Prequalification of Units and aggregated portfolios

Version 2.1.01   Valid from the 24th of April 2024

1. Introduction & Purpose

In this document, requirements, and mandatory tests for the various reserve types, i.e., FCR in DK1, FFR, FCR-N and FCR-D in DK2 as well as aFRR and mFRR are gathered and presented. The document is closely linked to the document "Ancillary services to be delivered in Denmark – Tender conditions[1]", which specifies requirements for the ancillary services in detail.

The purpose of this document is to describe the different technical requirements and the tests and have all the necessary information to be able to be prequalified for ancillary services.

Energinet strives towards technological neutrality, therefore no distinction is made between consumption and production. It is also up to the market participant if they want their unit to be tested as a stand-alone or as part of an aggregated portfolio.

In compliance with SOGL §155, article 6 (For FCR) and §159 article 6 (For FRR) all prequalified units must be reevaluated at minimum every 5 year. The requirement is VALID from the implementation of SOGL, the 2nd of August 2017. Reevaluation can happen through activation in the market, where the demanded response is delivered. This can happen by voluntarily sending in data for a unit.

- Section 2 is an overview of the prequalification process.
- Section 3 contains the common requirements for all that wish to prequalify to deliver ancillary services.
- Sections 4 - 9 are the technical requirements and test sequences for each specific product in DK1 & DK2.
- Section 10 contains additional requirements for prequalification of aggregated portfolios and fluctuation consumption & production.
- Section 11 are the requirements for the measurement systems.
- Section 12 describes the auditing of provisions.
- Section 13 is an appendix mostly containing configurations for aFRR controllers and a list of needed signals.

If any questions or feedback, feel free to contact the prequalification team at their email addresses or send an email to PQ.Audits@Energinet.dk.

[1] Doc.no. 13/80940-90 "Ancillary services to be delivered in Denmark – Tender conditions". The document is available at Energinet's website.

2. Prequalification Process

The prequalification process ensures that the ancillary service provider can provide the provisions in accordance with the requirements from Energinet. The process ensures that Energinet has all the necessary documentation for the entities providing ancillary services. The required tests, documentation and data are described in this document. Further information about the practicalities can be obtained from the reserve connecting TSO.

The prequalification process as illustrated in Figure 1, begins with the potential provider notifying Energinet of their intention to conduct a test and as inviting Energinet to observe the test. Once the tests have been successfully completed, an official application must be submitted to Energinet. This information must be sent to PQ.audits@energinet.dk. To expediate the process, please attach all the relevant documentation. Energinet will verify whether all necessary information for the application is available, and if not, Energinet will request additional information before proceeding with the application review.

Once all the information has been received, Energinet will review the application. If the application does not meet the technical requirements, Energinet will request amendments and the process starts over. If the application lives up to the technical requirements, Energinet will send an official approval document, and only then is the entity allowed to participate in the ancillary service markets. Figure 1 - Overview of the prequalification process.

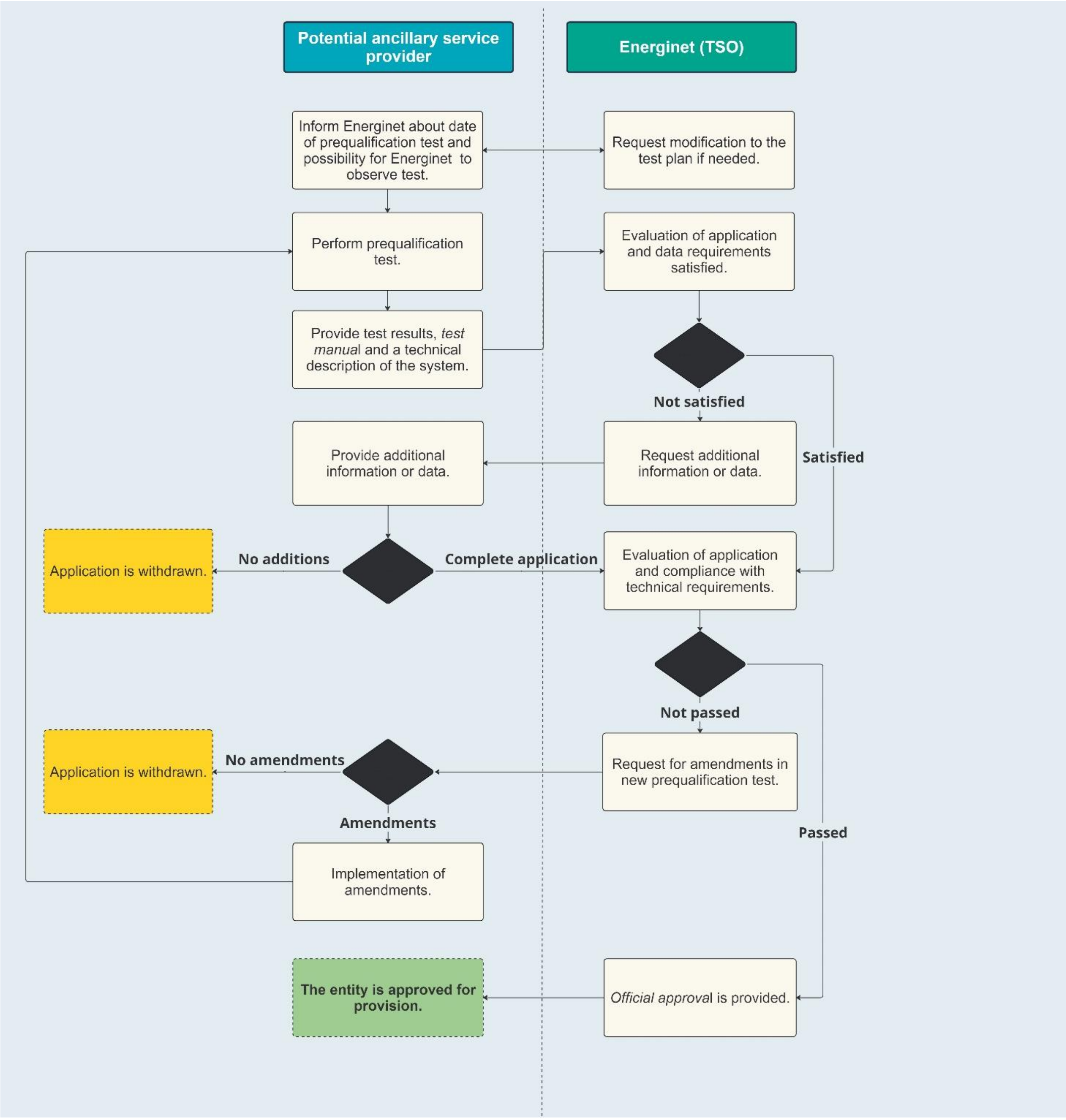

Figure 1 - Overview of the prequalification process.

3. Common requirements

Before a unit/system can join the market, it must be verified that the unit/system can provide the specific ancillary service.

Prequalification tests are done in close communication with Energinet. Energinet must be allowed to be present during tests of new units/control concepts. The service provider may carry out follow-up tests independently as agreed and subject to the submission of detailed documentation. However, Energinet will normally ask to be present during all tests. Tests in connection with prequalification for the provision of reserves are first and foremost done to determine if the unit/system can be approved for provision. If the unit/system is approved, a maximum threshold is set for the volume of power that the unit or aggregated portfolio of units can offer in the reserve capacity market in question.
The cost of IT connections, maintenance, grid tariffs etc. for energy provisions and tests/reliability testing must be covered solely by the service provider.

When sending test results, a test manual and a technical description of the system must be provided. The documents should be sent to PQ.Audits@Energinet.dk.

The test results must have the following format to be accepted:

TIMESTAMP [DD-MM-YYYY HH:MM:SS]	ACTUAL POWER [MW]	PLANNED POWER [MW]	FREQUENCY DEVIATION [mHz]

Table 1 - Format for test results.

The results can either be delivered in a .csv file, with semicolon separator (;) or as an excel sheet.
For mFRR & aFRR the frequency deviation is to be replaced with a setpoint signal.

3.1 Abbreviations utilized independent of specific ancillary service markets.

The table below designates generic parameters which are utilized across all ancillary service markets.

Parameter	Explanation
$\lvert\Delta P_{ss,theo.}\rvert$	The theoretical steady state response is measured in [MW]. The definition varies across ancillary service products. The purpose of it is to demonstrate what the theoretical power response is. It is equivalent to the target value.
$P_{ss,x}$	The actual steady-state response from the unit after ramps.
$\lvert\Delta P_{x\,min}\rvert$	The activated power x minutes after the start of the ramp.
$\Delta P(t)$	The active power response at time instant t.

Table 2 – Abbreviations used during the tests.

4. Test of FCR in DK1

This section describes the fundamental requirements for FCR (Frequency containment reserve) and required tests to be performed before entering the market.

4.1 FCR response requirements

FCR is used to stabilise the frequency close to the reference frequency (50 Hz) and to reduce the number of frequency dips/jumps. The service is activated for both small and large frequency deviations, as the function is activated in case of deviations from 50 Hz. Units providing FCR must measure the frequency and automatically activate reserves on their own accord, as they will not receive an external activation signal.

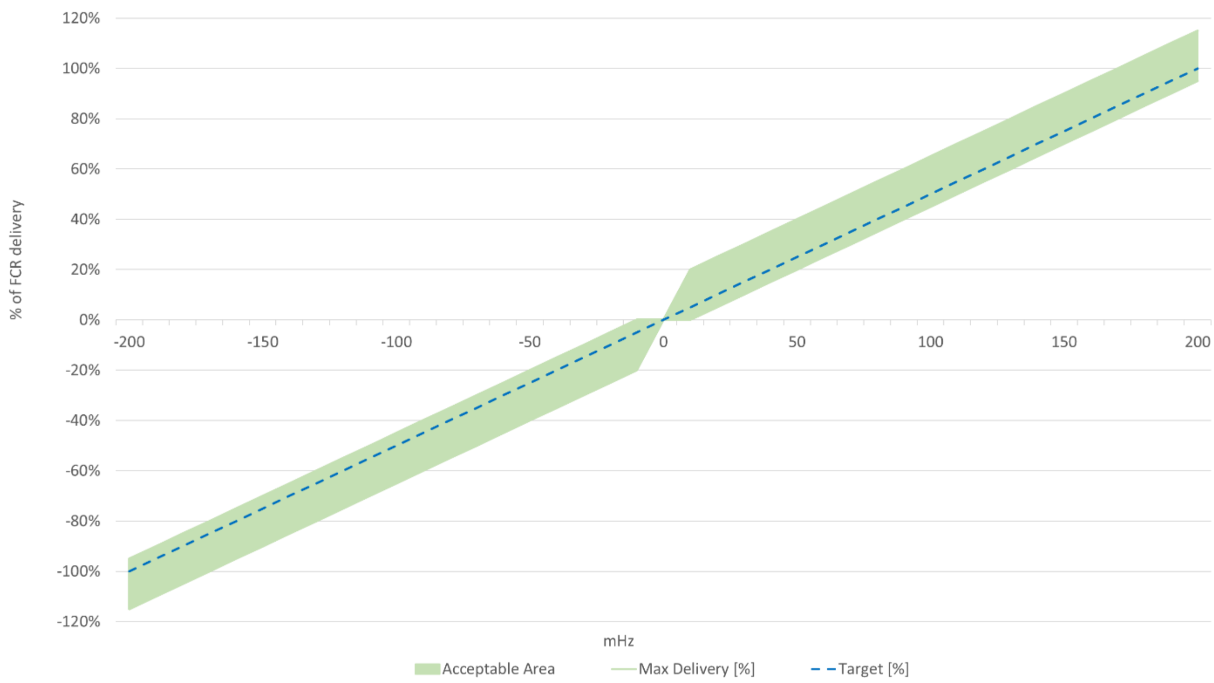

Figure 2 - Power response from FCR including the accepted tolerance area.

Power response to frequency fluctuations must be provided linearly to the frequency deviation in question for frequency deviations of up to ±200 mHz relative to the reference frequency as seen in Figure 2. For example, if the DK1 frequency deviates by 100 mHz, half of the reserve is activated.

The tolerance area is defined as +15%/-5%, thus an over-delivery is more accepted than under-delivery. The sign flips depending on the direction of the frequency deviation.

The tolerance creates a band equivalent to +30/-10 mHz. If a portfolio consists of several binary units, the acceptance criteria is to stay within this band. Thus, as a minimum FCR with binary units needs at least 5 steps in each direction.

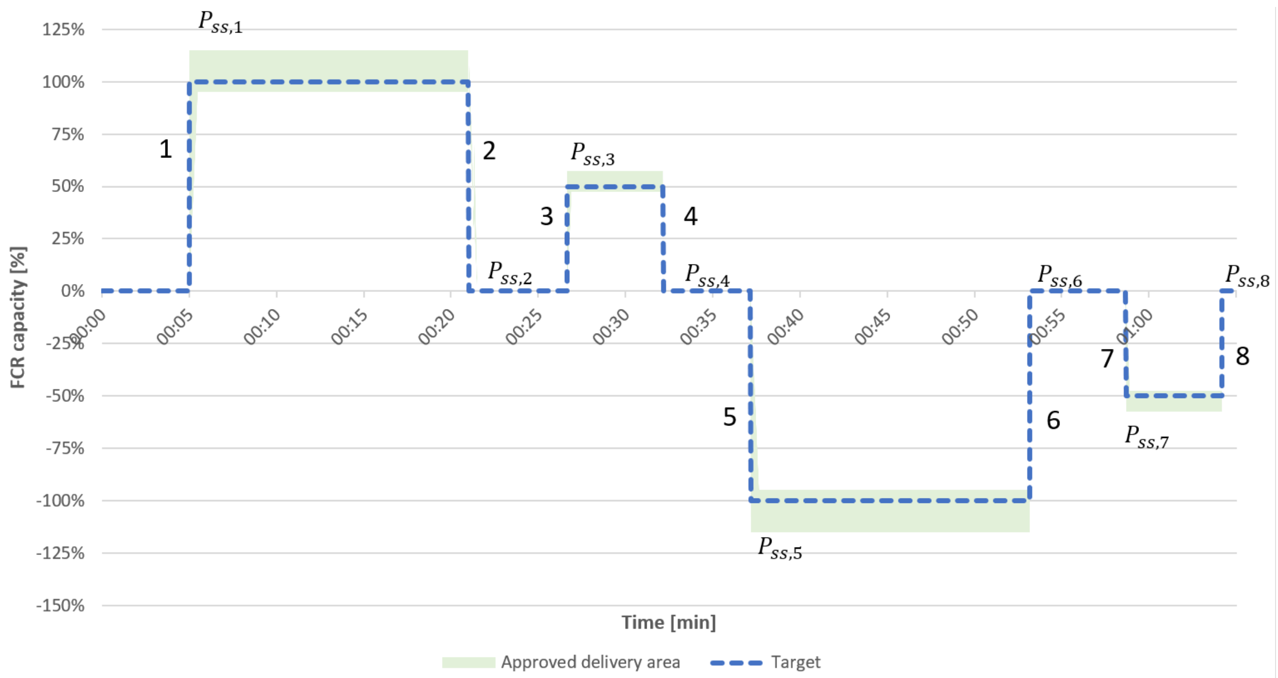

Figure 3 - Tests of minimum requirements for response for FCR at both upward and downward regulation (DK1).

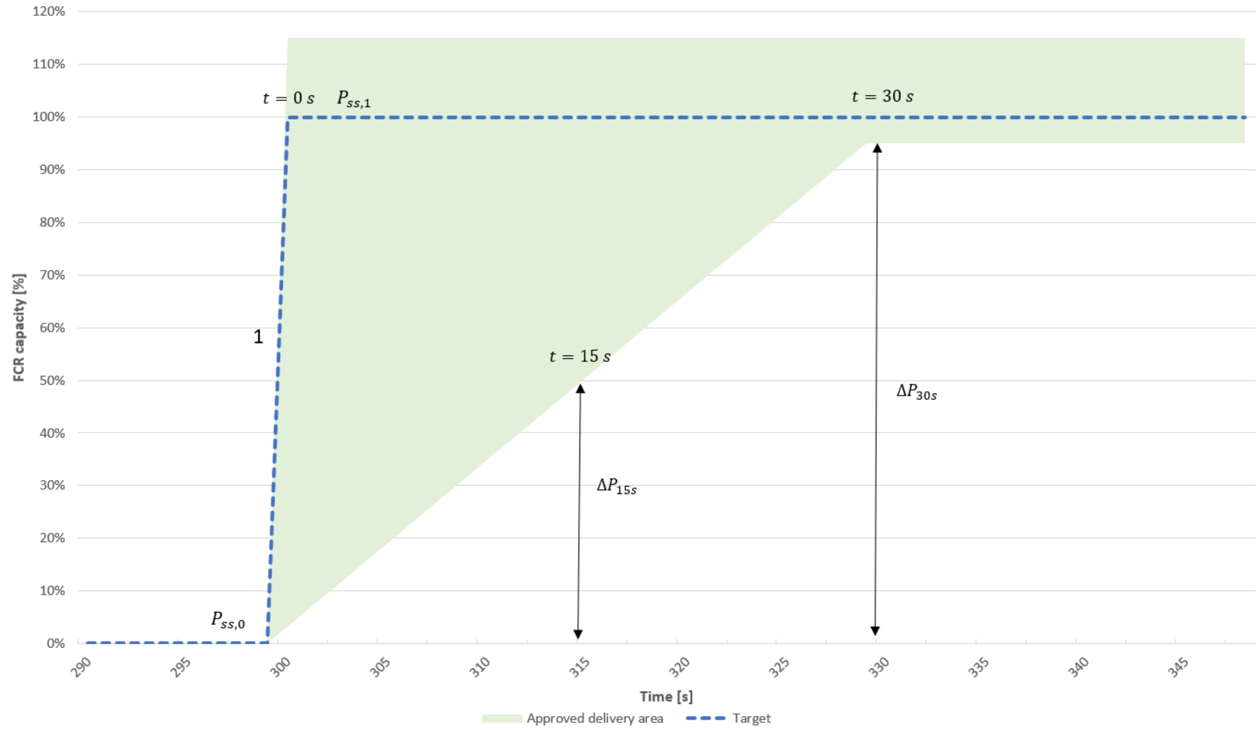

Figure 4 - A close-up visualization of step 1 in Figure 3.

