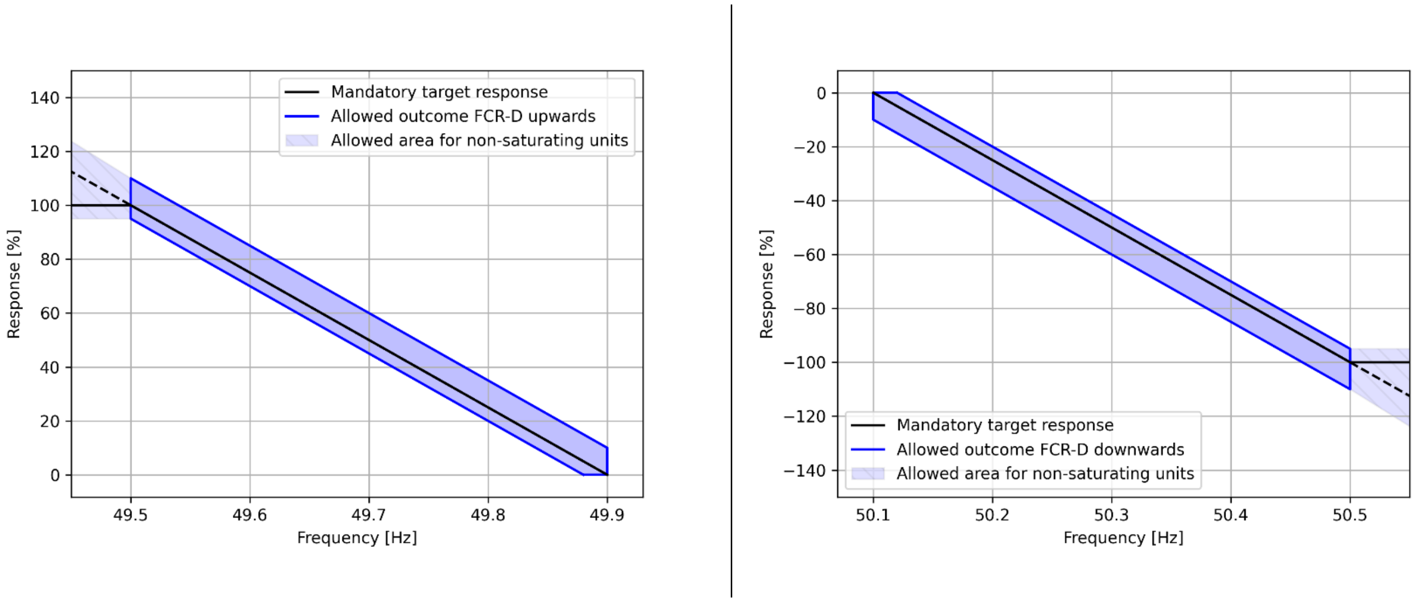


Figure 8 *Activation of piecewise linear FCR-D resources. The black line indicates the mandatory target response and the blue area defines the allowed outcome of the deviations.*

FREQUENCY [HZ]	RESPONSE [%]	FREQUENCY [HZ]	RESPONSE [%]
49.88	0	50.12	0
49.50	95	50.50	-95
49.50	110	50.50	-110
49.90	10	50.10	-10
49.90	0	50.10	0
49.88	0	50.12	0

Table 11 *Coordinates of the corners in Figure 8. Clockwise starting from the minimum activation at 49.88 Hz and 50.12 Hz respectively. Left FCR-D upwards regulation, right FCR-D downwards regulation.*

The linearity test shall be performed for dynamic FCR-D up- and downwards providing entities with a non-continuous controller. Furthermore, regardless of the continuity capability, all FCR-D static providing entities must perform the linearity test. The test is performed by applying a sequence of frequency steps of 100 mHz per step as shown in Figure 9 with the upwards and downwards directions portrayed. Each step shall be maintained for a duration of 60 seconds to allow the response to reach steady state and then another 60 seconds where the steady state response is evaluated.

The linearity test shall be performed at two operating conditions. This shall be the operational conditions with the high loading and low droop setting and the low loading and high droop setting.

When the FCR response has reached steady state for a specific step (7 in total per direction), it must stay close to a proportional response to the frequency deviation. For upward regulation (frequency below 50 Hz) the requirement is +10 % and -5 % referring to $\Delta P_{ss,theoretical}$ for a full activation. For downward regulation (frequency above 50 Hz) the requirement is +5 % and -10 % referring to $\Delta P_{ss,theoretical}$ for a full activation. To avoid including very short variations in the FCR response, a 10 second moving average of the FCR response is assessed 60 seconds after a step in the frequency. The moving average is assessed for 60 seconds, hence there has to be 120 seconds between the steps.

Figure 10 depicts the allowed response area for the moving average, for the frequency steps from 49.6 Hz → 49.5 Hz → 49.6 Hz. The same principles apply for all the steps. Table 12 contains the requirement to obey with for all frequency steps and Table 13 explains the utilized variables.