REQ. NUMBER	RAMP NUMBER	REQUIREMENT SPECIFICATION (DESCRIPTIVE)	REQUIREMENT SPECIFICATION (MATHEMATICALLY)
1	At any ramp	15% overshoot is allowed. 5% undershoot is allowed.	Upwards direction: $-0.05 \leq \frac{P_{ss,1} - P_{ss,} - \lvert \Delta P_{ss,theoretical} \rvert}{\lvert \Delta P_{ss,theoretical} \rvert} \leq 0.15$ Downwards direction: $-0.05 \leq \frac{P_{ss,5} - P_{ss,6} + \lvert \Delta P_{ss,theoretical} \rvert}{\lvert \Delta P_{ss,theoretical} \rvert} \leq 0.15$
2	At any ramp	There must be a response within 2 seconds. There must be a larger than 50% response within 15 seconds. There must be a 100% response within 30 seconds.	$\lvert \Delta P_{2s} \rvert > 0$ $\lvert \Delta P_{15s} \rvert \geq 0.5 * \lvert \Delta P_{ss,theoretical} \rvert$ $\lvert \Delta P_{30s} \rvert \approx 1 * \lvert \Delta P_{ss,theoretical} \rvert$

Table 3 – Explaining the requirements for full FCR response test, as depicted in

Figure 3.

Please note that completion of the full tests specified in Figure 3 is only a requirement if the unit owner has applied to provide both upward and downward regulation. If only upward regulation is to be provided, the response to a negative frequency deviation must be verified and vice versa for only downward regulation.

4.2 Approval of frequency measurement

FCR providing units will not receive an activation signal from the TSO. It is required for the unit/provider to have a frequency meter installed locally, which can measure the grid frequency. The unit must activate based on the frequency measurement.

Therefor a prequalification of the units connected frequency meter is required. The grid frequency must be measured for 1 hour on a 1 second resolution and sent to the TSO with the rest of the test data. The frequency measurement requirements can be seen in Section 11.
The TSO recommends the providers to have decentralized frequency meters to higher security of delivery, but it is allowed to use the same frequency meters for multiple units, if a fallback solution is in place. This could be a backup frequency meter, placed somewhere else, which creates redundancy in case of power outage or similar.

4.3 Units with limited energy reservoir (LER)

There are additional requirements for units and portfolios with limited energy reservoir (LER units), such as batteries, and other units that can deplete 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 this means that a unit is defined as a LER unit if it cannot deliver 2 hours in both directions (up and down). Thus, an FCR providing unit is labeled a LER unit if it cannot endure maximum 4 hours of activation.

Even though there might be a LER unit 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 relevant.

4.3.1 Requirements for LER units

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). For FCR the table states you must reserve 25% of the prequalified FCR amount to NEM.

NEM and AEM are in CE called ARM and Reserve mode, however Energinet has chosen to use the same names as in DK2 and the Nordics. The minimum energy required (TminLER) in CE is still being discussed, and might end up being 30 minutes each direction, instead of the current 24 minutes.

E.g. If you wish to prequalify 1 MW of FCR from a LER unit, you must reserve 0.25 MW in both directions, which require at least a 1.25 MW LER unit. You must also reserve 24 minutes of energy in both directions, which requires at least 0.4 MWh capacity charged, as well as room to charge the LER unit 0.4 MWh more. This is a total energy storage of 0.8 MWh.

Documentation on how NEM and AEM are implemented is required and a test must be run to ensure they work as expected.

		FCR UP	FCR DOWN
REQUIRED POWER UPWARDS	[MW]	$+C_{FCR\ Up}$	$+0.25 \cdot C_{FCR\ Down}$
REQUIRED POWER DOWNWARDS	[MW]	$-0.25 \cdot C_{FCR\ Up}$	$-C_{FCR\ Down}$
REQUIRED ENERGY UPWARDS	[MWh]	$0.4\text{h} \cdot C_{FCR\ Up}$	-
REQUIRED ENERGY DOWNWARDS	[MWh]	-	$-0.4\text{h} \cdot C_{FCR\ Down}$

Table 4 – Showing the power and energy reservations for FCR.

4.3.2 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 at the same time 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 ($|\Delta f| \leq$ 50 mHz deviation from 50 Hz). When the frequency is outside the normal band ($|\Delta f| >$ 50 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 in Table 5Table . For FCR the unit enters NEM mode when there is energy left equivalent to 24 minutes of full response, or there is room for an equivalent of 24 minutes of full response. A full response referring to the sold FCR capacity in the market.

	FCR Up	FCR Down
SOC ENABLE NEM, *UPPER*	N/A.	$24\ minutes$
SOC DISABLE NEM, *UPPER**	N/A	$24\ minutes$
SOC DISABLE NEM, *LOWER**	$24\ minutes$	N/A
SOC ENABLE NEM, *LOWER*	$24\ minutes$	N/A

Table 5 - NEM thresholds for FCR.

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:

$$NEM_{Allowed} = \begin{cases} -1, & \text{if } 49.95 < f < 50.05 \text{ and } SOC < \ SOC_{NEM,lower,enable/disable} \\ 1, & \text{if } 49.95 < f < 50.05 \text{ and } SOC > \ SOC_{NEM,upper,enable/disable} \\ 0, & \text{otherwise} \end{cases}$$

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

It is important to note that both conditions must be met.
The 300 second average of $NEM_{allowed}$ is used and if the $NEM_{Current}$ is for example 0.5, then you must enable half of your NEM amount.

For FCR this is calculated as follows:

$$P_{tot,FCR} = P_{FCR} + P_{NEM} = P_{FCR} + 0.25 \cdot C_{FCR} \cdot NEM_{Current}$$

Table 6 shows explanations for the utilized parameters. It is vital to emphasize that $P_{tot,FCR}$ and P_{FCR} are direction-dependent, i.e. when providing downregulation their values are negative, and vice versa with the upregulation direction. C_{FCR} is always denoted positively since it reflects the sold capacity of FCR.

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

Table 6 - Explanation of symbols in used formulas for FCR.

For FCR P_{NEM} is set to be minimum 25% of the prequalified FCR capacity. The capacity reserved for NEM can be used in other markets, but not sold as ancillary service capacity, if it is used for energy management purposes.

4.3.3 Alert State Energy Management (AEM)

The Alert State Energy Management (AEM) mode must be entered when the entity is within the ranges seen in Table 7 For FCR the unit enters AEM mode when there is energy left equivalent to 5 minutes of full response, or there is room for an equivalent of 5 minutes of full response. A full response referring to the sold FCR capacity in the market. The entity can enter AEM no matter the frequency of the system.

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

Table 7 - Shows when the entity should enable and disable AEM.

An entity that enters AEM is regarded as unavailable and must report to Energinet that they are unable to deliver. When the entity is in AEM the frequency reference is altered and a new frequency reference is calculated. When this reference is changed from f_0, it is referred to as f_{ref} instead. 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.

$$f_{AEM} = \begin{cases} f_0, & \text{if } SOC \in \left[SOC_{AEM,lower}, SOC_{AEM,upper}\right] \\ f(t), & \text{otherwise} \end{cases}$$

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

$$P_{FCR}(t) = C_{FCR} \cdot \frac{\Delta f(t)}{200\ mHz} = C_{FCR} \cdot \left(f_{ref} - f(t)\right)$$

PARAMETER	EXPLANATION
$\boldsymbol{P_{FCR}(t)}$	Is the total power provided by the entity
$\boldsymbol{C_{FCR}}$	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
$\boldsymbol{f_{AEM}}$	Is either 50 Hz or the f(t) dependent on whether AEM is enabled or not

Table 8 – Explanation of variables/parameters.

This equation calculates the amount of FCR provided, by taking the difference between the reference frequency and the current frequency.

4.3.4 Demonstration of NEM and AEM Mode

The demonstration of NEM and AEM is up to the provider. This section is only to demonstrate a solution.

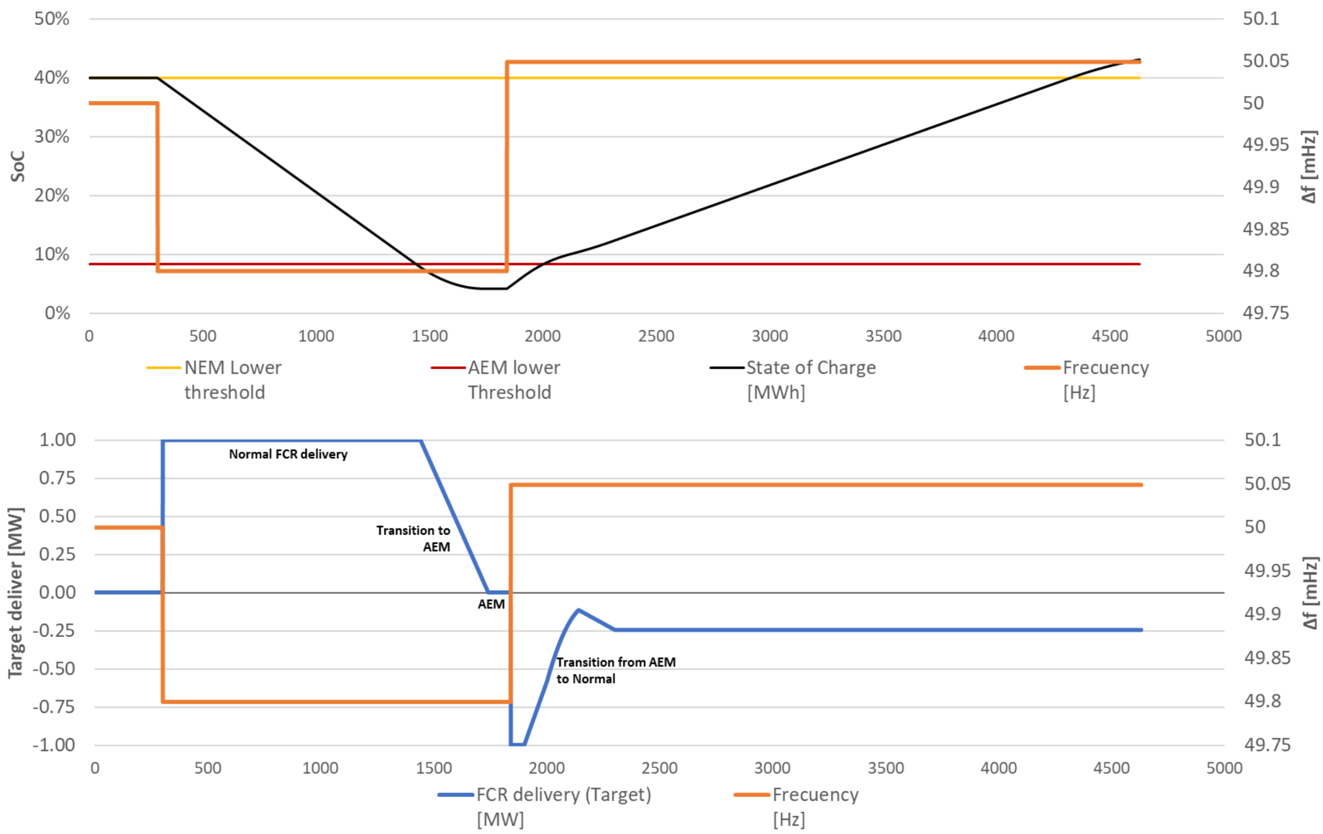

Figure 5 – Visual demonstration of energy management for FCR.

STEP	
1	100% activation
2	Continue until AEM is fully activated
3	Change frequency to 49.95/50.05 Hz,
4	NEM is activated
5	AEM is slowly deactivated as SOC is increasing

Table 9 - Demonstration of energy management for FCR.

The LER unit is operating close to NEM threshold and when frequency is stepped to maximum response. NEM will not activate due to frequency being out of normal range (+/- 50 mHz). The unit will maintain delivery until AEM threshold and initiate transition into AEM delivery. When AEM is fully transitioned, the frequency should switch again to 50 Hz (e.g., add the 50 mHz in deviation to minimize restoration time). The SoC will increase due to NEM activation, AEM will immediately respond to the frequency change (capped to -1 MW) and benefit the SoC. However, due to the 5 min mean, the AEM response will transition towards 0 MW. When SoC exceeds the AEM threshold, AEM deactivates and the FCR delivery will transition from AEM to normal – these three transitions results in the seemingly odd delivery. Eventually, the SoC exceeds the NEM threshold and deactivate. All modes are then testes in one direction, which is considered enough for an approval.

5. Test of FCR-D in DK2

This section describes the fundamental requirements for FCR-D (Frequency containment reserve for disturbance) and required ancillary service tests to be done before the unit can form part of/be used in the market.

5.1 FCR-D response requirements

FCR-D is used to reduce frequency dips/jumps. The service is activated in case of large frequency deviations, as this function is activated at frequencies below 49.9 Hz or larger than 50.1 Hz, as visualized in Figure 6.

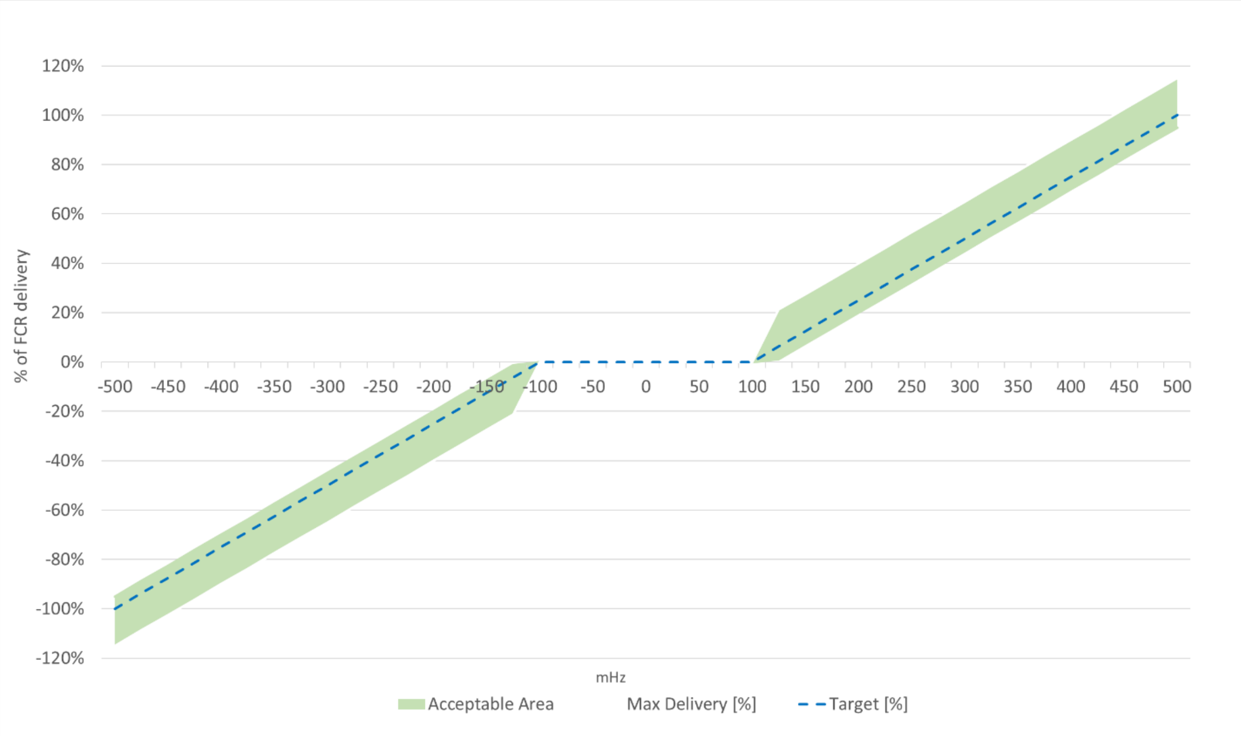

Figure 6 - Activation frequencies for FCR-D ranging with +-400 mHz from 49.9 and 50.1 Hz.

Regulation is performed as a very fast-reacting proportional control. Units providing FCR-D must measure the frequency and automatically activate reserves on their own accord, as they will not receive an external activation signal.

FCR-D is split into two distinct subtypes, namely ***FCR-D dynamic*** and ***FCR-D static***. Table 10 designates what tests to perform, dependent on the specific FCR-D product type.
The FCR-D Dynamic is a product that can activate and deactivate FCR-D in a droop-based manner, and the entity is tested that their response has sufficient 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 after activation, where the entities must deactivate and reestablish to allow for a new activation. Non-continuous FCR is where the response is step based.

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 5.1.1	Section 5.1.3	Section 5.1.4	Section 5.1.5

Table 10 - 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 and describe the necessary tests to perform.

5.1.1 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 11. 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 5.3. Figure 6 illustrate the test sequence for downregulation and upregulation, respectively. The ramp rate can be calculated per ramp. For instance, for FCR-D upregulation, the frequency changes from 49.9 Hz in ramp 0 to 49.45 Hz in ramp 1, which should be effectuated upon within 3.1 seconds (from second 30 to second 33.1). Thus, the ramp rate for this specific frequency change is equal to 0.14 Hz/s.

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 ($\Delta P_{ss} = max$). *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 ($\Delta P_{ss} = 0$)
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 11- FCR-D dynamic up- and downwards fast ramp test. Ramp speed [Hz/s] changes dependent on the specific ramp.

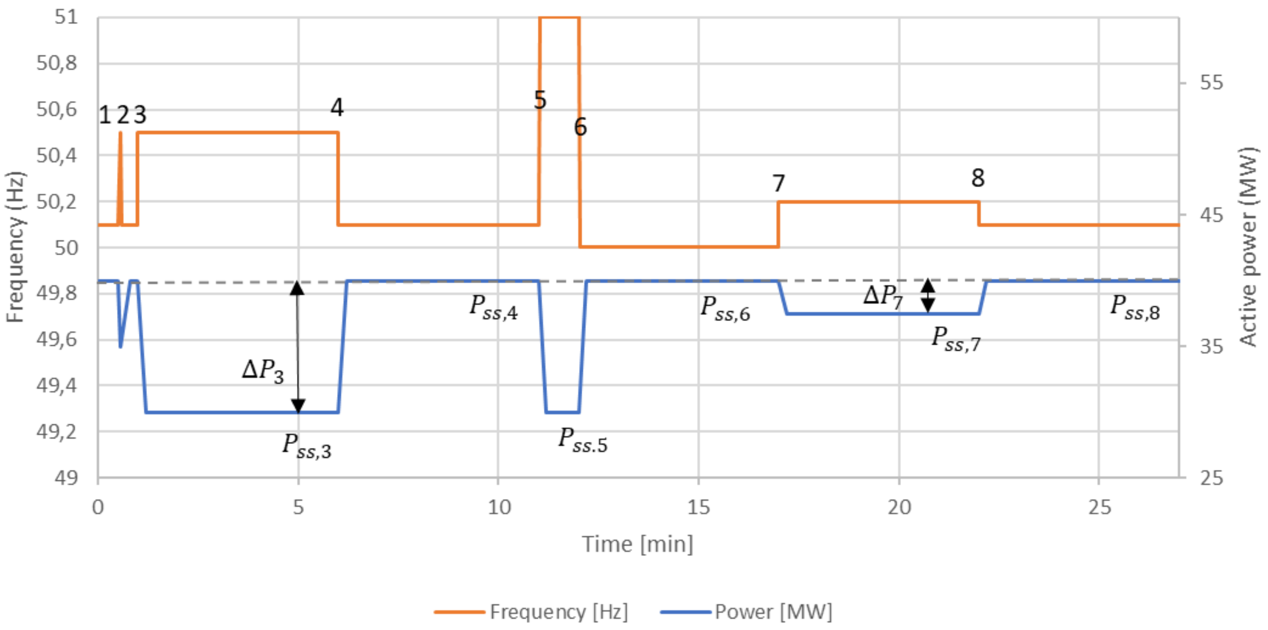

Figure 7 - FCR-D dynamic downwards fast ramp test. FCR-N is omitted in this illustration.

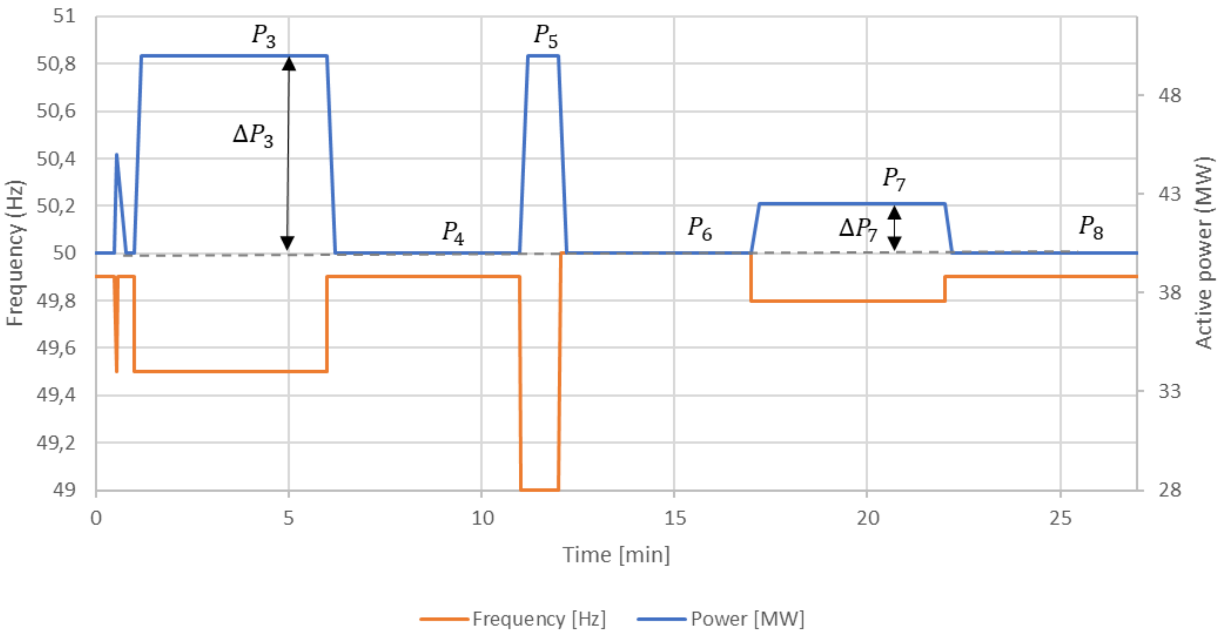

Figure 8 - FCR-D dynamic upwards fast ramp test. FCR-N is omitted in this illustration.

Figure 7 and Figure 8 shows the necessary requirements to fulfill during the fast ramp test sequence. It is designated in Table 12 for which ramps the specific requirements are valid for.

REQ. NUMBER	RAMP NUMBER	REQUIREMENT SPECIFICATION (DESCRIPTIVE)	REQUIREMENT SPECIFICATION (MATHEMATICALLY)
1	At ramp 3	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: $-0.05 \leq \frac{P_{ss,3} - P_{ss,4} - \lvert\Delta P_{ss,theoretical}\rvert}{\lvert\Delta P_{ss,theoretical}\rvert} \leq 0.2$ Downwards direction: $-0.2 \leq \frac{P_{ss,3} - P_{ss,4} + \lvert\Delta P_{ss,theoretical}\rvert}{\lvert\Delta P_{ss,theoretical}\rvert} \leq 0.05$
2	Ramp 5	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]), be able to deliver minimum 86% of the theoretical steady state response ($\lvert\Delta P_{ss,theoretical}\rvert$). The activated power shall not decrease below the power at 7.5 seconds at any point in time until start of ramp 6 (back to 50.0 Hz).	$\lvert\Delta P_{7.5s}\rvert \geq 0.86 * \lvert\Delta P_{ss,theoretical}\rvert$ $\lvert\Delta P_{7.5s\to 60s}\rvert \geq 0.86 * \lvert\Delta P_{ss,theoretical}\rvert$
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.	$\lvert E_{7.5s}\rvert \geq 3.2s * \lvert\Delta P_{ss,theoretical}\rvert$
4	Ramp 1 & 2	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 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.	Upwards direction: $\max_{k=t_{nadir}\to t_{nadir+40}} \int_{t_{nadir}}^{t=k} \left(\Delta P(t) - \min\left(\lvert\Delta P_{nadir}\rvert, 0.5 \cdot \lvert\Delta P_{ss,theo}\rvert\right)\right) dt \leq 1.7 \cdot \lvert\Delta P_{ss,theo}\rvert$ Downwards direction: $\max_{k=t_{zenith}\to t_{zenith+40}} \int_{t_{zenith}}^{t=k} \left(-\Delta P(t) - \min\left(\lvert\Delta P_{zenith}\rvert, 0.5 \cdot \lvert\Delta P_{ss,theo}\rvert\right)\right) dt \leq 1.7 \cdot \lvert\Delta P_{ss,theo}\rvert$

Table 12 - Requirements associated to the conduction of the fast ramp test for dynamic FCR-D.

Figure 9 unfolds requirement number 2 and 3, and Figure 10 visually describes requirement number 4. Table 13 contains explanations for each of the utilized variable/parameter names.

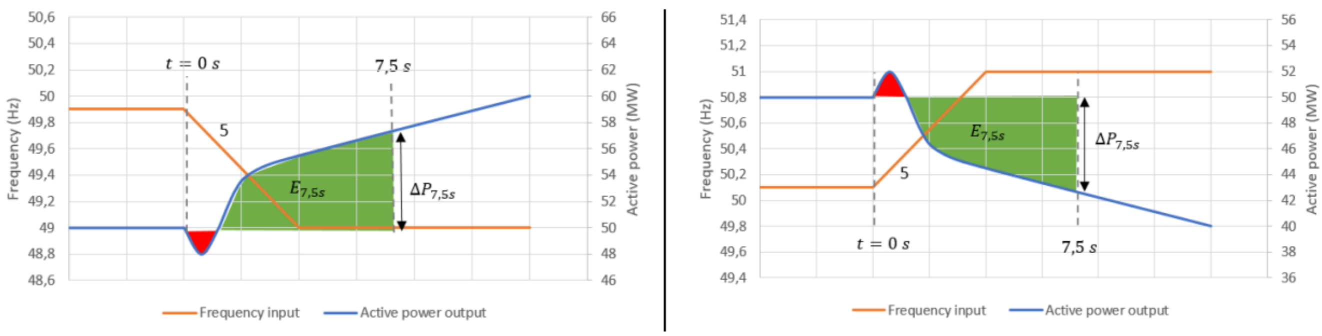

Figure 9 - Dynamic performance requirements on ramp 5 (as seen in Figure 7 & Figure 8) for FCR-D dynamic upwards (left) and downwards (right). $E_{7.5s}$ is equal to the green area subtracted with the red area.

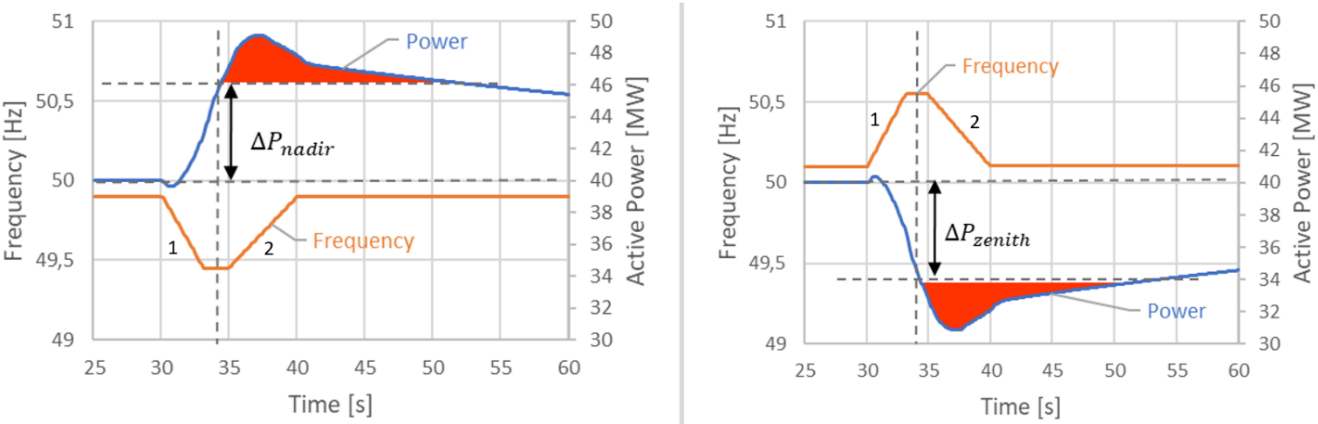

Figure 10 - Deactivation test on ramp 1 and 2 for FCR-D dynamic upwards (left) and FCR-D dynamic downwards (right).

PARAMETER	EXPLANATION
$\|\boldsymbol{\Delta P_{ss,theo.}}\|$	The theoretical steady state response is measured in [MW] for a frequency change from 49.9 [Hz] to 49.5 [Hz] and 50.1 [Hz] to 50.5 [Hz] for FCR-D upregulation and FCR-D downregulation, respectively.
$\boldsymbol{P_{ss,x}}$	The actual steady-state response from the unit after ramp number x.
$\|\boldsymbol{\Delta P_{7.5s}}\|$	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.
$\|\boldsymbol{E_{7.5s}}\|$	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 13 - Explanation of variables/parameters utilized in Table 12.

5.1.2 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 11. 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.

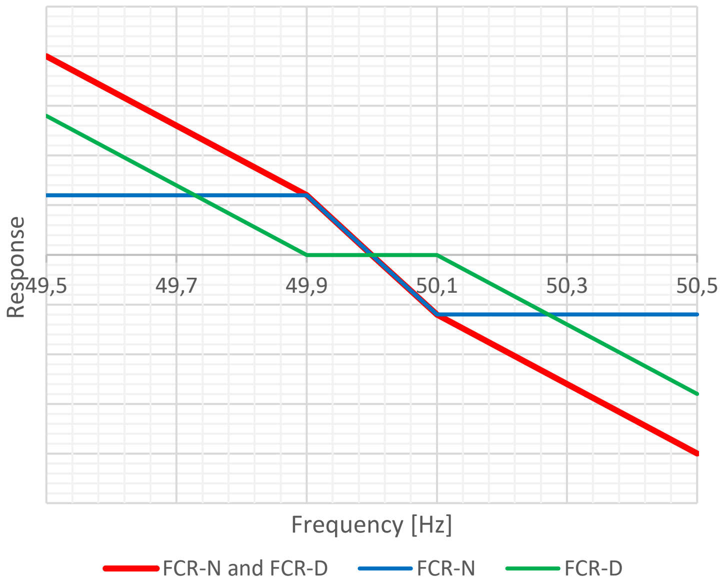

Figure 11 - Steady state active power activation as a function of frequency, droop profile of FCR-N (blue), FCR-D (green) and both combined (red).

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-D, is shown in Table 14. The utilized variables are explained in Table 15.

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 7 and Figure 8 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 14 - Requirements associated to the conduction of the fast ramp test for co-delivery of dynamic FCR-D and FCR-N, as outlined with ramp number 7 and 8 in Figure 7.

PARAMETER	EXPLANATION
$\lvert\boldsymbol{\Delta P_{FCR-D,\mathrm{up},ss,theo.}}\rvert$	The theoretical steady state response is measured in [MW] for a frequency change from 49.9 [Hz] to 49.5 [Hz] and 50.1 Hz to 50.5 Hz for FCR-D upregulation and FCR-D downregulation, respectively.
$\lvert\boldsymbol{\Delta P_{FCR-N,ss,theo.}}\rvert$	The theoretical steady state response is measured in [MW] for a frequency change from 50 to 50.1/49.9 [Hz] for FCR-N.
$\boldsymbol{P_{ss,6}}$	Steady state power response after ramp 6.
$\boldsymbol{P_{ss,8}}$	Steady state power response after ramp 8.

Table 15 - Explanation of variables/parameters utilized in Table 14.

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5.1.3 Sine response test sequence

The sine response test shall be performed for all FCR-D dynamic providing entities. The test is executed by performing a sine response testing as shown in Figure 12. 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 ± 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 16 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.

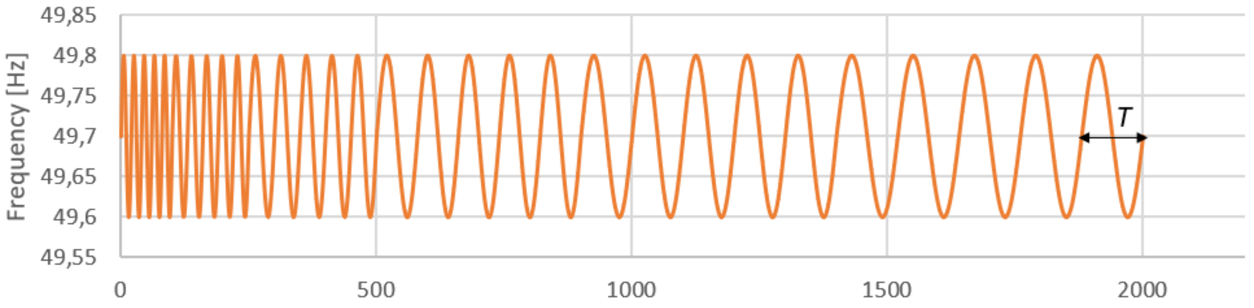

Figure 12 – Illustration of the full FCR-D sine test for upregulation. Down regulation is equal in amplitude but centered at 50.3 Hz.

Between each change in periods, it is possible to pause the test for a duration, however coherent 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 16 - 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).

5.1.4 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 17. The ramps shall be effectuated at a rate that matches the need start and ending times of the ramps. Figure 13 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 17 - FCR-D static up- and downwards ramp static test.

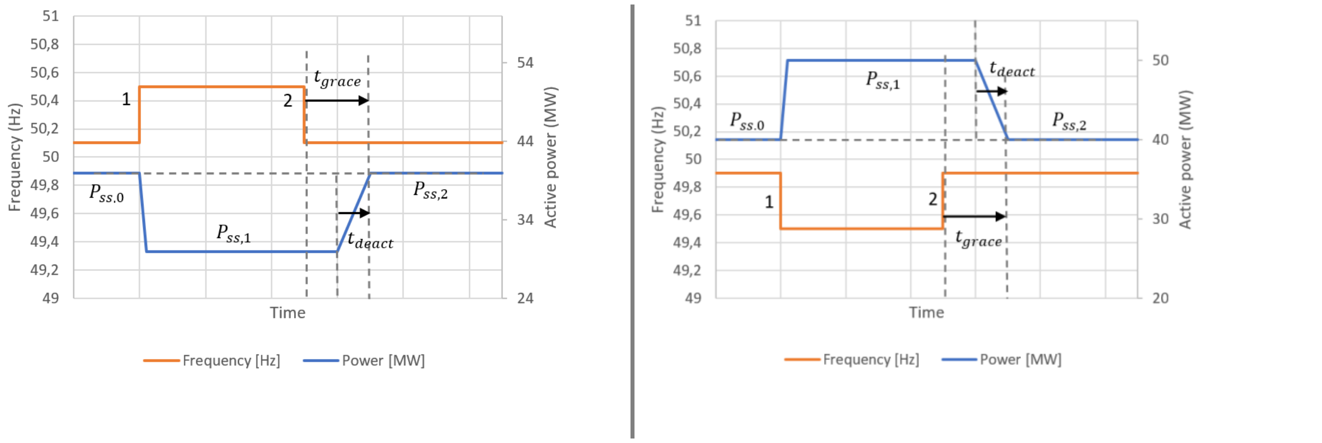

Figure 13 - FCR-D static downwards (left) and upwards (right) ramp test. FCR-N is omitted in this illustration.

Table 18 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 19 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: $-0.05 \le \frac{P_{ss,1} - P_{ss,0} - \lvert \Delta P_{ss,theo.} \rvert}{\lvert \Delta P_{ss,theo.} \rvert} \le 0.1$ Downwards direction: $-0.1 \le \frac{P_{ss,1} - P_{ss,0} + \lvert \Delta P_{ss,theo.} \rvert}{\lvert \Delta P_{ss,theo.} \rvert} \le 0.05$
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).	$\lvert \Delta P_{7.5s} \rvert \ge 0.86 * \lvert \Delta P_{ss,theo.} \rvert$ $\lvert \Delta P_{7.5s \to 60s} \rvert \ge 0.86 * \lvert \Delta P_{ss,theo.} \rvert$
3	Ramp 1	The supplied energy must for 7.5 seconds from the start of the ramp, be equivalent to minimum 3.2 seconds multiplied with the theoretical steady state response.	$\lvert E_{7.5s} \rvert \ge 3.2\text{s} * \lvert \Delta P_{ss,theo.} \rvert$
4	Ramp 1	The overshoot in the power response to ramp 1 must not exceed 20%.	$\lvert \Delta P_{max} \rvert \le 1.2 * \lvert \Delta P_{ss,theo.} \rvert$
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	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 18 - Requirements associated to the conduction of the ramp static test sequence for static FCR-D, as outlined in Figure 13.

PARAMETER	EXPLANATION
$\boldsymbol{P_{ss,0}}$	The actual power baseline the of unit, before ramp 1.
$\lvert\boldsymbol{\Delta P_{ss,theo.}}\rvert$	The theoretical steady state response is measured in [MW] for a frequency change from 49.9 to 49.5 [Hz] FCR-D upregulation and 50.5 to 50.1 [Hz] for FCR-D downregulation. It is calculated with the provider's steady state response calculation method.
$\lvert\boldsymbol{\Delta P_{max}}\rvert$	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.
$\lvert\boldsymbol{\Delta P_{7.5s}}\rvert$	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 7.5 s after the start of the ramp, which is calculated as: $E_{7.5s} = \int_{t}^{t+7.5s} \Delta P(t)dt$

Table 19 - Explanation of variables/parameters utilized in Table 18.