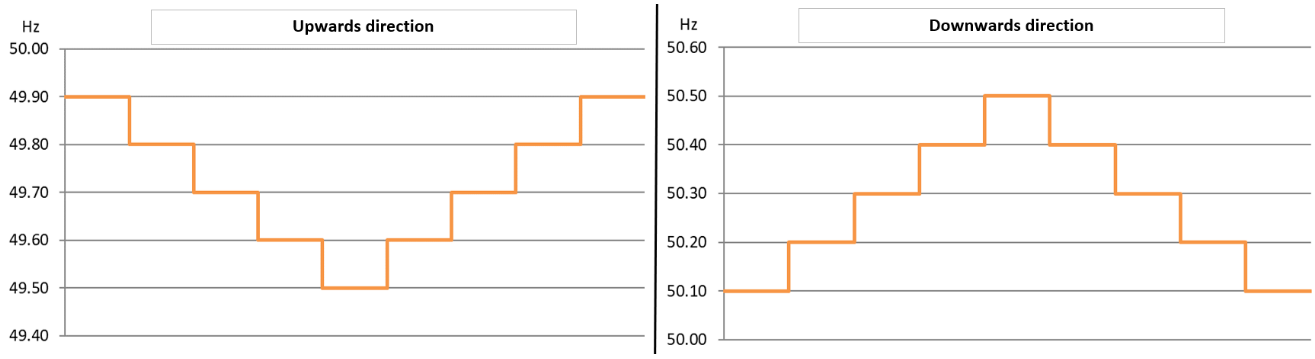


Figure 9 *FCR-D up- (left part) and downwards (right part) linearity test sequence.*

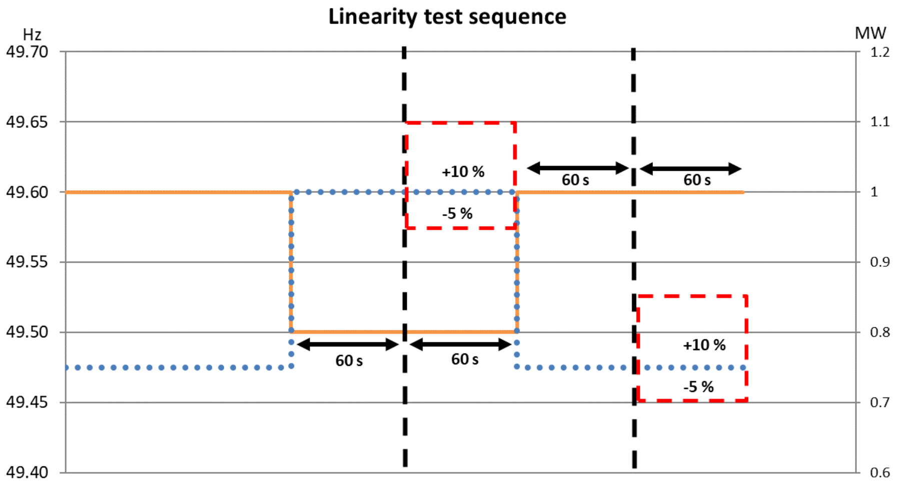


Figure 10 *Allowed response area for FCR-D for the frequency steps from 49.6 Hz → 49.5 Hz → 49.6 Hz. The orange line is the frequency step. The blue dotted line is the directly proportional FCR response per MW. The red dashed squares indicate the allowed response area.*

REQ. NUMBER	RAMP NUMBER	REQUIREMENT SPECIFICATION (DESCRIPTIVE)	REQUIREMENT SPECIFICATION (MATHEMATICALLY)
1	All steps (from 1 to 7)	The steady state response must not differ too much from the theoretical steady state response. The maximal allowed under-delivery in the test result is 5 % and over-delivery 10 % for upwards. Vice versa for downwards regulation. For as long as the frequency deviation persist, the steady state response shall stay within the steady state limits.	$0.95 \leq \frac{\lvert\Delta\bar{P}\rvert}{\lvert\Delta P_{ss,theoretical}\rvert} * \frac{0.4}{\lvert\Delta f\rvert} \leq 1.1$

Table 12 *Requirements associated to the conduction of the linearity test for FCR-D.*

PARAMETER	EXPLANATION
$\lvert\boldsymbol{\Delta P_{ss,theo.}}\rvert$	The theoretical steady state response is measured in [MW] for a frequency change from 49.9 [Hz] to 49.5 [Hz] for FCR-D upregulation.
$\boldsymbol{\Delta P(t)}$	the moving average of the provided FCR for the evaluated step at time t, calculated as: $$\Delta\bar{P}(t) = \frac{1}{k}\sum_{i=t-k/2}^{t+k/2} \Delta P_{FCR,i}$$
$\boldsymbol{\Delta P_{FCR}}$	the delivered FCR
$\boldsymbol{\Delta f}$	frequency deviation from 50 Hz for the evaluated step.
K	width of the moving average, equal to 10 seconds

Table 13 *Explanation of variables/parameters utilized in Table 12.*

3. Test of FCR-N in DK2

This section describes the fundamental requirements for FCR-N and required ancillary services tests to be done before the unit can be used in the market.

To get prequalified for FCR-N, there are three different tests that must be ran. While the tests have similar names to the FCR-D tests, they are distinct tests.

PRODUCT	STEP RESPONSE TEST	SINE RESPONSE TEST	LINEARITY TEST
FCR-N	√	√	√
SPECIFIC SECTION FOR CLARIFICATION	Section 3.1	Section 3.2	Section 3.3

Section 3.1, 3.2 and 3.3 outline the specific tests to perform for FCR-N providing entities.

3.1 Step response test

The step response test shall be performed for all FCR-N providing entities. The purpose of the test is to investigate the steady state response of the providing unit. The test is executed by performing a frequency step response at specific time instances, as outlined in Table 14. When testing for endurance (non-LER units), the test is performed with the most challenging combination of load and droop, from an endurance point of view. Figure 11 illustrates the test sequence for the step response test. Endurance and energy management of entities with LER is unfolded in Section 5.