5.1.5 Linearity test sequence

FCR-D resources have to contribute within the blue area in Figure 14. 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 14 are provided in Table 20. 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.

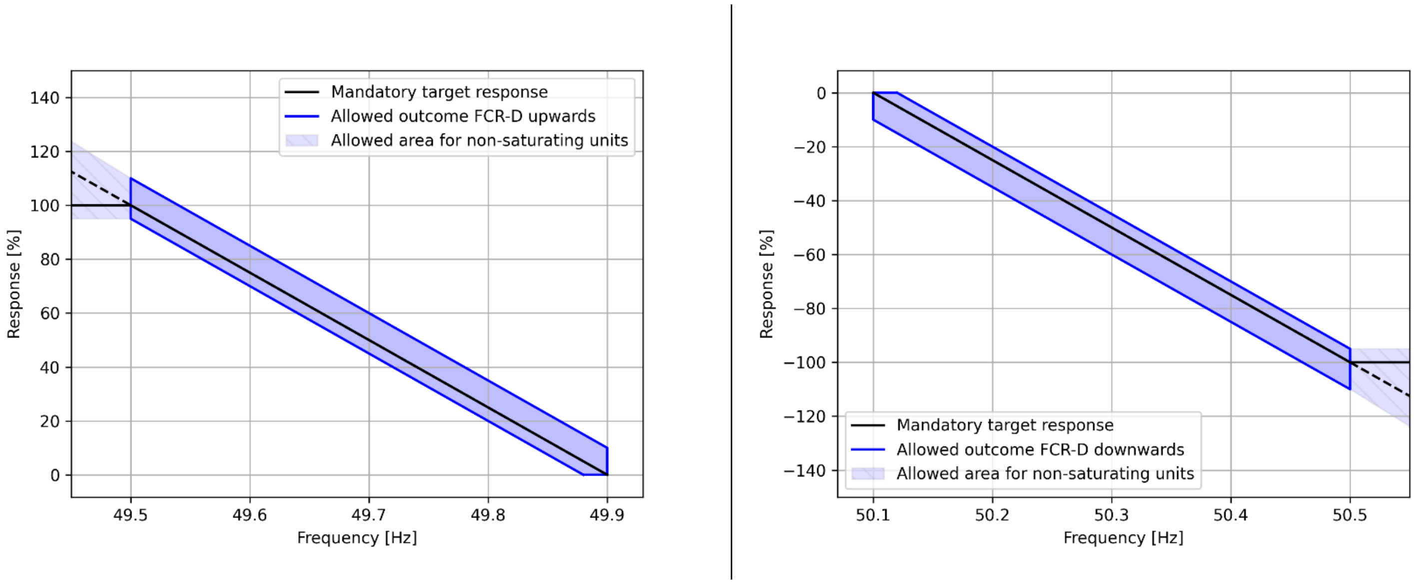

Figure 14 - Activation of piecewise linear FCR-D resources. The black line indicates the mandatory target response, and the blue area defines the allowed outcome of the deviations.

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 20 - Coordinates of the corners in Figure 14. 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 Table 20 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. While the test only has 5 steps, there must be at least 7 steps in operation. The 5 steps are simply to decrease the test time.

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. 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 16 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 21 contains the requirement to obey for all frequency steps and Table explains the utilized variables.

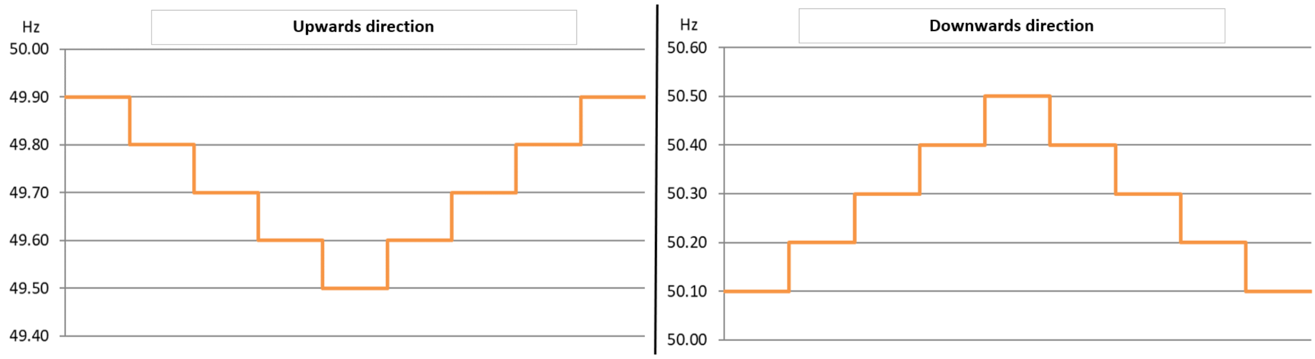

Figure 15 - FCR-D up- (left part) and downwards (right part) linearity test sequence.

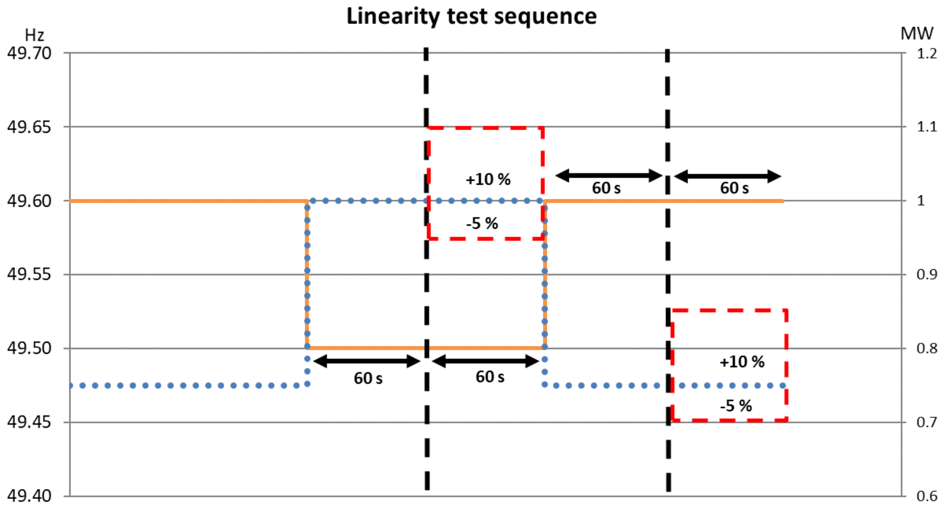

Figure 16 - Allowed response area for FCR-D for the frequency steps from 49.6 Hz → 49.5 Hz → 49.6 Hz. The orange line is the frequency step. The blue dotted line is the directly proportional FCR response per MW. The red dashed squares indicate the allowed response area for the 10 second moving average.

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. For upwards regulation, the maximal allowed overshoot is +10% and maximal allowed undershoot is -5%. For downregulation, it is vice versa, thus +5% and -10%. 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 21 - 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 and 50.1 [Hz] to 50.5 [Hz] for FCR-D downregulation.
$\boldsymbol{\Delta\bar{P}(t)}$	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

Δf	frequency deviation from 50 Hz for the evaluated step.
K	width of the moving average, equal to 10 seconds

Table 22 - Explanation of variables/parameters utilized in Table 21.

5.2 Approval of frequency measurement

FCR-D providing units will not receive an activation signal from the TSO. It is required for the unit/provider to have a frequency meter installed locally, which can measure the grid frequency. The unit must activate based on the frequency measurement.
Therefor a prequalification of the units connected frequency meter is required. The grid frequency must be measured for 1 hour on a 1 second resolution and sent to the TSO with the rest of the test data. The frequency measurement requirements can be seen in Section 11.
The TSO recommends the providers to have decentralized frequency meters to higher security of delivery, but it is allowed to use the same frequency meters for multiple units, if a fallback solution is in place. This could be a backup frequency meter, placed somewhere else, which creates redundancy in case of power outage or similar.

5.3 Units with limited energy reservoir (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.

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.

5.3.1 Requirements for LER units

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 23 shows the amounts reserved for FCR-D. NEM and AEM will be explained in a later subsection. For FCR-D you must reserve 20% of the prequalified FCR-D amount to NEM in the opposite direction.

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.

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

Table 23 - showing the power and energy reservations for FCR-D.

5.3.2 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 in Table 24. For FCR-D the battery enters NEM mode when there is energy left equivalent to 20 minutes of full response, or there is room for an equivalent of 20 minutes of full response.

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

Table 24 - 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 used, and if the $NEM_{Current}$ is for example 0.5, then you must enable half of your NEM amount. For FCR-D this is calculated as follows:

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

Table 25 provides an explanation of utilized parameter names. It is vital to emphasize that $P_{tot,FCR-D}$ and P_{FCR-D} are direction-dependent, i.e. when providing downregulation their values are negative, and vice versa with the upregulation direction. C_{FCR-D} is always denoted positively since it reflects the sold capacity of FCR-D.

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 ancillary service capacity, if it is used for energy management purposes.

5.3.3 Alert state energy management (AEM)

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

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

$$f_{AEM} = \begin{cases} f_0, & \text{if } SOC \in \left[SOC_{AEM,lower}, SOC_{AEM,upper}\right] \\ f(t), & \text{otherwise} \end{cases}$$

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

When this reference is changed from f_0. it is referred to as f_{ref} instead.

$$P_{FCR-X}(t) = C_{FCR-D} \cdot \frac{\Delta f(t)}{400\ mHz} = C_{FCR-D} \cdot \left(f_{ref} - f(t)\right)$$

PARAMETER	EXPLANATION
$\boldsymbol{P_{FCR-X}(t)}$	Is the total power provided by the entity
$\boldsymbol{C_{FCR-D}}$	Is the amount of FCR-X that is meant to be provided
$\boldsymbol{f_{ref}}$	Is the frequency reference
$\boldsymbol{f(t)}$	Is the frequency to timestep t
$\boldsymbol{f_{AEM}}$	Is either 50 Hz or the f(t) dependent on whether AEM is enabled or not

Table 27 - How to adjust the power provided in AEM.

This equation calculates the amount of FCR-D 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 49.9/50.1 Hz there is no dead band.

5.3.4 Demonstration of NEM/AEM

NEM & AEM must be tested, however it is up to the provider how they would like to test the systems. Table 28 outlines a suggestion for demonstration of NEM and AEM functionalities. The corresponding test sequence is shown in Figure 17, which includes input frequency, active power output (% of FCR-D capacity) and state of charge of the LER unit.

STEP	
1	100% activation
2	Continue until entering NEM threshold
3	Change frequency to 49.9/50.1 Hz
4	NEM is activated
5	100% activation untill NEM is deactivated and entering AEM threshold
6	AEM is activated
7	Change frequency to 49.9/50.1 Hz

Table 28 – Energy management test for FCR-D up.

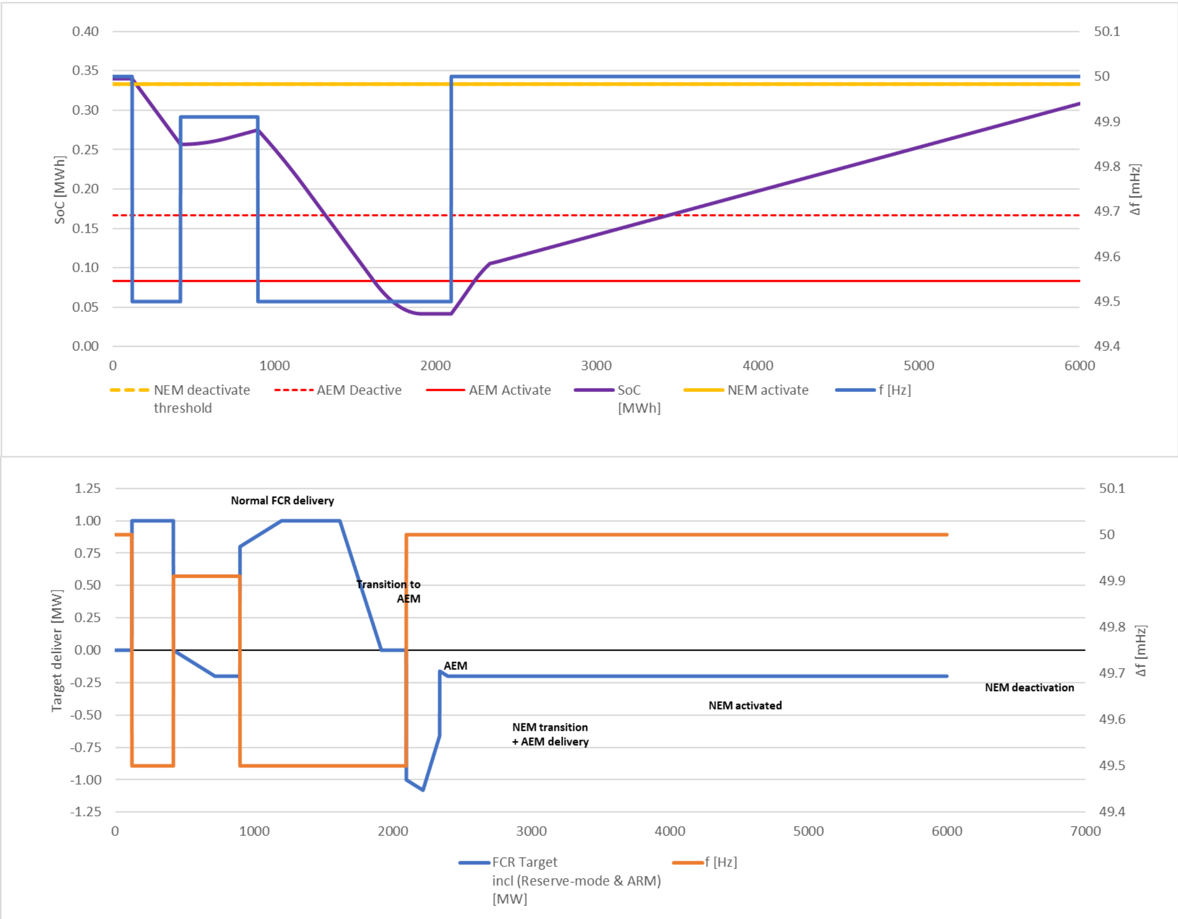

Figure 17 - Energy management test of FCR-D up.

6. Test of FCR-N in DK2

This section describes the fundamental requirements for FCR-N (frequency containment reserve - normal operation) and required ancillary service tests to be done before the unit can form part of/be used in the market.

6.1 FCR-N response requirements

FCR-N is used to stabilise the frequency close to the reference frequency (50 Hz) and to reduce the number of frequency dips/jumps. The service is activated for both small and large frequency deviations, as the function is activated in case of deviations from 50 Hz, as visualized in Figure 18. Thus, FCR-N providing units must be fully activated at +/- 100 mHz frequency deviations.

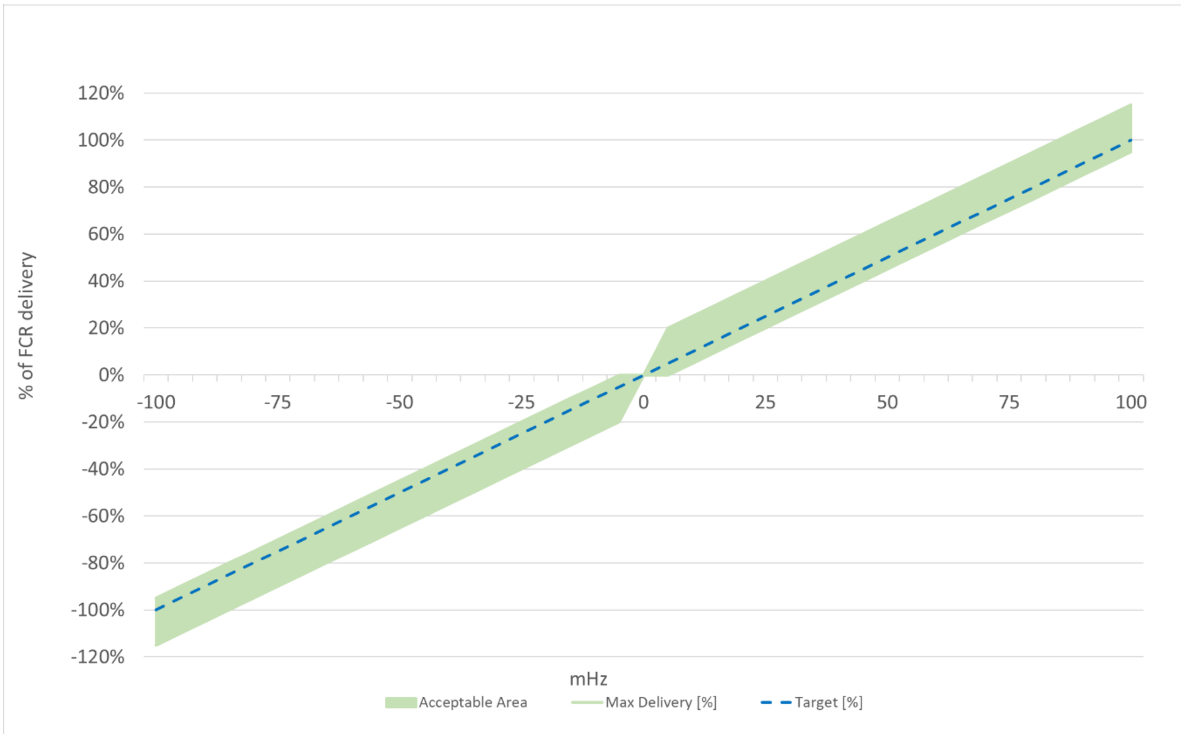

Figure 18 - Activation frequencies for FCR-N ranging with +/- 100 mHz from 50 Hz.

To get prequalified for FCR-N, there are three different tests that must be run. 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 6.1.1	Section 6.1.2	Section 6.1.3

Table 29 - showing the different tests that must be run to prequalify for FCR-N.

Section 6.1.1, 6.1.2 and 6.1.3 outline the specific tests to perform for FCR-N providing entities.

6.1.1 Step response test sequence

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 30Table . 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 19 illustrates the test sequence for the step response test. Endurance and energy management of entities with LER is unfolded in section 6.2

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 30 - FCR-N step test sequence.

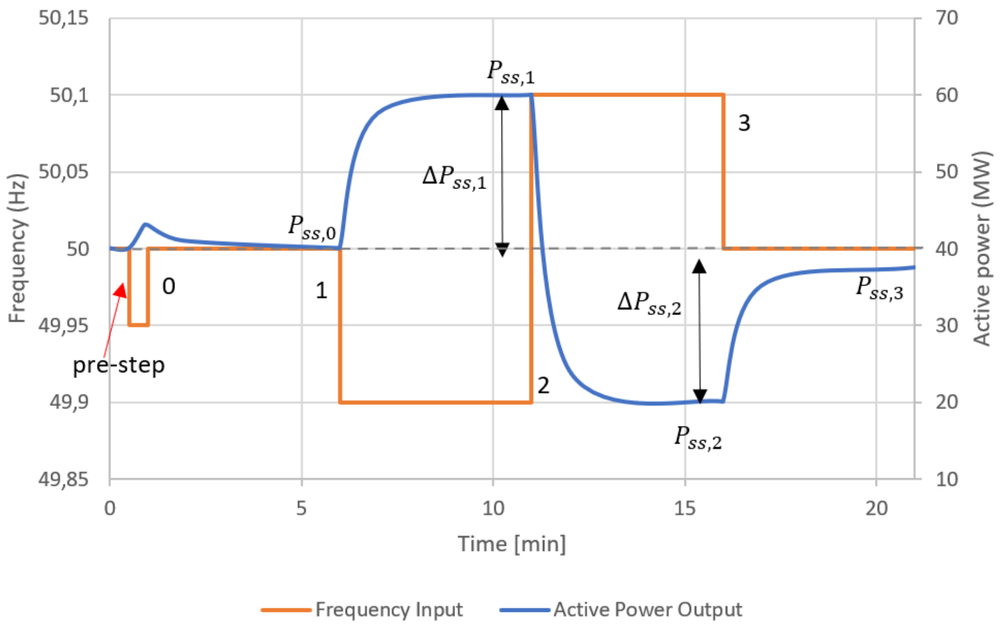

Figure 19 - FCR-N step response sequence.

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 31 shows the requirements to obey when performing the step response test for FCR-N. Table 32 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: $-0.2 \leq \frac{\Delta P_{ss,2} + \lvert\Delta P_{ss,theoretical}\rvert}{\lvert\Delta P_{ss,theoretical}\rvert} \leq 0.05$
2	Ramp 1	There is no restrict ramp rate requirement for FCR-N. However, to obey with the sine response test, the actual response must 60 seconds after the initialization of the activation, be able to deliver minimum 63% of the theoretical steady state response.	$\lvert\Delta P_{60s}\rvert \geq 0.63 * \lvert\Delta P_{ss,theo.}\rvert$ $\lvert\Delta P_{150s}\rvert \geq 0.95 * \lvert\Delta P_{ss,theo.}\rvert$

Table 31 - Requirements associated to the conduction of the step response test FCR-N.

PARAMETER	EXPLANATION
$\lvert\boldsymbol{\Delta P_{ss,theo.}}\rvert$	The theoretical steady state response is measured in [MW] for a frequency deviation of 0.1 Hz in upwards or downwards direction.
$\boldsymbol{P_{ss,x}}$	The actual steady-state response from the unit after ramp number x.
$\lvert\boldsymbol{\Delta P_{60s}}\rvert$	It is the activated power 60 seconds after the start of the ramp.
$\boldsymbol{\Delta P(t)}$	The active power response at time instant t.
$\boldsymbol{P_0}$	Baseline power consumption/production.

Table 32 - Explanation of variables/parameters utilized in Table 31.

6.1.2 Sine response test sequence

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 20. 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 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.

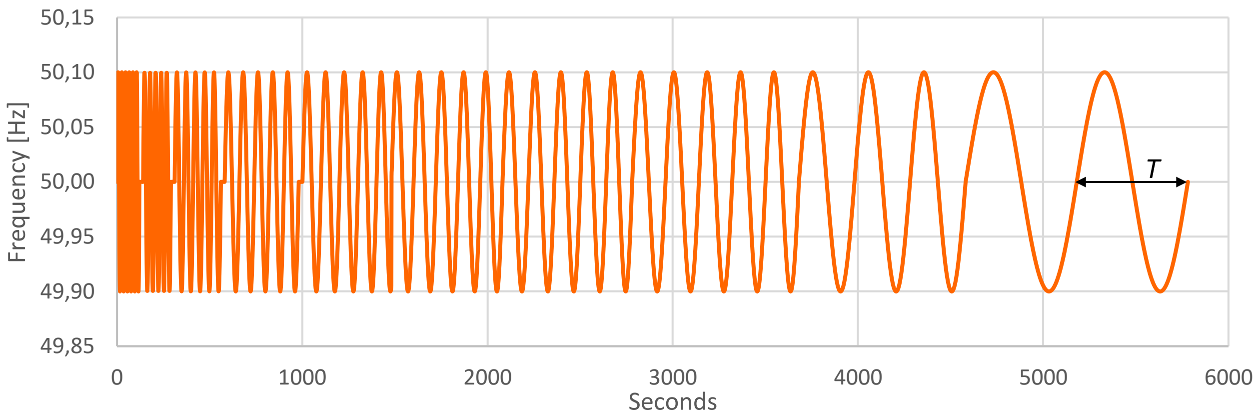

Figure 20 - illustrates the full FCR-N sine test without breaks.

Between each change in periods, it is possible to pause the test for a duration, however coherent 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 33 - 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).

6.1.3 Linearity test sequence

Piecewise linear FCR-N resources must activate their contribution within the blue area in Figure 21. 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 21 are provided in Table 34 below. The coordinates are given clockwise starting from the maximum response in downwards direction at 50.1 Hz. The full requirement is calculated via linear interpolation of the provided coordinates.

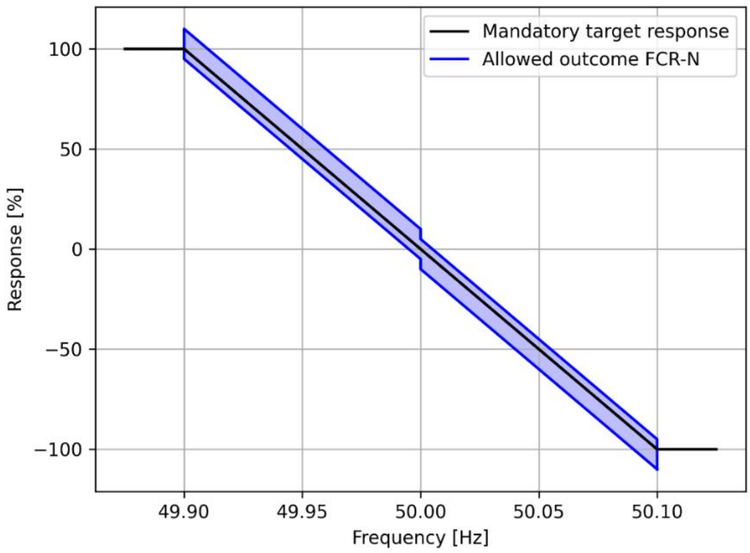

Figure 21 - Activation of piecewise linear FCR-N resources. The black line indicates the mandatory target response, and the blue area defines the allowed outcome of the deviations.

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

Table 34 - Coordinates of the corners Figure 21. 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 22. 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).

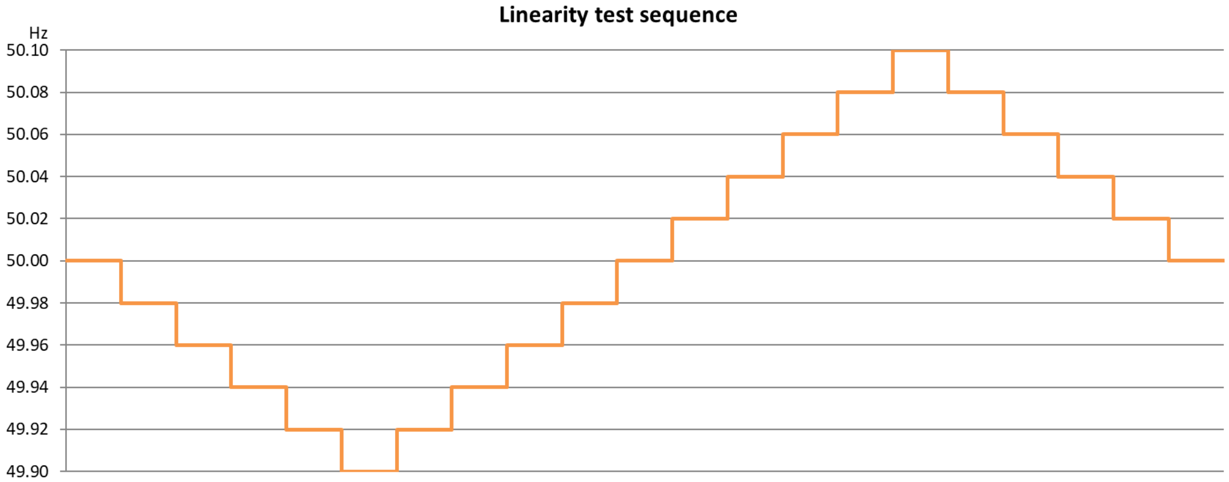

Figure 22 - FCR-N linearity test sequence.

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 23 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 35 contains the requirement to obey with when performing the linearity test and Table 36 explains the utilized variables.

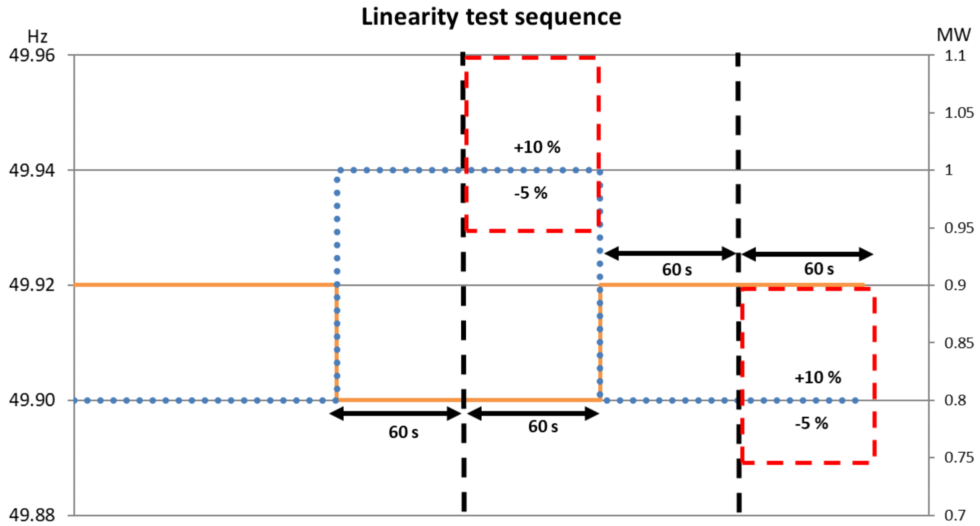

Figure 23 - Allowed response area for FCR-N for the frequency steps from 49.92 Hz → 49.90 Hz → 49.92 Hz. The orange line is the frequency step. The blue dotted line is the directly proportional FCR response. The red dashed squares indicate the allowed response area, denoted to assess the FCR response 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 maximum 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 35 - Requirement associated to the conduction of the linearity step test for FCR-N, as outlined in Figure 23.

PARAMETER	EXPLANATION
$\lvert\boldsymbol{\Delta P_{ss,theo.}}\rvert$	The theoretical steady state response is measured in [MW] for a frequency deviation of 0.1 [Hz] in upwards or downwards direction.
$\Delta\bar{\boldsymbol{P}}(\boldsymbol{t})$	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 36 - Explanation of variables/parameters utilized in Table 35.

6.2 Approval of frequency measurement

FCR-N providing units will not receive an activation signal from the TSO. It is required for the unit/provider to have a frequency meter installed locally, which can measure the grid frequency. The unit must activate based on the frequency measurement.

Therefor a prequalification of the units connected frequency meter is required. The grid frequency must be measured for 1 hour on a 1 second resolution and sent to the TSO with the rest of the test data. The frequency measurement requirements can be seen in Section 11.

The TSO recommends the providers to have decentralized frequency meters to higher security of delivery, but it is allowed to use the same frequency meters for multiple units, if a fallback solution is in place. This could be a backup frequency meter, placed somewhere else, which creates redundancy in case of power outage or similar.

6.3 Units with limited energy reservoir (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-N this means that a unit is defined as a LER unit if it cannot deliver 2 hours in both directions (up and down). Thus, an FCR-N providing unit is labeled a LER unit if it cannot endure maximum 4 hours of activation.

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.

6.3.1 Requirements for LER units

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 37 shows the amounts reserved for FCR-N. For FCR-N the table states you must reserve 34% of the prequalified FCR-N amount to NEM.

E.g. 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 hour of energy in both directions, which requires at least 1 MWh capacity charged, as well as room to charge the LER unit 1 MWh more.

Documentation on how NEM and AEM are implemented is required and a test must be run to ensure they work as expected.

		FCR-N
REQUIRED POWER UPWARDS	[MW]	$+1.34 \cdot C_{FCR-N}$
REQUIRED POWER DOWNWARDS	[MW]	$-1.34 \cdot C_{FCR-N}$
REQUIRED ENERGY UPWARDS	[MWh]	$1\text{h} \cdot C_{FCR-N}$
REQUIRED ENERGY DOWNWARDS	[MWh]	$1\text{h} \cdot C_{FCR-N}$

Table 37 - showing the power and energy reservations for FCR-N.

6.3.2 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 38Table 38. For FCR-N, the battery enters NEM mode when there is energy left equivalent to 30 minutes of full response, or there is room for an equivalent of 30 minutes of full response. FCR-N leaves NEM when there is room for 57.5 minutes or 57.5 minutes left.

	FCR-N
SOC ENABLE NEM, *UPPER*	$30\ minutes$
SOC DISABLE NEM, *UPPER**	$57.5\ minutes$
SOC DISABLE NEM, *LOWER**	$57.5\ minutes$
SOC ENABLE NEM, *LOWER*	$30\ minutes$

Table 38 - 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 must enable half of your NEM amount. For FCR-N this is calculated as follows:

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

Table 39 provides an explanation of utilized parameter names. It is vital to emphasize that $P_{tot,FCR-N}$ and P_{FCR-N} are direction-dependent, i.e. when providing downregulation their values are negative, and vice versa with the upregulation direction. $C_{FCR} - N$ is always denoted positively since it reflects the sold capacity of FCR-N.

PARAMETER	EXPLANATION
$P_{tot,FCR-N}$	Is the total power provided by the entity
P_{FCR-N}	Is the amount of FCR-N that is meant to be provided
P_{NEM}	Is the capacity reserved for NEM
C_{FCR-N}	Is the sold capacity of FCR-N
$NEM_{Current}$	Is the current NEM
f_{AEM}	Is either 50 Hz or the f(t) dependent on whether AEM is enabled or not

Table 39 - Explanation of symbols in used formulas for NEM 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, if it is used for energy management purposes.

6.3.3 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 40. For FCR-N, AEM is enabled when there is energy left equivalent to 5 minutes of full response, or there is room for an equivalent of 5 minutes of full response. The entity then leaves AEM when there is more than 10 minutes left, or room for more than 10 minutes. The entity can enter AEM no matter the frequency of the system.

	FCR-N
SOC ENABLE AEM, UPPER	5 minutes
SOC DISABLE AEM, UPPER	10 minutes
SOC DISABLE AEM, LOWER	10 minutes
SOC ENABLE AEM, LOWER	5 minutes

Table 40 - 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.

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

$$f_{AEM} = \begin{cases} f_0, & \text{if } SOC \in [SOC_{AEM,lower}, SOC_{AEM,upper}] \\ f(t), & \text{otherwise} \end{cases}$$

When this reference is changed from f_0. it is referred to as f_{ref} instead.

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

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

Table 41 -showing how to adjust the power provided in AEM.

This equation calculates the amount of FCR-N provided, by taking the difference between the reference frequency and the current frequency.

6.3.4 Demonstration of NEM/AEM

It is up to the provider how they wish to demonstrate the two energy management features, an example of how it could be done, is shown in Table 42. Figure 24 displays the corresponding test sequence, which shows the input frequency, active power output (% of FCR-N capacity) and the state of charge of the LER unit.

STEP	
1	90% activation untill entering NEM threshold
2	Fully activate NEM
3	Change frequency to 49.89/50.11 Hz
4	100% activation untill NEM is deactivated and entering AEM threshold
5	AEM is activated
6	Change frequency to 50 Hz
7	Change frequency to 50.1 Hz
	Change frequency to 50.15 Hz

Table 42 – Demonstration of NEM + AEM.