RAMP NUMBER	FREQUENCY [HZ]	START TIME [MIN]	START TIME ENDURANCE TEST FOR NON-LER [MIN]	DURATION [MIN]	COMMENT
	50	0	0	0.5	Starting point of the test.
PRE-STEP	49.95	0.5	0.5	0.5	Small step to handle backlash
0	50	1	1	5	Step towards zero response at frequency equal to 50 Hz.
1	49.9	6	6	5 / 15*	Step towards $\Delta P_{ss,1}$ power response output. *Endurance test must for non-LER units be performed for 15 minutes.
2	50.1	11	21	5 / 15*	Step towards $\Delta P_{ss,2}$ power response output. *Endurance test must for non-LER units be performed for 15 minutes.
3	50	16	36	5	Step towards zero power response.
		21	41		End of test

Table 14 *FCR-N step test sequence.*

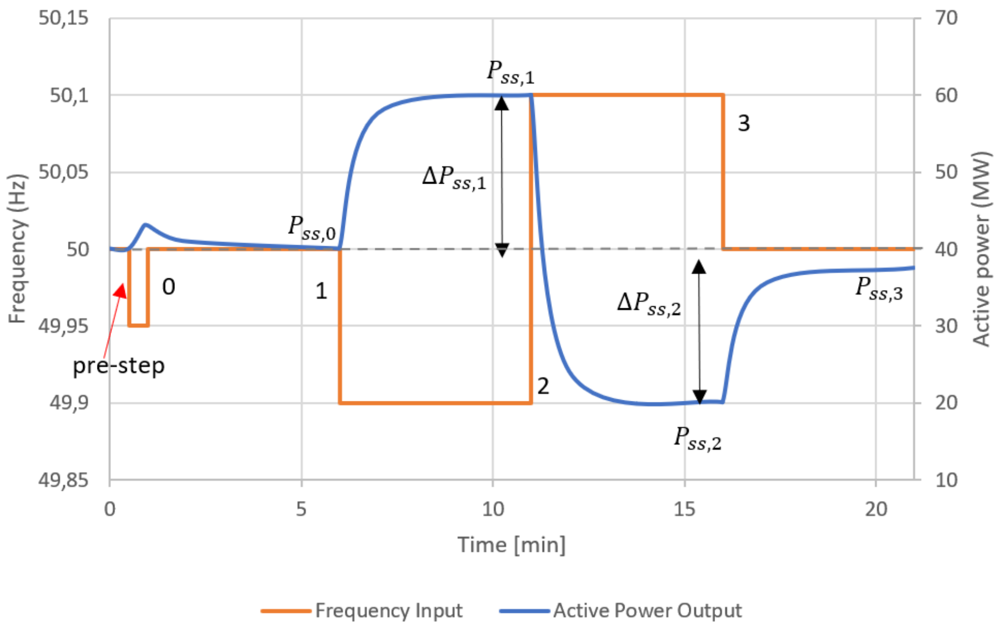


***Figure 11** FCR-N step response sequence.*

The steady state response for an FCR-N providing unit is calculated in the upwards direction as

$$\Delta P_{ss,1} = P_{ss,1} - \frac{1}{2}(P_{ss,0} + P_{ss,3})$$

And the steady state response in the downwards direction is calculated as

$$\Delta P_{ss,2} = P_{ss,2} - \frac{1}{2}(P_{ss,0} + P_{ss,3})$$

where $P_{ss,0}$ is the steady state power at f_0=50 Hz before step 1 and $P_{ss,3}$ is the steady state power at f_3=50.0 Hz after step 3, $P_{ss,1}$ is the steady state power at f_1=49.9 Hz and $P_{ss,2}$ is the steady state power at f_2=50.1 Hz.

Table 15 shows the requirements to obey when performing the step response test for FCR-N. Table 16 assists with explanatory text on the utilized parameters/variables.

REQ. NUMBER	RAMP NUMBER	REQUIREMENT SPECIFICATION (DESCRIPTIVE)	REQUIREMENT SPECIFICATION (MATHEMATICALLY)
1	Ramp 1 and 2	The steady state response must not differ too much from the theoretical steady state response. The maximal allowed under-delivery in the test result is 5 % and over-delivery 20 % for upwards. Vice versa for downwards regulation. For as long as the frequency deviation persist, the steady state response shall stay within the steady state limits.	Upwards direction: $-0.05 \leq \frac{\Delta P_{ss,1} - \lvert\Delta P_{ss,theoretical}\rvert}{\lvert\Delta P_{ss,theoretical}\rvert} \leq 0.2$ Downwards direction: $-0.2 \leq \frac{\Delta P_{ss,2} + \lvert\Delta P_{ss,theoretical}\rvert}{\lvert\Delta P_{ss,theoretical}\rvert} \leq 0.05$

***Table 15** Requirements associated to the conduction of the step response test FCR-N.*

PARAMETER	EXPLANATION
$\lvert\Delta P_{ss,theo.}\rvert$	The theoretical steady state response is measured in [MW] for a frequency deviation of 0.1 Hz in upwards or downwards direction.
$P_{ss,x}$	The actual steady-state response from the unit after ramp number x.
$\lvert\Delta P_{7.5s}\rvert$	It is the activated power 7.5 seconds after the start of the ramp.
$\Delta P(t)$	The active power response at time instant t.
P_0	Baseline power consumption/production.