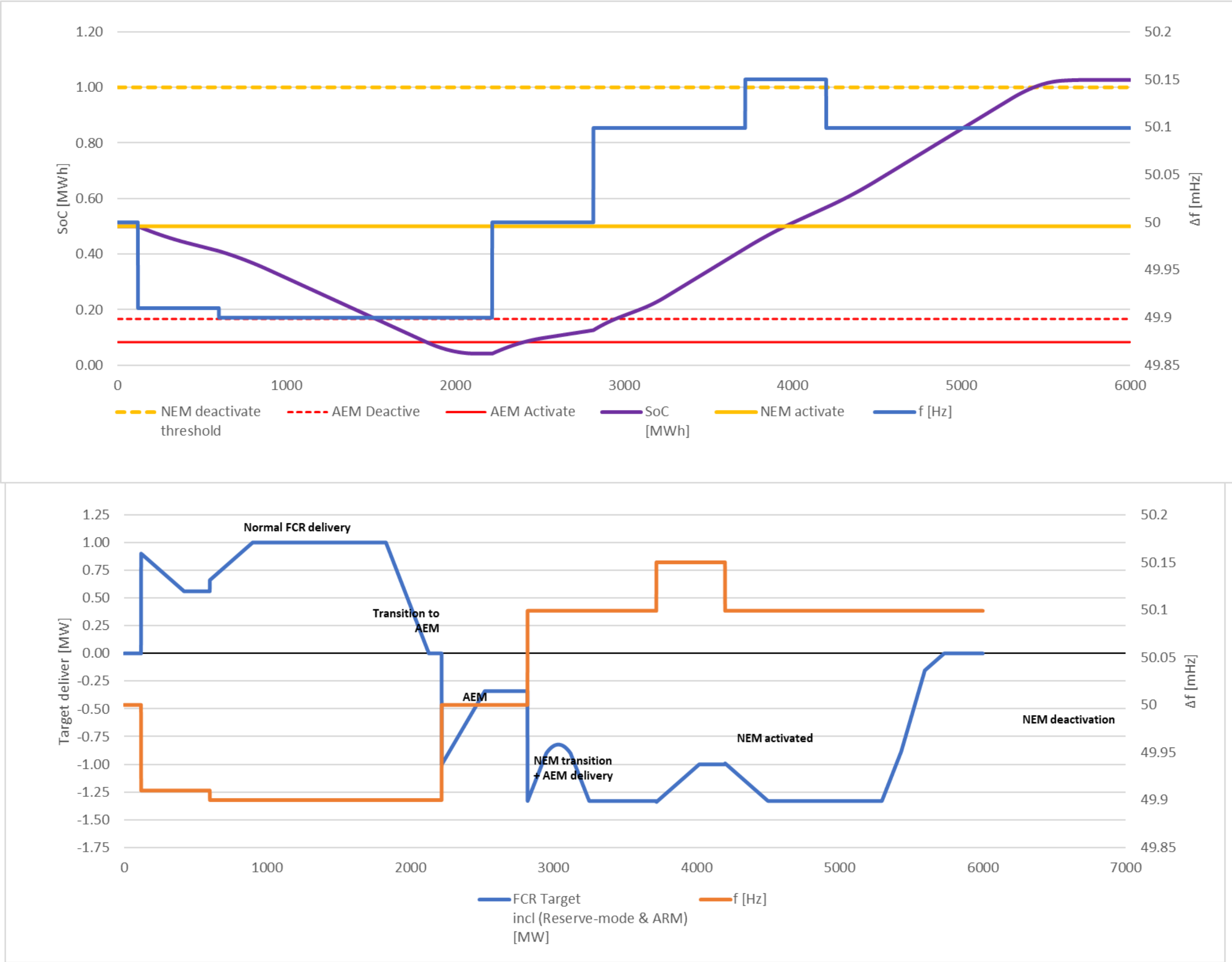

Figure 24 - Energy management test of FCR-N.

7. Test of FFR in DK2

This section describes the fundamental requirements for FFR (fast frequency reserve) and required ancillary service tests to be done before the unit can form part of/be used in the market.

FFR is used to stabilise the frequency, in case major outages occur in low inertia situations, and to reduce frequency dips/jumps to avoid exceeding the threshold of a deviation greater than 1 Hz. The service is only activated for large frequency deviations, as the function is activated in case of deviations of 300 mHz or more from 50 Hz. FFR is only activated in the upward direction.

Units tasked with providing FFR must measure the frequency and automatically activate reserves on their own accord, as they will not receive an external activation signal.

Three combinations of activation level and full activation time are possible, and these are equally effective in meeting system FFR response demands. Table 43 presents the three options.

ALTERNATIVE	ACTIVATION LEVEL [HZ]	MAXIMUM FULL ACTIVATION TIME [S]
A	49.7	1.3
B	49.6	1.0
C	49.5	0.7

Table 43 - Possible activation thresholds, A, B and C, for FFR activation level and respective maximum activation times.

Under-frequency situations have proven very critical compared to over-frequency situations. Therefore, FFR is only purchased for under-frequency situations.

The FFR volume activated by a frequency deviation is governed by a step function and therefore not linearly dependent on the frequency (proportional to the frequency deviation). This means that if, for example, the frequency in DK2 deviates, exceeding the threshold, the entire reserve is activated.

Table 43 shows minimum and maximum responses from the time of FFR activation to the time when the reserve must be fully provided. The maximum response corresponds to a permissible overshoot of 35% of the reserve.

In addition to the option to choose between different activation levels in relation to the frequency threshold, it is also possible to choose between a short and a long FFR activation period of minimum 5 or 30 seconds, respectively. Independently of the choice of activation level with respective maximum activation time, the activation period can be freely chosen.

For short periods, FFR response deactivation cannot exceed a 20% per second gradient. For step-by-step deactivation, steps must not exceed 20%.

ALTERNATIVE	FFR PROVISION PERIOD [S]	DEACTIVATION REQUIREMENTS [S]
1	5 s	Gradient spanning minimum 5 s or steps of maximum 20% spanning minimum 5 s
2	30 s	No requirements

Table 44 - Possible FFR provision periods, 1 and 2, and respective deactivation requirements.

Alternative 1 must be deactivated completely within 30 seconds.
Following response deactivation, the unit must, at a minimum, hold approximately the same set point for 10 seconds.

Following an activation, the providing unit may change set point, for example if there is a need to recharge or another type of rebound effect. The new set point must equal the load set point prior to activation. A rebound of less than 25% of activated FFR power. It is permissible to hold this set point until 15 minutes after the time of activation, after which the FFR unit must be re-established and ready for another activation.

Any tests must be carried out as detailed as Figure 25. The FFR provider simulates a frequency deviation of a scale that triggers an FFR response. Activation level, activation time, duration, and deactivation time to be tested must be selected and Energinet must be informed prior to any test.

Response sequences for reserve tests must be within the "acceptable response area".

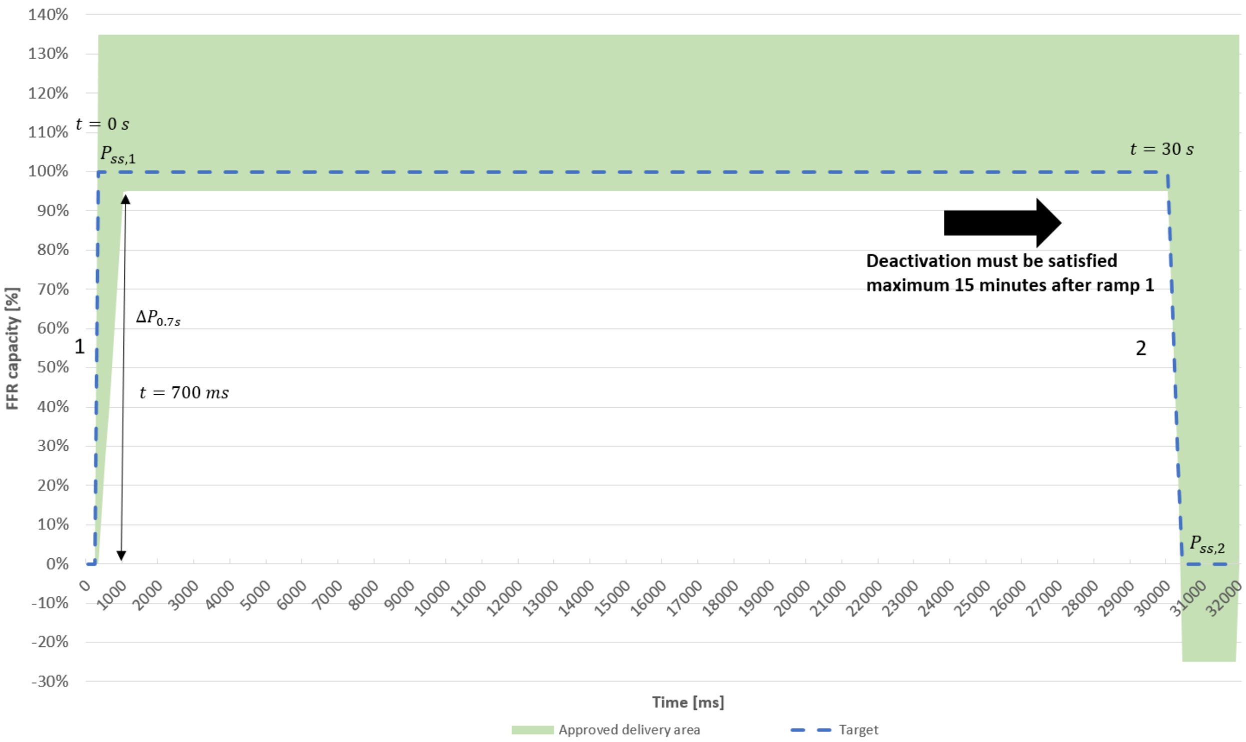

Figure 25 - FFR response sequence for Alternative 2 in Table 46 (0.7s reaction time, 30s steady state response, instantaneous deactivation at ramp 2).

Ramp Number	Start time [s]	End time, ramp [s]	End time [s]	Test duration [s]	Comments
1	0.3	1.0	30	30	Full activation shall be accomplished within 0.7 seconds. The activation lasts for a total of 30 seconds to ensure at least 5 seconds of steady state response. This ramp may vary according to the chosen ramping alternative. If Alternative C is selected, the full activation must be accomplished within 700 ms.
2	30	31	900	900	Proof the deactivation from full response to zero response with a deactivation ramp at a rate of 20%/sec, and the deactivation must be effectuated within 15 minutes. Zero activation must be reached within 15 minutes from the initialization of the activation.

Table 45 - Time parameters for response sequences described in Figure 25.

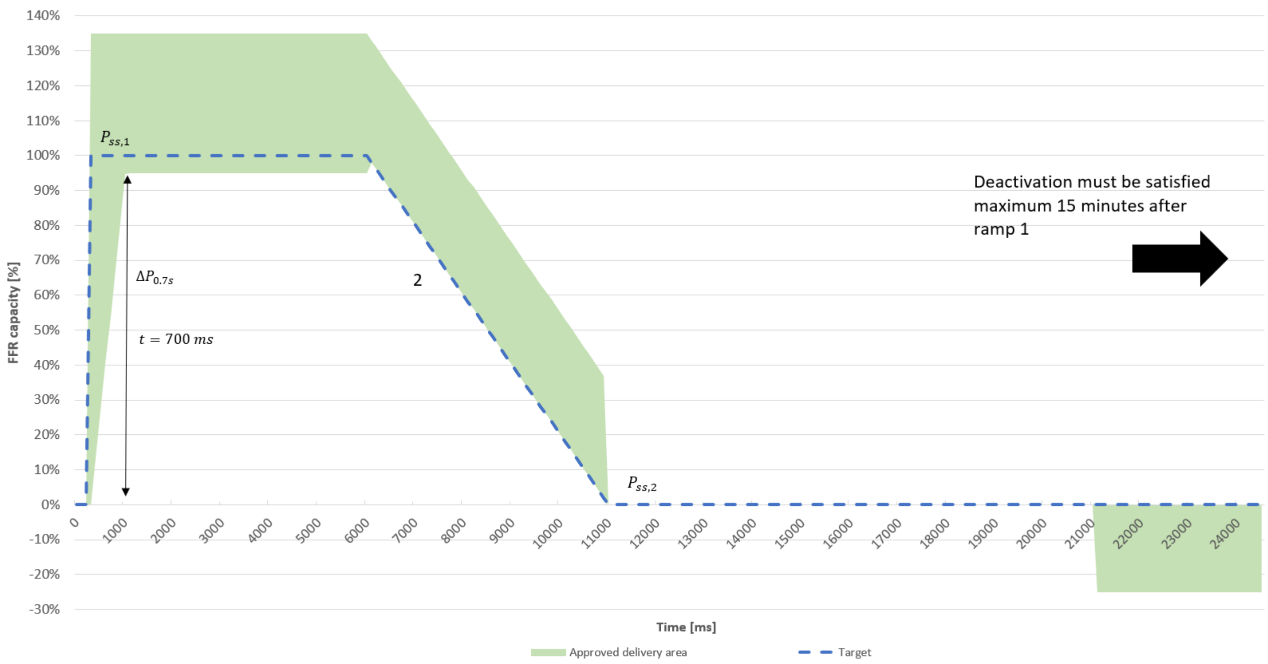

Figure 26 - FFR response sequence for Alternative 1 in Table 46 (0.7s reaction time, 5s steady state response, 5 second deactivation rate at ramp 2).

Ramp Number	Start time [s]	End time, ramp [s]	End time [s]	Test duration [s]	Comments
1	0.3	1.0	6.0	6.0	Full activation shall be accomplished within 0.7 seconds. The activation lasts for a total of 6.0 seconds to ensure at least 5 seconds of steady state response. This ramp may vary according to the chosen ramping alternative. If Alternative C is selected, the full activation must be accomplished within 700 ms.
2	6.0	11.0	900	900	Proof the deactivation from full response to zero response with a deactivation ramp at a rate of 20%/sec, and the deactivation must be effectuated within 15 minutes. Zero activation must be reached within 15 minutes from the initialization of the activation.

Table 46 - Time parameters for response sequences described in Figure 26

7.1 Approval of frequency measurement

FFR providing units will not receive an activation signal from the TSO. It is required for the unit/provider to have a frequency meter installed locally, which can measure the grid frequency. The unit must activate based on the frequency measurement.
Therefor a prequalification of the units connected frequency meter is required. The grid frequency must be measured for 1 hour on a 0.1 second resolution and sent to the TSO with the rest of the test data. The frequency measurement requirements can be seen in Section 11.
The TSO recommends the providers to have decentralized frequency meters to higher security of delivery, but it is allowed to use the same frequency meters for multiple units, if a fallback solution is in place. This could be a backup frequency meter, placed somewhere else, which creates redundancy in case of power outage or similar.

8. Test of mFRR in DK1 and DK2

This section describes the fundamental requirements for mFRR (manual reserves) and required ancillary service tests to be done before the unit/system can form part of/be used in the market.

Prequalification has earlier only been necessary for units that participate in the capacity market. However, the transition into a common Nordic, and eventually a common European market (MARI), the energy activation markets for mFRR requires voluntary bids to be prequalified as well.

From primo 2025, a valid prequalification is required prior bidding in to aFRR/mFRR EAM.

Each production or consumption unit providing manual reserves must have an IT connection to Energinet's control centre. The control centre must at a minimum present the following online:

- status of production or consumption unit out of/in operation
- metered data for production or consumption unit's
    - net production or consumption in the Point of Connection

Requirements and point of delivery for notifications and measurement data is to be agreed with Energinet.

8.1 mFRR response requirements

mFRR is a manual upward and downward regulating reserve, which is used, for example, to relieve primary (FCR, FCR-N and FCR-D) and secondary (aFRR) reserves. mFRR is activated by Energinet’s control centre by the activation of energy bids on the market, for example after the automatic reserves have stabilised and restored the frequency close to the reference frequency (50 Hz) in connection with a frequency deviation.

Figure 27 and Figure 28 show the test response sequence for units that provide mFRR in DK1 and DK2.

The “approved delivery area” sets the boundaries for the mFRR response. It denotes the range at which the unit can be ramped, to ensure a 15-minute full activation. The large response area allowed is permissible because activation occurs through the submission of operational schedules/consumption schedules which reflect the unit's response. The approved delivery area dictates a linear response with full activation time equivalent to 15 minutes. However, it is allowed to incorporate minor deviations, i.e., having a delay time of 5 minutes, and then effectuating the full activation within the remaining 10 minutes. This applies to both prequalification tests of reserves and subsequent operation.
It will be based on case-by-case evaluations carried out by Energinet, to what extent minor deviations from the 15-minute full activation time are deemed not viable.

The “ENDK Signal” reflects the maximum ramping speed visualized with a step response.

The step test sequences for both mFRR up- and downregulation with the associated test requirements, are outlined in Table 47 and Table 48, respectively.

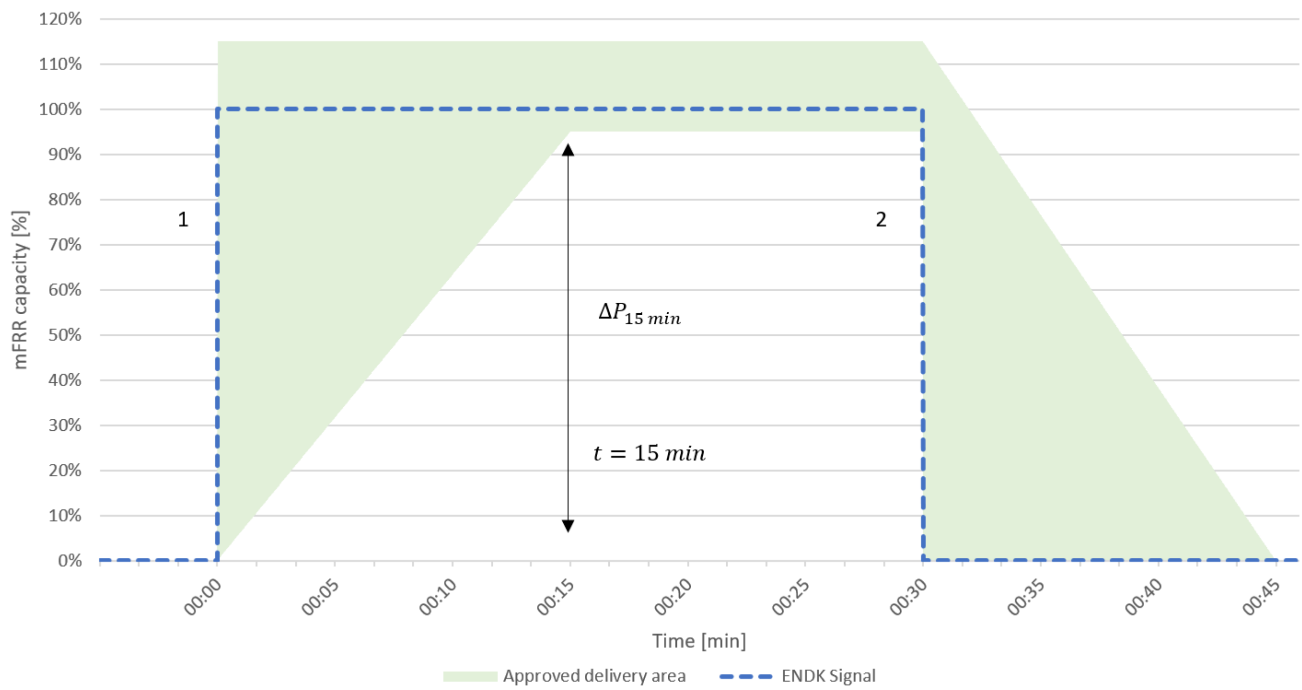

Figure 27 – mFRR upregulation activation response, denoting a full response at 15 minutes.