***Table 16** Explanation of variables/parameters utilized in Table 15.*

3.2 Sine response test

The sine response test shall be performed for all FCR-N providing entities. The test is executed by performing a sine response testing as shown in Figure 12. A sinusoidal frequency disturbance shall be applied varying between 49.9 Hz and 50.1 Hz. The sine response test is to be performed for a range of different periods, listed in Table 17 along with required stationary periods (*T*).

The sine test is only required for the most challenging operational condition (High/low droop and load) and thus the sine test is only performed once. The applicant shall describe the reasoning behind choosing the operational condition for the test - e.g., low load is the most challenging due to limited ramping.

When set on the operational condition, the applicant can design the test sequence via Energinet's Excel file.

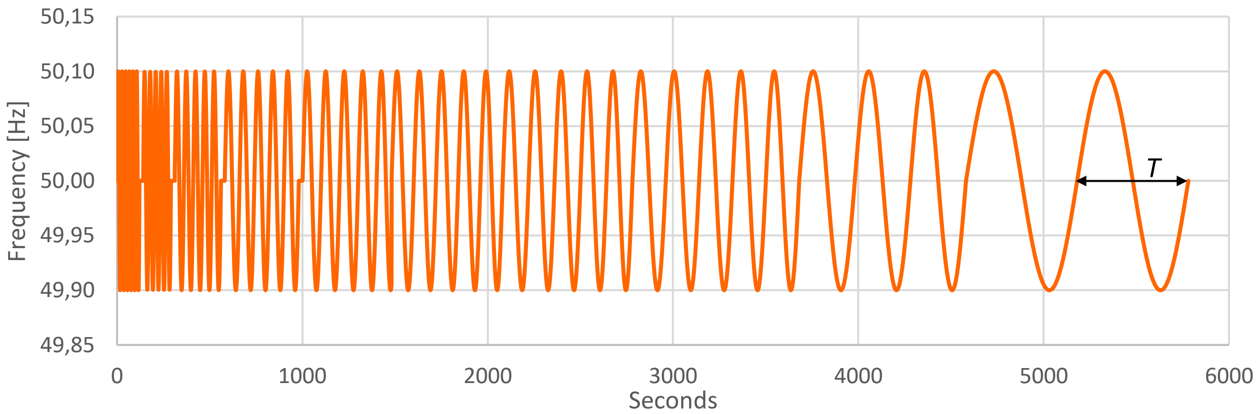


***Figure 12** illustrates the full FCR-N sine test without breaks.*

Between each change in periods, it is possible to pause the test for a duration, however coherence time sampling is needed.

PERIOD, *T* [S]	10	15	25	40	50	60	70	90	150	300
NO. OF STATIONARY PERIODS	5	5	5	5	5	5	5	5	3	2

***Table 17** shows the different sine frequency and iterations.*

The sine test yields information about the stability of the FCR applying entity and its performance to the stability requirements (Nyquist stability criteria and transfer function requirements).

3.3 Linearity step test

Piecewise linear FCR-N resources must activate their contribution within the blue area in Figure 13 below. For stepwise activated resources this means that the number of steps must be at least 14. The black line in the figure indicates the mandatory steady state target response for the controller. The controller shall aim to be as close and centered as possible to the target response. Deviations from the target response are allowed if caused by uncertainties in the response, natural variations in production/consumption, or due to fixed step sizes of the resources connected to the relay.

The coordinates for the corners of the blue area in Figure 13 are provided in Table 18 below. The coordinates are given clockwise starting from the minimum activation at 50.1 Hz. The full requirement is calculated via linear interpolation of the provided coordinates.

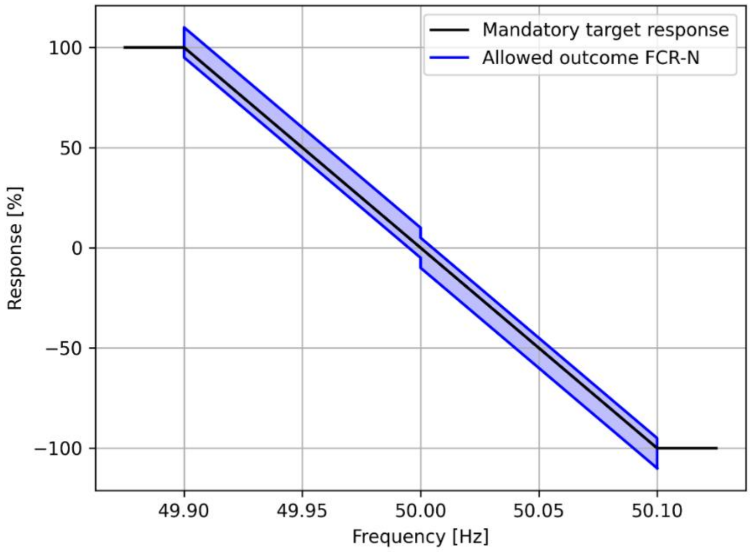


Figure 13 *Activation of piecewise linear FCR-resources. The black line indicates the mandatory target response, and the blue area defines the allowed outcome of the deviations.*

FREQUENCY [HZ]	RESPONSE [%]
50.10	110
50.00	10
50.00	5
49.90	-95
49.90	-110
50.00	-10
50.10	95
50.10	110

Table 18 *Coordinates of the corners in Figure 13. Clockwise starting from the maximal activation at 50.10 Hz.*

The linearity test shall be performed for FCR-N providing entities with a non-continuous response. The test is performed by applying a sequence of frequency steps of 20 mHz per step as shown in Figure 14. The test sequence will start at 50 Hz, move step wise down to 49.9 Hz, then up step wise to 50.1 Hz, and then back down to 50 Hz again. Each step shall be maintained for a duration of at least 120 seconds. The first 60 seconds allows the response to reach steady state and then the next 60 seconds are used for evaluation of the steady state response. If steady state is not reached within the first 60 seconds, the provider is allowed to wait longer (up to 4 minutes).

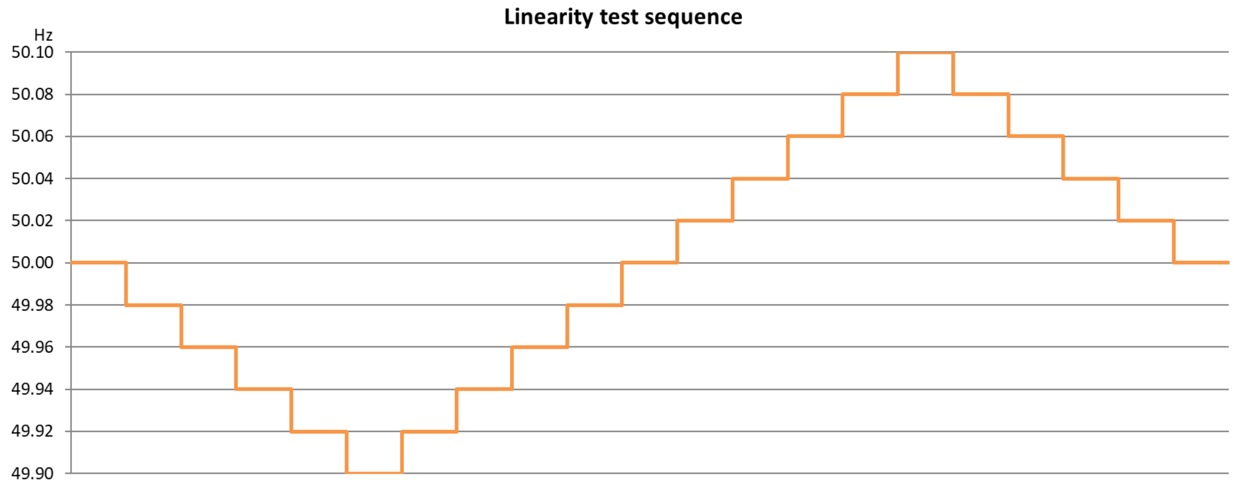


Figure 14 *FCR-N linearity test sequence.*

The linearity test shall be performed at two operating conditions. This shall be the operational conditions with the high loading and low droop setting and the low loading and high droop setting.

When the FCR response has reached steady state, it must stay close to a proportional response to the frequency deviation. For upwards regulation (frequency below 50 Hz) the requirement is +10 % and -5 % referring to $\Delta P_{ss,theoretical}$. For downwards regulation (frequency above 50 Hz) the requirement is +5 % and -10 % referring to $\Delta P_{ss,theoretical}$. To avoid including very short variations in the FCR response, a 10 second moving average of the FCR response is assessed for 60 seconds, starting 60 seconds after a step in the frequency. The provider is allowed to wait longer (up to 4 minutes) if steady state is not reached in 60 seconds, and the moving average is then assessed during the last 60 seconds. Thus, boundaries with +10 % and -5 % should be reached within 60 seconds from the frequency step change.

Figure 15 depicts the allowed response area for the moving average, for the frequency steps from 49.92 Hz → 49.90 Hz → 49.92 Hz. The same principles apply for all the steps. Table 19 contains the requirement to obey with when performing the linearity test and Table 20 explains the utilized variables.

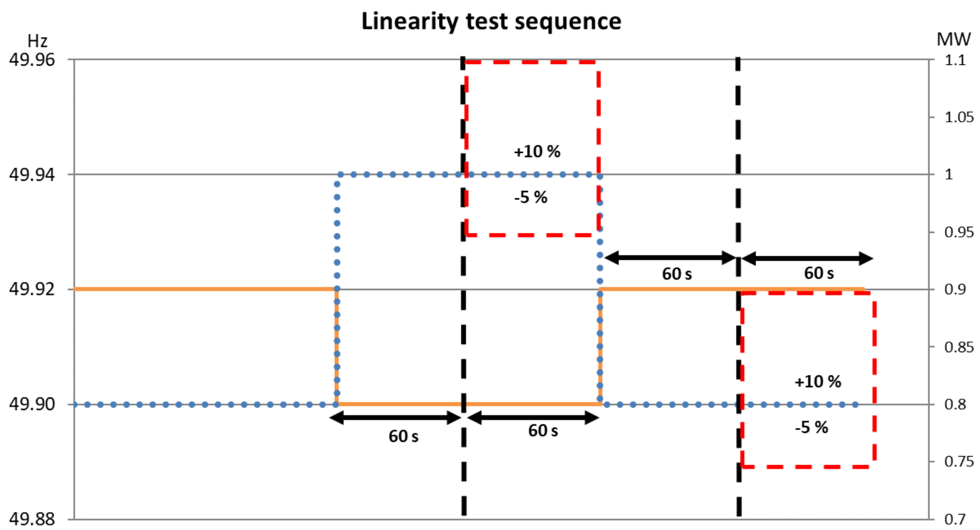


Figure 15 *Allowed response area for FCR-N for the frequency steps from 49.92 Hz → 49.90 Hz → 49.92 Hz. The orange line is the frequency step. The blue dotted line is the directly proportional FCR response. The red dashed squares indicate the allowed response area, denoted to assess the FCR response for 60 seconds.*