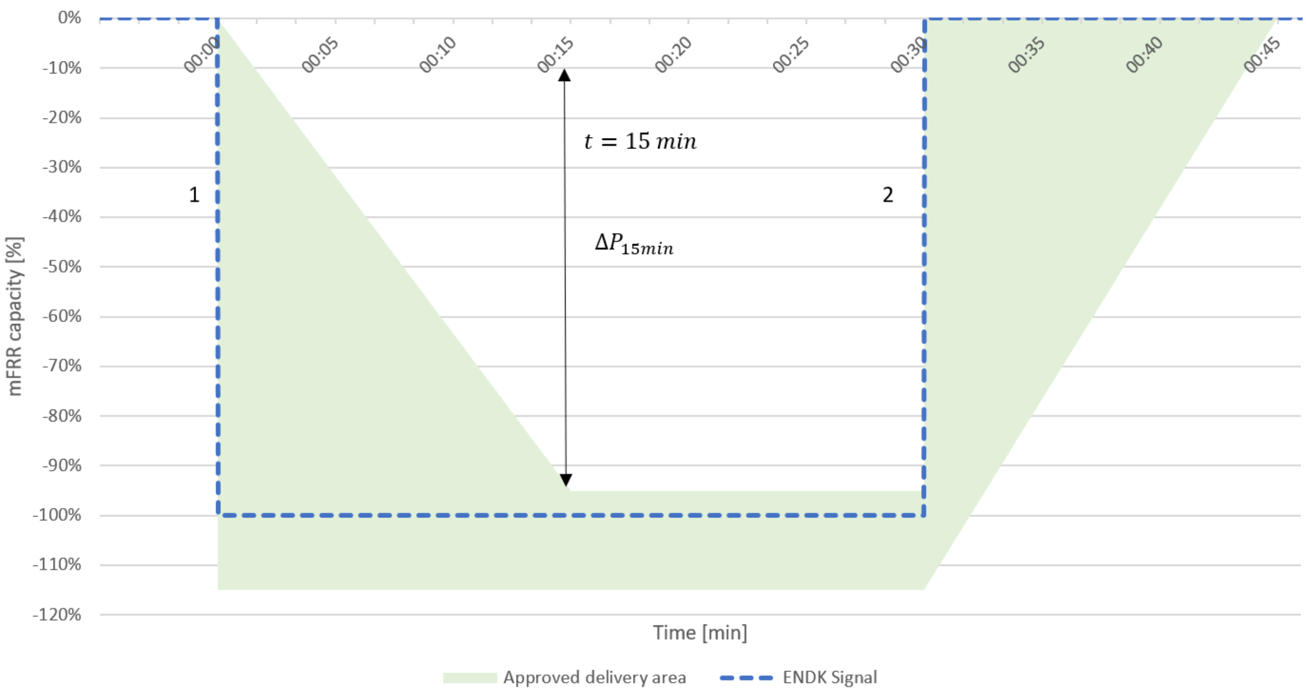

Figure 28 - mFRR downregulation activation, denoting a full response at 15 minutes.

Ramp Number	Start time [min]	End time, ramp [min]	End time [min]	Test duration [min]	Comments
1	0	15	30	30	Full upregulation/downregulation response activation shall be accomplished within 15 minutes. The activation lasts for a total of 30 minutes to ensure at least 15 minutes of steady state response.
2	30	45	45	15	Proof the deactivation from full response to zero response within 15 minutes.

Table 47 - mFRR step test sequence for both up- and downregulation.

REQ. NUMBER	RAMP NUMBER	REQUIREMENT SPECIFICATION (DESCRIPTIVE)	REQUIREMENT SPECIFICATION (MATHEMATICALLY)
1	Second part of ramp 1 and 2	For the steady state response part of the mFRR test sequence, which should be reached within a full activation time (FAT) of 15 minutes, the mFRR provision is allowed to maximal deviate with 15% and minimum deviate with 5%, compared to the theoretical provision.	Upwards direction: $-0.05 \leq \frac{P_{ss,1} - P_{ss,2} - \lvert \Delta P_{ss,theoretical} \rvert}{\lvert \Delta P_{ss,theoretical} \rvert} \leq 0.15$ Downwards direction: $-0.15 \leq \frac{P_{ss,2} - P_{ss,1} + \lvert \Delta P_{ss,theoretical} \rvert}{\lvert \Delta P_{ss,theoretical} \rvert} \leq 0.05$
2	First part of ramp 1 and 2	The transient part of the response, before reaching steady state, must be performed within 15 minutes. The actual steady-state power response ($\lvert \Delta P_{15min} \rvert$) shall 15 minutes after initialization of the activation, ordered by Energinet, be able to deliver 100% of the theoretical steady state response ($\lvert \Delta P_{ss,theoretical} \rvert$).	Full activation: $\lvert \Delta P_{15min} \rvert \geq \lvert \Delta P_{ss,theoretical} \rvert * 0.95?$

Table 48 - mFRR step test requirements both up- and downregulation.

9. Test of aFRR in DK1 and DK2

This section describes the fundamental requirements for aFRR (secondary reserves, LFC) and required ancillary service tests to be done before the unit/system can form part of/be used in the market.

It is important to note that participating in the aFRR energy market (PICASSO platform) requires a valid prequalification.

There are two sets of requirements for aFRR, dependent on whether the unit/portfolio is in DK1 or DK2.

9.1 aFRR response requirements

The aFRR response times are different for DK1 and DK2.

- DK1: Full activation must be achieved within 15 minutes (**phased out by 01-10-2024**)
- DK2: Full activation must be achieved within 5 minutes.

The balance responsible party determines whether aFRR capacity is provided from a single unit or from an aggregated unit portfolio.

DK1 will have the same requirements and test as DK2 (i.e 5 minutes FAT) when DK1 expectedly joins PICASSO in 2024. To be ready for PICASSO and not require a new prequalification, the provider can run the DK2 functional test already now for units in DK1. When DK1 joins PICASSO all prequalified units with 15 minutes FAT are no longer allowed to participate in the market.

Energinet only has one communication line per balance responsible party. If a balance responsible party only offers one unit for use in this market, Energinet will allow direct communication from Energinet's SCADA system to this unit. If the balance responsible party's portfolio comprises several units that will submit capacity bids separately or in an aggregated capacity bid, Energinet will only assign one communication line, in this case to the balance responsible party's SCADA system. The balance responsible party is then responsible for further communication to its units.

The Energinet LFC function set point value will be a "continuous" signal with a refresh interval of 4 to 10 seconds. Reserved capacity is activated using a proportional distribution that reflects the result of the capacity auction (pro rata).

9.2 Approval of concept

The balance responsible party must submit a description of the system that will receive and execute activations. This description must explain how requirements stated in this document are met. The description must be approved by Energinet before the balance responsible party can be allowed to participate in the capacity and automatic balancing markets.

9.2.1 Communication test

A signal test must be carried out between Energinet and the balance responsible party and between the balance responsible party and at least one unit.

The approval procedure comprises both signal and activation tests that document the functionality of the balance responsible party's system. The balance responsible party's capacity and energy offerings are based on portfolio provisions, necessitating ongoing follow-up during normal operation as an important part of the assessment of whether the balance responsible party meets conditions.

9.2.1 Functional test DK1

A step-based activation signal is sent to the provider, represented with the “ENDK signal” in Figure 29. The response from the unit or the aggregated portfolio, must be within the area “approved delivery area” in Figure 29. Minimum response at the test with a gradient corresponding to the “delay”, from the receival of the set point change and until the response is measured, with a maximum of 135 seconds for DK1. Table 49 specifies the exact time instances for the test steps. A delay of up to 30 seconds is allowed for the first response.

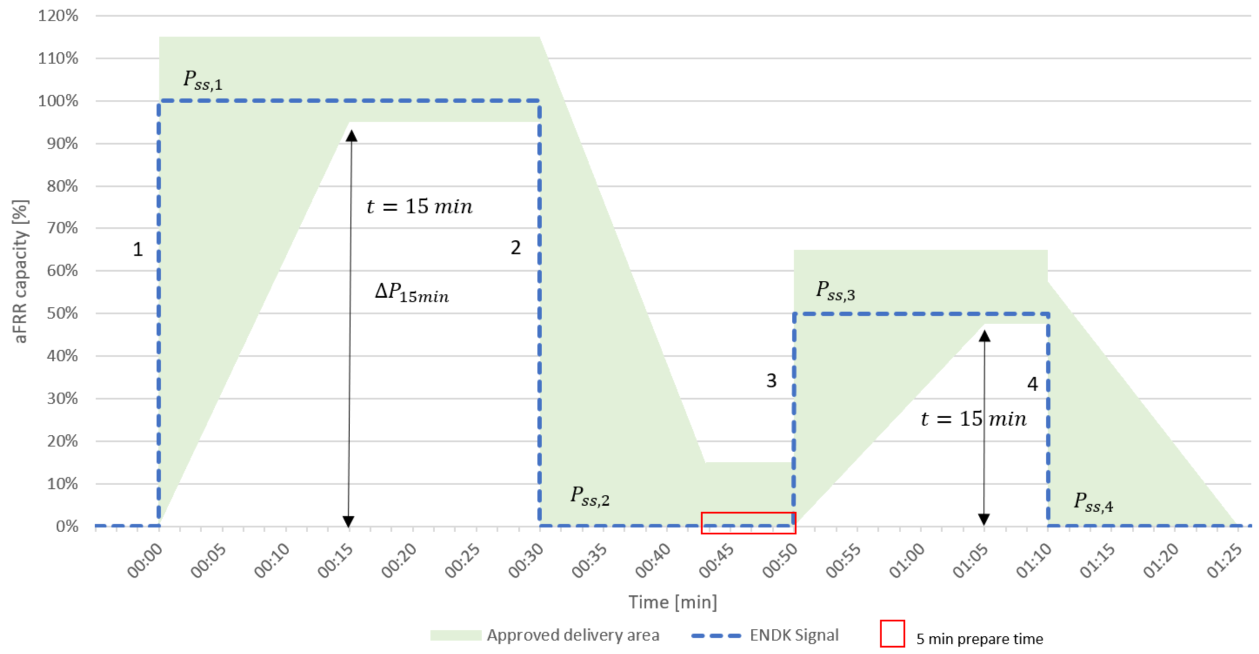

Figure 29 - aFRR functional test response (DK1).

Ramp Number	Start time [min]	End time, ramp [min]	End time [min]	Test duration [min]	Comments
1	0	15	30	30	Full activation shall be accomplished within 15 minutes. The activation lasts for a total of 30 minutes to ensure at least 15 minutes of steady state response.
2	30	45	45	15	Proof the deactivation from full response to zero response within 15 minutes.
Preparation time	45		50	5	Ensuring that zero response can be sustained for a 5-minute period. The 15% over-delivery is still valid here.
3	50	65	70	20	½ response activation shall be accomplished within 15 minutes. The activation lasts for a total of 20 minutes to ensure at least 5 minutes of steady state response.
4	70	85	85	15	Proof the deactivation from ½ response to zero response within 15 minutes.

Table 49 - aFRR functional test sequence (DK1).

REQ. NUMBER	RAMP NUMBER	REQUIREMENT SPECIFICATION (DESCRIPTIVE)	REQUIREMENT SPECIFICATION (MATHEMATICALLY)
1	At ramp 1 & 3	For the steady state response part of the aFRR test sequence, which should be reached within a full activation time (FAT) of 15 minutes, the aFRR provision is allowed to maximal deviate with 15% and minimum deviate with 5%, compared to the theoretical provision.	$-0.05 \leq \frac{P_{ss,1} - P_{ss,2} - \lvert\Delta P_{ss,theoretical}\rvert}{\lvert\Delta P_{ss,theoretical}\rvert} \leq 0.15$
2	Ramp 1 & 3	The transient part of the response, before reaching steady state, must be performed within 15 minutes. The actual steady-state power response ($\lvert\Delta P_{15min}\rvert$) shall 15 minutes after initialization of the activation, ordered by Energinet, being able to deliver 100% of the theoretical steady state response ($\lvert\Delta P_{ss,theoretical}\rvert$). For the ½ response testing, the same is applicable.	Full response: $\lvert\Delta P_{15min}\rvert \geq \lvert\Delta P_{ss,theoretical}\rvert$ ½ response: $\lvert\Delta P_{15min}\rvert \geq 0.5 * \lvert\Delta P_{ss,theoretical}\rvert$

Table 50 - aFRR test sequence requirements (DK1).

9.2.2 Functional test DK2

The functional test is based on three different types of responses:

- FAT-test: Full activation within 5 minutes, hereafter steady-state operation and finally deactivation in 5 minutes.
- Spike-test: Signal with full activation for 5 minutes, and then a drop to no delivery.
- Step-test: Signal with partial activation and deactivation.

The three tests can be completed at different times, or in conjunction, where the resting periods can be shorter or longer than designated.

Figure 30 outlines the necessary test to perform for aFRR prequalification.

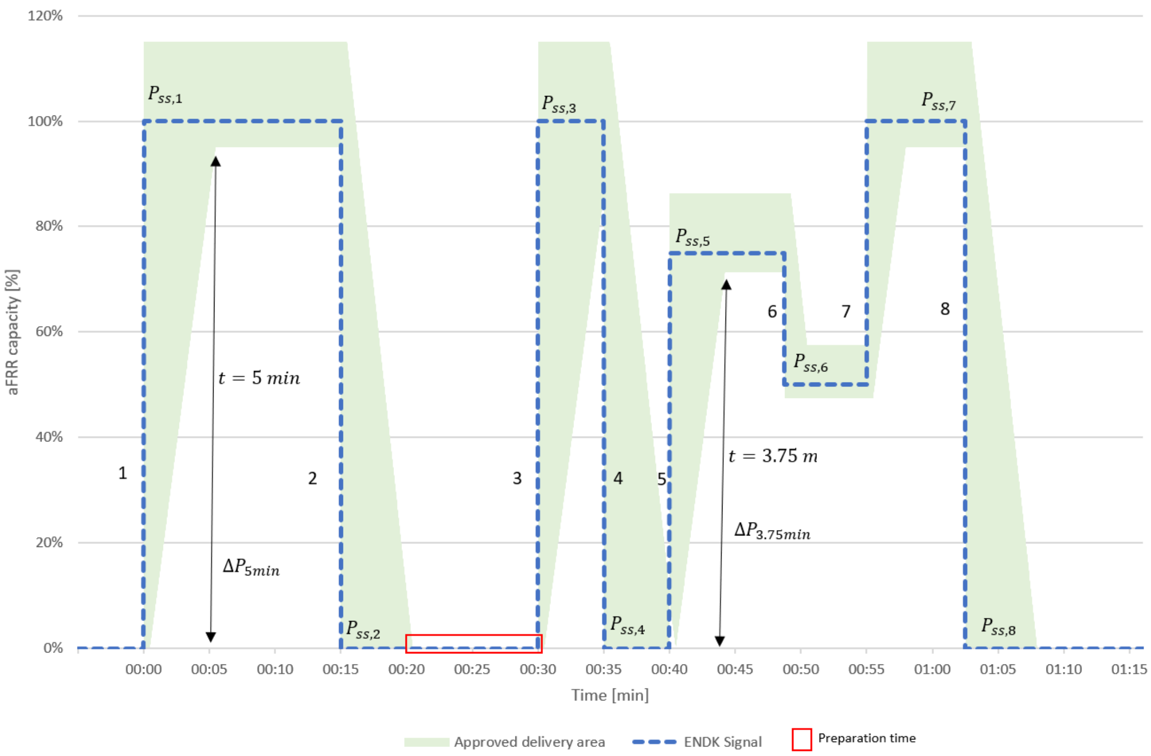

Figure 30 - aFRR functional test response (DK2).

Ramp Number	Start time [min]	End time, ramp [min]	End time [min]	Test duration [min]	Comments
1	0	5	15	15	Full activation shall be accomplished within 5 minutes. Ramp 1 lasts for a total of 15 minutes to ensure at least 10 minutes of steady state response.
2	15	20	20	15	Proof the deactivation from full response to zero response within 5 minutes.
Preparation time	20		30	10	Ensuring that zero response can be sustained for a 10-minute period.
3	30	35	35	5	Full activation shall be accomplished within 5 minutes. Ramp 5 lasts for a total of 7.5 minutes to ensure at least 5 minutes of steady state response.
4	35	40	40	5	Proof the deactivation from ½ response to zero response within 2.5 minutes.
5	40	43.75	48.75	8.75	Proof of 75% activation within 3.75 minutes.
6	48.75	50	55	6.25	Proof of 50% activation within 1.25 minutes. Thus, decreasing the activation from 75 to 50% within 1.25 minutes.
7	55	57.5	62.5	7.5	Achieving 100% activation within 2.5 minutes, following a 5 minute steady state period.
8	62.5	67.5	67.5	5	Achieving 0% activation within a 5-minute period.

Table 51 - aFRR functional test sequence (DK2).

REQ. NUMBER	RAMP NUMBER	REQUIREMENT SPECIFICATION (DESCRIPTIVE)	REQUIREMENT SPECIFICATION (MATHEMATICALLY)
1	All ramps	For the steady state response part of the mFRR test sequence, which should be reached within a full activation time (FAT) of 15 minutes, the mFRR provision is allowed to maximal deviate with 15% and minimum deviate with 5%, compared to the theoretical provision.	Upwards direction: $-0.05 \leq \frac{P_{ss,1} - P_{ss,2} - \lvert \Delta P_{ss,theoretical} \rvert}{\lvert \Delta P_{ss,theoretical} \rvert} \leq 0.15$
2	All ramps	The transient part of the response, before reaching steady state, must be performed within 5 minutes. The actual steady-state power response ($\lvert \Delta P_{15min} \rvert$) shall 5 minutes after initialization of the activation, ordered by Energinet, being able to deliver 100% of the theoretical steady state response ($\lvert \Delta P_{ss,theoretical} \rvert$). For the ½ response testing, the same is applicable.	Full & ½ response: $\lvert \Delta P_{5min} \rvert \geq \lvert \Delta P_{ss,theoretical} \rvert$

Table 52 - aFRR test sequence requirements (DK2).

9.2.3 Configuration of BRP control system

Input power is calculated based on the activation signal. This calculation is based on an expected response corresponding to a delayed response to an activation signal. In terms of balancing control set-up, the respective balance responsible party decides whether to distribute response equally between participating units or not. If a market participant wants Energinet to use an online value, this is possible.

9.2.4 Signal list

aFRR is an automatic power regulation function that reacts to an online regulation signal sent by Energinet to the units via the balance responsible party.

To provide this reserve, a new function must be built into the control systems of the unit. The function ensures that the units regulate up and down in response to an online regulation signal from Energinet. The online regulation signal is an addition/a correction to the units' existing power regulation signal. The reference is the providers' power schedules.

The online regulation signal sent by Energinet must be distributed by the balance responsible party to the units participating in aFRR regulation so that the combined reaction is meeting the requirements based on the regulation signal sent by Energinet. From the unit to Energinet, only an online availability signal is required, which indicates that the unit is actively responding to the regulating signal from Energinet.

The units can consider online calculation of availability of up and down regulation (MW), regulating gradients (MW/minute), as well as time constants (seconds) and online send these inputs to the production balance responsibility party, who gathers the partial results into a combined result, which is then sent to Energinet. Alternatively, Energinet will use the ramps and time gradients from the prequalification test, as the input to the online signal.