REQ. NUMBER	RAMP NUMBER	REQUIREMENT SPECIFICATION (DESCRIPTIVE)	REQUIREMENT SPECIFICATION (MATHEMATICALLY)
1	All steps (from 1 to 14)	The steady state response must not differ too much from the theoretical steady state response. The maximal allowed under-delivery in the test result is 5 % and over-delivery 10 % for upwards. Vice versa for downwards regulation. For as long as the frequency deviation persist, the steady state response shall stay within the steady state limits.	$0.95 \leq \frac{\lvert\Delta\bar{P}\rvert}{\lvert\Delta P_{ss,theoretical}\rvert} * \frac{0.1}{\lvert\Delta f\rvert} \leq 1.1$

Table 19 *Requirement associated to the conduction of the linearity step test for FCR-N, as outlined in Figure 15.*

PARAMETER	EXPLANATION
$\lvert\boldsymbol{\Delta P_{ss,theo.}}\rvert$	The theoretical steady state response is measured in [MW] for a frequency change from 49.9 [Hz] to 49.5 [Hz] for FCR-D upregulation.
$\boldsymbol{\Delta P(t)}$	the moving average of the provided FCR for the evaluated step at time t, calculated as: $$\Delta\bar{P}(t) = \frac{1}{k}\sum_{i=t-k/2}^{t+k/2} \Delta P_{FCR,i}$$
$\boldsymbol{\Delta P_{FCR}}$	the delivered FCR
$\boldsymbol{\Delta f}$	frequency deviation from 50 Hz for the evaluated step
K	width of the moving average, equal to 10 seconds

Table 20 *Explanation of variables/parameters utilized in Table 19.*

4. General terms for FCR-D and FCR-N

4.2 Prior to market participation

Before a unit/system can join the market, it must be verified that the unit/system can provide the specific ancillary service, within the specified response time, while still maintaining the technical requirements of that service.

The sections below specify the technical requirements followed by required tests designed to verify the unit's ability to deliver.

The cost of information technology (IT) connections, maintenance, grid tariffs etc. for energy provisions and tests/reliability testing must be paid solely by the service provider.

4.3 Requirements of measurement system

The FCR providing unit shall be able to validate the measurements of frequency and power in an acceptable sample time, resolution, and accuracy according to Table 21.

	SAMPLING RATE	RESOLUTION	ACCURACY
FREQUENCY	≤1 sec	5 mHz	±10 mHz
POWER	≤1 sec	0,01 MW	±0,5-5%*

Table 21 *shows the required sampling time, resolution and accuracy for measurements. The power accuracy depends on the size of the unit. *Depends on the capacity of the asset.*

The sampling rate should be higher or equal to 1 second, however lower sampling rate, e.g., 1 second resolution, naturally yields harder requirements due to shorter reaction time.

The accuracy of the frequency meter is validated by Energinet by retrieving 1-hour data log from the FCR providing unit and compared to internal Energinet measurements.

4.4 Prequalification of aggregated resources

For aggregated portfolios, the market participant must submit a description of the aggregation concept, including a description of the communication mode selected. This description must state how requirements and specifications are complied with. The description must be approved by Energinet before the market participant can join the market with the concept selected. The reserve providing entity must always provide a response that meets the technical requirements, while the individual resources in the group on their own do not necessarily have to.

The aggregator must in accordance with *Main agreement on the supply of ancillary services*, keep an updated list of ancillary service units, that the aggregator over-sees. Documentation must contain information about MW, type, placement, and potential consumption pattern over a given period.

In general, a prequalified portfolio is allowed to extent with 25% of the original capacity without new prequalification process, however with a maximal extension of 10 MW. Energinet can deviate from the general conditions if needed.

The addition of units to a prequalified portfolio does not extend the validity date of the prequalification, which remains the same as for the initial prequalification.

4.5 Frequency Meters for Aggregated portfolios

For aggregated units, the ancillary service is provided through an aggregator or a balance responsible party. Energinet looks at the overall volume of power sold by the aggregator, which means at least only one frequency meter is required, which then distributes the signal to the units providing the service. If using a central frequency meter, there is a requirement of an alternative method, in case of meter error, disconnection or similar. This could be a backup frequency meter, placed somewhere else, which creates redundancy in case of power outage or similar. The backup procedure for the central frequency meter is described and approved along with the other deliverances for prequalification. The aggregator may choose to use several meters.

4.6 Audit of Provisions

Only units and systems that have undergone a functional test can participate in the FCR-D market. When a unit/system has been approved and begins to provide ancillary services, regular inspections/audits will be carried out to determine whether the unit/system provides the ancillary services in the agreed/approved quality and quantity.

The market participant must provide the quantities sold. In case of minor provision shortages, payment for any non-provision is deducted from the full volume. In case of major provision shortages, payment of the costs of replacement purchases and quarantine may be a possibility, cf. the tender specification. The lifting of a quarantine will be subject to either a renewed approval of the unit or the submission of detailed documentation proving that any faults have been remedied. Please note that the approved maximum capacity, which a unit can offer in a reserve capacity market, does not necessarily match the volume available in any given period.

4.7 Prognosis & baseline

The information about the requirements for the prognosis & baseline can be found in the appendix of the general prequalification document, *Prequalification of Units and Aggregated Portfolios.*

5. Endurance and limited energy reservoirs (LER)

There are additional requirements for units and portfolios with limited energy reservoir (LER units), such as batteries, and other units that depletes within a shorter period. The categorization as a LER unit/portfolio is based on if the unit can sustain a full FCR-response for 2 concurrent hours, without including charging and discharging strategies.

For FCR-D this means a unit is defined as a LER unit, if it cannot deliver 2 hours in either up or down, when only bidding into one direction at a time, if bidding into both directions, the unit is defined as LER if it cannot deliver both directions, at the same time, for 2 hours, i.e., less than 4-hour unit. For FCR-N this is a minimum of 4 hours.

Even though there might be batteries in an FCR-portfolio, it is only defined as a LER-portfolio if the entire portfolio is not able to sustain the full FCR-responses required.

If the unit is not defined as a LER unit, this section and the requirements are not important and can be skipped.

If the unit or portfolio is defined as a LER unit, energy management solution must be implemented, and power and energy must be reserved for this. The reservation is for Normal State Energy Management (NEM) as well as Alert State Energy Management (AEM). Table 22 shows the amounts reserved for FCR-N and FCR-D. NEM and AEM will be explained in a later subsection. For FCR-D the table states you must reserve 20% of the prequalified FCR-D amount to NEM.

E.g., If you wish to prequalify 1 MW for FCR-D upwards, you must reserve 0.2 MW in the downwards direction for NEM as well as 20 minutes of full FCR-D upwards delivery, or 0.33 MWh of energy.

If you wish to prequalify 1 MW of FCR-N, you must reserve 0.34 MW in both directions, which require at least a 1.34 MW LER unit. You must also reserve 1-1.25 hour of energy in both directions, which requires at least 1-1.25 MWh capacity charged, as well as room to charge the LER unit 1-1.25 MWh more.

Documentation on how NEM and AEM are implemented is required and a test must be run to ensure they work as expected. A proposal for a test can be found in the document, *Technical Requirements for Frequency Containment Reserve Provision in the Nordic Synchronous Area*:

		FCR-N	FCR-D UP	FCR-D DOWN
REQUIRED POWER UPWARDS	[MW]	$+1.34 \cdot C_{FCR-N}$	$+C_{FCR-D\ Up}$	$+0.20 \cdot C_{FCR-D\ Down}$
REQUIRED POWER DOWNWARDS	[MW]	$-1.34 \cdot C_{FCR-N}$	$-0.20 \cdot C_{FCR-D\ Up}$	$-C_{FCR-D\ Down}$
REQUIRED ENERGY UPWARDS	[MWh]	$1 - 1.25\text{h} \cdot C_{FCR-N}$	$\frac{1}{3}\text{h} \cdot C_{FCR-D\ Up}$	-
REQUIRED ENERGY DOWNWARDS	[MWh]	$1 - 1.25\text{h} \cdot C_{FCR-N}$	-	$-\frac{1}{3}\text{h} \cdot C_{FCR-D\ Down}$

Table 22 *showing the power and energy reservations for FCR-N and D.*

5.2 Normal State Energy Management (NEM)

Normal State Energy Management (NEM) is a way to ensure that LER units have enough energy available in the reservoir to activate FCR, and to reduce the imbalances caused by the State of Charge (SOC) management.

The purpose of NEM is to change the baseline/setpoint of the unit providing FCR to restore the SOC. NEM is only allowed to be activated when the system is in normal state, which is when the frequency is within the normal band (+/- 100 mHz deviation from 50 Hz). When the frequency is outside the normal band (+/- 100 mHz), the entity must disable NEM. If the unit is close to a full depletion, the unit must enter Alert State Energy Management (AEM).

The bounds for when the entity is allowed to enter NEM are predetermined and can be seen Table 23. For FCR-N the battery enters NEM mode when there is 30 minutes remaining of energy left, or there is room for 30 more minutes of energy. FCR-N leaves NEM when there is room for 57.5 minutes of energy or 57.5 minutes of energy left. For FCR-D it happens at 20 minutes instead and it leaves NEM at 20 minutes again.

	FCR-N	FCR-D Up	FCR-D Down
SOC ENABLE NEM, *UPPER*	$30\ minutes$	N.A.	$20\ minutes$
SOC DISABLE NEM, *UPPER**	$57.5\ minutes$	N.A	$20\ minutes$
SOC DISABLE NEM, *LOWER**	$57.5\ minutes$	$20\ minutes$	N.A.
SOC ENABLE NEM, *LOWER*	$30\ minutes$	$20\ minutes$	N.A.

***Table 23** showing when the entity should enable and disable NEM.*

NEM changes the setpoint of the LER unit, and this transition must happen over a 5-minute period in a 1 second resolution.

The setpoint is calculated through two equations:

$$NEM_{Allowed} = \begin{cases} -1, & \text{if } 49.9 < f < 50.1 \text{ and } SOC < SOC_{NEM,lower,enable/disable} \\ 1, & \text{if } 49.9 < f < 50.1 \text{ and } SOC > SOC_{NEM,upper,enable/disable} \\ 0, & \text{otherwise} \end{cases}$$

$$NEM_{Current}(t_i) = \frac{1}{N} \sum_{n=1}^{N=300} NEM_{Allowed}(t_{i-n})$$

It is important to note that both conditions must be met.

The 300 second average of the $NEM_{allowed}$ is taken, and if the $NEM_{Current}$ is for example 0.5, then you can enable half of your NEM amount.

For FCR-N this is calculated as follows:

$$P_{tot,FCR-N} = P_{FCR-N} + P_{NEM} = P_{FCR-N} + 0.34 \cdot C_{FCR-N} \cdot NEM_{Current} \,.$$

PARAMETER	EXPLANATION
$\boldsymbol{P_{tot,FCR-N}}$	Is the total power provided by the entity
$\boldsymbol{P_{FCR-N}}$	Is the amount of FCR-N that is meant to be provided
$\boldsymbol{P_{NEM}}$	Is the capacity reserved for NEM
$\boldsymbol{C_{FCR-N}}$	Is the sold capacity of FCR-N
$\boldsymbol{NEM_{Current}}$	Is the current NEM

***Table 24** Explanation of symbols in used formulas for FCR-N.*

For FCR-N P_{NEM} is set to be minimum 34% of the prequalified FCR-N capacity. The capacity reserved for NEM can be used in other markets, but not sold as capacity.

For FCR-D this is calculated as follows:

$$P_{tot,FCR-D} = P_{FCR-D} + P_{NEM} = P_{FCR-D} + 0.2 \cdot C_{FCR-D} \cdot NEM_{Current}$$

PARAMETER	EXPLANATION
$\boldsymbol{P_{tot,FCR-D}}$	Is the total power provided by the entity
$\boldsymbol{P_{FCR-D}}$	Is the amount of FCR D that is meant to be provided
$\boldsymbol{P_{NEM}}$	Is the capacity reserved for NEM
$\boldsymbol{C_{FCR-D}}$	Is the sold capacity of FCR D
$\boldsymbol{NEM_{Current}}$	Is the current NEM

***Table 25** Explanation of symbols in used formulas for FCR-D.*

For FCR-D P_{NEM} is set to be minimum 20% of the prequalified FCR-D capacity. The capacity reserved for NEM can be used in other markets, but not sold as capacity.

5.3 Alert state Energy Management (AEM)

The Alert State Energy Management mode is a mode that must be entered when the entity is within the ranges seen in Table 26 For FCR-D and -N AEM is enabled when there is either room for 5 more minutes of energy, or there is 5 minutes of energy left. The entity then leaves AEM when there is more than 10 minutes of energy left, or room for more than 10 minutes of energy. The entity can enter AEM no matter the frequency of the system.

	FCR-N	FCR-D UPWARDS	FCR-D DOWNWARDS
SOC ENABLE AEM, UPPER	5 minutes	N.A.	5 minutes
SOC DISABLE AEM, UPPER	10 minutes	N.A.	10 minutes
SOC DISABLE AEM, LOWER	10 minutes	10 minutes	N.A.
SOC ENABLE AEM, LOWER	5 minutes	5 minutes	N.A.

Table 26 *showing when the entity should enable and disable AEM.*

When the entity is in AEM the frequency reference is altered and the new frequency reference is calculated as follows:

An entity that enters AEM is regarded as unavailable and must report to Energinet that they are unable to deliver. The f_0 is simply 50 Hz if not in the AEM activation range.

If AEM is activated, the frequency reference is an average of the past 5 minutes.

$$f_{ref} = \frac{1}{N} \sum_{n=1}^{N=300} f_{AEM}.$$

When this reference is changed from f0. it is referred to as f_{ref} instead.

$$P_{FCR-X}(t) = C_{FCR-X} \cdot \Delta f(t) = C_{FCR-X} \cdot \left(f_{ref} - f(t)\right)$$

PARAMETER	EXPLANATION
$\boldsymbol{P_{FCR-X}(t)}$	Is the total power provided by the entity
$\boldsymbol{C_{FCR-X}} \cdot$	Is the amount of FCR-X that is meant to be provided
$\boldsymbol{f_{ref}}$	Is frequency reference
$\boldsymbol{f(t)}$	Is the frequency to timestep t

Table 27 showing how to adjust the power provided in AEM

This equation calculates the amount of FCR-X provided, by taking the difference between the reference frequency and the current frequency. For FCR-D the dead band is still calculated from the 50 Hz, and if the frequency reference is 49.9 Hz there is no dead band.

6. Excemptions

6.2 Reduced capacity

In case a provider cannot fulfill the steady state response requirement (Requirement 1), it is allowed to introduce a capacity reduction factor on the theoretical capacity, so that the requirement is fulfilled. In other words, the TSO allows the provider to have an extra overshoot by reducing the prequalified capacity. The reduction factor must stay within the limits shown in Table 28.

PRODUCT	UPPER LIMIT	LOWER LIMIT
FCR-N	1	0.9
FCR-D DYNAMIC	1	0.75
FCR-D STATIC	1	0.84

Table 28 *Shows the upper and lower limit for reduced capacity for the different products.*

6.3 Mode shifting

FCR-D activations have a low full activation time, which might challenge some providers to fulfill both the performance requirement and the stability requirement. For these units it is allowed to use mode shifting in the controller. This means the provider can achieve a high performance for a short period of time after a disturbance before shifting back to a high stability. The controller must have high performance mode and high stability mode to do mode shifting. The shifting between the two modes must be tested during the fast ramp test sequence. The shift between the two modes must happen smooth and bump-less. The following rules apply for mode shifting:

- The high performance mode can be used at frequency deviations lower than 49.8 Hz for FCR-D upwards and 50.2 for FCR-D downwards.
- The provider must deactivate the high performance mode within 10 seconds and shift to high stability mode.
- After using high performance mode, it must be blocked for 5-15 minutes (5 minutes is recommended).

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