Signals must be exchanged via IEC 60870-6 TASE.2, IEC 60870-5-104 or IEC 61-850. The signal list is in appendix 13.1.

10. Additional & Special requirements

This chapter outlines the additional and special requirements that might be required to comply with, when desiring to prequalify for the various ancillary service products. This concerns portfolios constituting of multiple units (aggregated portfolios) and units who are non-controllable, hence, needs to implement a forecast and associated baseline.

Thus, this chapter describes additional requirements to the mandatory ancillary service performance tests.

10.1 Prequalification of aggregated portfolios

For aggregated unit portfolios, the collection of units must be approved and prequalified for the provision of ancillary services. In other words, Energinet prequalifies an aggregated unit portfolio using the aggregator's aggregation tool and control system, so that tests are done to determine the practical provision and actual capacity of the overall unit. Hence, the same setup must be used when providing reserves in the market, as used and prequalified in the testing. A portfolio of units will be tested and approved based on their overall performance in relation to the applicable requirements for the ancillary service it offers. The aggregator is thus responsible for ensuring that underlying units are always aggregated, allowing them to comply with any system-related conditions for the provision of ancillary services.

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. If not, they can only be sold to the market if aggregated. If individual units can fulfill the requirements, they must be tested individually before being allowed to participate in the markets individually.

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 oversees. Documentation must contain information about MW, type, geographical placement, and potential consumption/production pattern over a given period.

10.1.1 Extension of prequalification for aggregated portfolios

A prequalified portfolio is allowed to extend the original capacity without a new prequalification process, if the provider can document that the additional units will have the same behavior and technical capabilities as the remaining portfolio. Energinet must approve the concept before any extension can happen. The extension can happen by extending the original capacity with maximum 25%, however the extension size must never exceed 10 MW. For instance, an existing prequalification of an aggregated portfolio of 100 kW, can only be extended to 125 kW, without conducting a new prequalification process. On the other hand, a 50 MW aggregated portfolio can extend with 10 MW extra capacity, hence reaching 60 MW aggregated portfolio (since 25% of 50 MW is 12,5 MW, which violates the second part of the extension requirement). To increase the portfolio by more than 25%, a combined prequalification of the original capacity, as well as the new capacity, must be run. Energinet can deviate from the general conditions if needed.

When increasing the volume, the service provider must inform Energinet and receive an associated confirmation for the extension of the portfolio.

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.

10.1.2 Exemptions on measurement requirements for aggregated portfolios

Energinet can give aggregated portfolios an exemption on parts of the measurement requirements described in Section 11. If the provider can document that all units have the same behaviour and technical capabilities, it can be accepted to only have the required measurements on 20% of the bid capacity and minimum 10% of the individual units. The remaining portfolio can deviate from the measurement requirements e.g. by having a lower resolution, accuracy, or sampling rate.

10.1.3 Storage of data for aggregated portfolios

For aggregated units, the ancillary service is provided through a balance responsible party itself or via an aggregator. Energinet looks at the overall volume of power sold by the balance responsible party, and this means that the storage of data to document service provision may be done at the aggregated level. Energinet's sole focus is to ensure that the actual provision can be verified and not from where actual provision has taken place. This means that the aggregator must comply with the applicable rules for storage of, for example, frequency data, but only at an aggregated level. The aggregator may store and submit data for spot checking from separate units if they want (relevant if faults are identified in audits).

10.1.4 Signals and energy settlement for aFRR and mFRR

Energinet looks at the total volume of power sold by the aggregator, and this means that only one online measurement is required for the aggregated volume when providing mFRR or aFRR.

In accordance with SO GL article 158 (1)(e), If the unit size in an aggregated portfolio exceeds 1.5 MW, there must be installed an online measurement per unit. If the unit size is less than 1.5 MW, only one online measurement is required to be installed.

The set-up for the provision of ancillary services from aggregated units is a deciding factor in settlement meter requirements. Set-up options include an aggregator with own balance responsibility or an aggregator collaborating with a balance responsible party. Due to the many set-up options, reference is made to market regulation D1 for details on settlement meter requirements.

10.2 Forecast & Baseline

Energinet allows all types of production and or consumption to deliver reserves. Energinet strives towards 100% technology neutrality in the purchase of reserves, as well as even conditions and competition. Reserves must deliver security of supply, and the important part that the reserve is delivered, and that there is always electricity available. When Energinet purchases reserves, it is done in a way that no technology is preferred over another.

There are significant differences between conventional units and fluctuation production as well as flexible consumption, regarding delivery of ancillary services. The most important differences are certainty of availability and the reference power, also called the baseline.

- How can a wind turbine park or an electric vehicle-portfolio guarantee at the time of bidding (the day before) that the capacity sold will be available.
- What would a wind turbine park or an electric vehicle-portfolio have produced or consumed, without active regulation because of participation in one or more ancillary service markets.

Hence, being able to differentiate between conventional power plants and fluctuating production/flexible consumption is vital.

10.2.1 Criteria for classification of fluctuating renewable or flexible consumption

Conventional power plants have a predefined operational power schedule as their reference. This schedule makes up the plants set baseline which should always be available if the power plant does not experience any outages. This operational schedule is determined by factors such as the electricity price on the day-ahead market and the heating requirements of Danish dispatchable generation units such as central and decentral power plants.

For renewable generation, i.e., wind turbines and PV parks, the reference primarily depends on the weather at the time of operation as marginal generation costs are very low. For demand-side response units, there may be a myriad of dependencies.

The below table showcases the parameters to fulfil deeming either a classification of a *centrally controlled unit*, or a *not-centrally controlled unit*. Energinet introduces the term *not-centrally controlled units,* which reflects units that must obey with specific requirements with regard to forecast and baseline in relation to ancillary service participation.

A *not-centrally-controlled unit* is in normal-operation influenced by stochastic variables, meaning external factors that introduce discrepancies between expected production/consumption (D-1) and realized production/consumption (within the operational instance). This stands in high contrast to centrally controlled units whose power schedule can be designed with a minimum of deviations between expected and realized power. Tabel 53 differentiates between centrally controlled and not-centrally controlled units.

Centrally controlled units (Dispatchable units)	Not-centrally controlled units
• Dispatchable • Baseline is often rooted in i.e., the day-ahead electricity price • The unit's baseline <u>has no</u> external affections (besides from outages)	• Non-dispatchable • Baseline is often dependent on the weather at the time of operation (for production) or end-user "disturbances" (for consumption) • The unit's baseline <u>has</u> external affections (in addition to outages • Must obey with the guidelines outlined in the section for *Requirement for forecast & baseline.*

Tabel 53 - Overview of attributes for centrally controlled and not-centrally controlled units.

Energinet has requirements for the calculation of available capacity that is bid into the reserve-markets, as well a requirement for a calculation of a baseline. These extra calculations for not-centrally-controlled units create a level playing field for participation in the ancillary service markets with conventional units (centrally controlled units).

<u>The calculation of available capacity is considered as an "ex ante" forecast and the baseline an "ex-post" estimation.</u>

10.2.2 Requirement for forecast & baseline

This section is only relevant for <u>not-centrally controlled units</u>

Requirements for the forecast at the time of bidding (Ex-ante)

To ensure availability at the time of delivery, Energinet allows only a small margin of error on the side of under delivery. This margin is expressed as a percentage of time where less than the entire capacity may be unavailable. The percentage corresponds with the 10th percentile of a probabilistic forecast. This margin has been obtained by weighing the importance of always ensuring sufficient capacity, while still allowing for reasonable participation from not-centrally-controlled technologies in the ancillary service markets.

The main concern, when allowing not-centrally-controlled units to enter the ancillary service markets, is that the capacity may not be entirely available in the MTUs it is sold. Since the ancillary services are our last response to handle system instabilities and imbalances, it is of great importance that the risk of under delivery is kept small. To put this requirement into perspective, the most common power forecasts predict the 50th percentile of the power output. Meaning the forecast will be equally wrong in both directions (over- and underestimate power). For typical day-ahead trading, the providers have an opportunity to correct any imbalances in the intraday market, which is not an option when providing reserve capacity. By using the 10th percentile Energinet ensures that these forecasts are more right than wrong, in the sense that 90% of the time the entire capacity or more will be available.

There are endless possibilities for creating a forecast with the specified requirements and the methodology on the service provider side is entirely optional. The requirements that must be met in a prequalification of forecast are as follows:

- Forecast must be made before GCT (gate closure time) of the desired market.
- Forecast resolution must be at least same time resolution as MTU (market time unit).
- Three months' worth of forecast data must be provided.
- For the same period, measured production/consumption from the unit to compare with (on a resolution in alignment with Requirements on the measurement system).
- The forecasted value must be available at least 90% of the time.

The forecast must be made available before GCT as it will be used as the threshold for how much capacity can be submitted to the market. I.e. if bidding in the second FCR-D auction the forecast must be available before 18:00 D-1.
Resolution of the forecast must always be at least the same as MTU, meaning if the market changes hourly the forecast must be hourly or better. A higher resolution can be allowed, but the lowest value within each MTU must be used as the highest allowable capacity.
Three months data ensures a proper test of the forecast and that it is functional in most common situations.
To be able to validate the forecast, the actual measured data from the same period must be supplied. This should be in MTU resolution, even if the forecast is provided in higher.
When comparing the forecast value and the actual measurements, the forecast value must be lower or equal to the actual for at least 90% of the time.

Alternatively, Energinet allows providing only 1 month of forecast data, but in this case the measurement data from the unit must be in same resolution as data logging for the prequalification tests of the unit, i.e. for FCR one month of measurements in one-second resolution. The same requirements for both resolution of forecast and acceptance applies. Energinet has the right to deviate from the general conditions.

When prequalification has been completed, it is the responsibility of the market participants to use the forecast as threshold for bidding capacity to the market. In addition, the forecast is viewed as just as important as the physical setup. Thus, should any significant changes be made to the workings and/or functionality of the forecast, Energinet must be noticed and allowed to review the updated accuracy. Energinet will continuously monitor if the sold capacity is available, and if deemed necessary an audit of the forecast may be conducted.

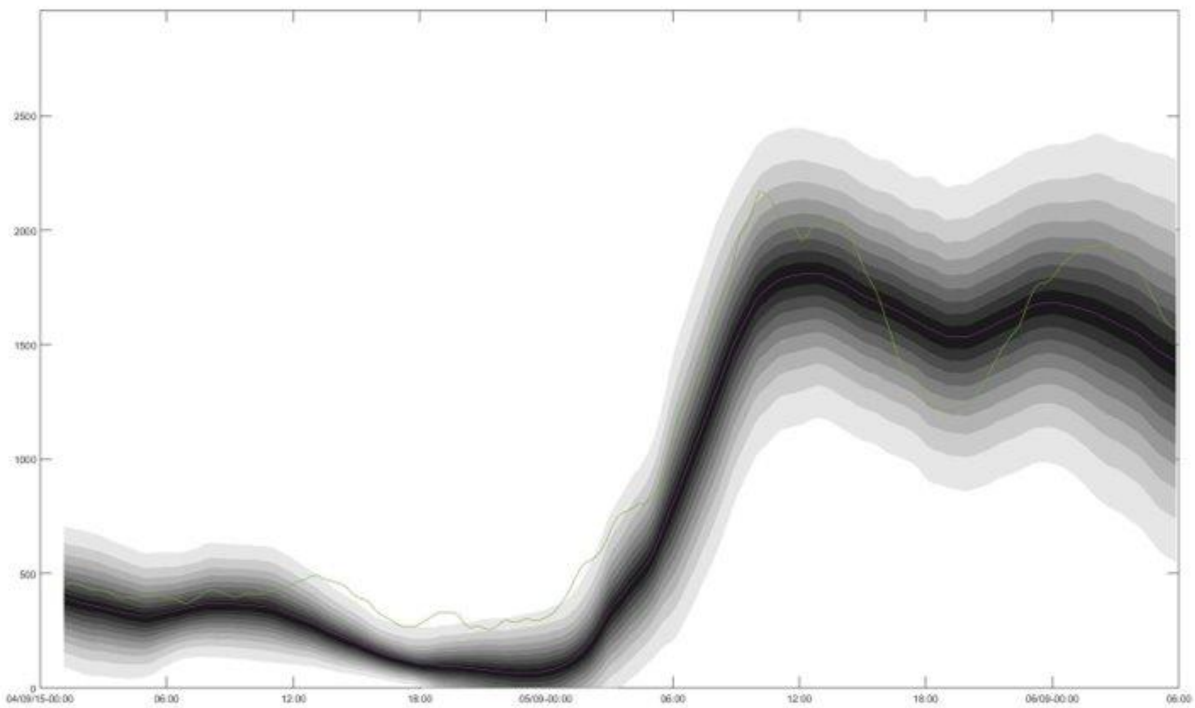

Figure 31 – Graphic illustration of application of 10% percentile in a probabilistic prognosis to estimate available capacity at the time of bidding for mFRR (9 o clock, D-1).

Requirements for the baseline in the operational moment (Ex-post)

For fluctuating production and flexible consumption (not-centrally controlled units), there is also a requirement for a calculation of a baseline or reference power. This is to compare the actual production/consumption with the possible production/consumption if a reserve activation had not happened. The calculations are allowed to be performed ex-post for the purpose to be able to validate the ancillary service response. The delivered ancillary service response is equal to the difference between the baseline and the actual consumption/production, as given in:

$$Ancillary\ service\ response = actual\ production - baseline$$

$$Ancillary\ service\ response = baseline - actual\ consumption$$

It must be emphasised that the baseline from the participant will be used as a reference to calculate the actual delivered flexibility. But there are no specific requirements for the precision of a baseline compared with historical data. An imprecise baseline will lead to an ancillary service response looking inadequate without necessarily being it. This will potentially lead to payment being repaid, or exclusion from the market, which is why the precision of the baseline calculation is very important.

The tables below provide an overview on the minimum baseline resolution for all markets in DK1 and DK2. However, it is vital to emphasize that the provider's chosen baseline resolution acts as foundation to calculate the actual ancillary service provision. Hence, the more high-resolution the baseline is computed at, the more precisely can Energinet verify the actual response. Thus, Energinet recommends an implementation of a baseline resolution equivalent to the resolution of data logging for the prequalification tests of the unit. An example for FCR-D: The actual production or consumption is logged with minimum 1 second resolution. If the baseline is computed on lower resolution, i.e., per minute, a linear interpolation between the loggings must be performed by the ancillary service provider. This is the fundament for Energinet's verification of the ancillary service response.

DK1	
Market	**Minimum baseline resolution**
FCR	Minute
aFRR	Minute
mFRR	15-minute

DK2	
Market	**Minimum baseline resolution**
FFR	Minute
FCR-D	Minute
FCR-N	Minute
aFRR	Minute
mFRR	15-minute

Requirements for data, type approval, and inadequate in deliveries for baselines are identical with the corresponding requirements for the prognosis (ex-ante).

11. Requirements on the measurement system

The measurement system shall fulfil certain requirements on accuracy, resolution and sample rate. The requirements vary dependent upon the concrete ancillary service market. The tables below describe the specifications to withhold. For the resolution, it is the easiest of the two requirements to fulfill.

MEASURED QUANTITY	RESOLUTION	ACCURACY	SAMPLING RATE
ACTIVE POWER	0.01 MW or 0.025%	+- 5%	1 Hz (one sample per second)
GRID FREQUENCY	5 mHz	+-10%	1 Hz

*Table 54- Requirements on measurement system for **FCR, FCR-D & FCR-N***

MEASURED QUANTITY	RESOLUTION	ACCURACY	SAMPLING RATE
ACTIVE POWER	0.01 MW or 0.025%	+- 5%	10 Hz (e.g., ten sample per second)
GRID FREQUENCY	5 mHz	+-10%	10 Hz

*Table 55 - Requirements on measurement system for **FFR***

MEASURED QUANTITY	RESOLUTION	ACCURACY	SAMPLING RATE
ACTIVE POWER	0.01 MW or 0.025 %	+- 5%	0.0167 Hz (every 60 seconds)

*Table 56- Requirements on measurement system for **mFRR***

MEASURED QUANTITY	RESOLUTION	ACCURACY	SAMPLING RATE
ACTIVE POWER	0.01 MW or 0.025 %	+- 5%	0.1 Hz

*Table 57 - Requirements on measurement system for **aFRR***

12. Audit of Provisions

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 needed quality and quantity. Faulty audits will lead to increasing auditing for the next month of time.

An audit will be sent out from the mailbox PQ.Audits@Energinet.dk, where the provider has a week from when receiving the email to return data. The provider should save data from +/- a day from where data has been requested. Is data requested for the 1st of February, data should be saved from the 31st of January and the 2nd of February, even if exceeding the required time to store data (relevant if the data is not sent within the required week).

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 specifications. 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. This will depend on various factors, and the market participant must be aware of this. This is particularly important when dealing with technologies with unpredictable production or consumption patterns.

13. Appendix

13.1 Lists of needed signals for aFRR

TASE 2:

ICCP INPUT

MXU	MW RESERVE UP	
MXD	MW RESERVE DOWN	
RTU	RAMP UP	
RTD	RAMP DOWN	
TCU	TIME CONSTANT UP	
TCD	TIME CONSTANT DOWN	
AUTO	INDICATION	(status signal indicating that the unit is available for aFRR regulation)

ICCP OUTPUT

EBAS	SETPOINT EXPECTED
EXPV	REGULATION EXPECTED
LFCS	LFC REGULATION CONTROL (ON/OFF, INDICATION)

Signals are sent every four seconds.

In case of breakdowns, the balance responsible party sends the TASE.2 signal 'AUTO INDICATION' to Energinet. At the same time, the balance operator is informed via telephone and e-mail.

IEC 60870-5-104 and IEC 61-850:

Participant to Energinet

Require-ment	*WATCHDOG*	*Indication*	*Status signal that indicates that the unit is available for LFC regula-tion.*
Optional	*MW RESERVE UP*	*Measurement*	*Available up regulation, maximum the contract amount*
Optional	*MW RESERVE DOWN*	*Measurement*	*Available down regulation, maximum the contract amount*
Optional	*RAMP UP*	*Measurement*	*MW/minut. How fast can the unit ramp up*
Optional	*RAMP DOWN*	*Measurement*	*MW/minut. How fast can the unit ramp down.*
Optional	*TIME CONSTANT UP*	*Measurement*	*The seconds delay compared to the signal from Energinet.*
Optional	*TIME CONSTANT DOWN*	*Measurement*	*The seconds delay compared to the signal from Energinet.*
Optional	*DEVIATION EXPECTED*	*Measurement*	Unbalance which the BRP for production expects to regulate

Energinet to participant:

Require-ment	SETPOINT EXPECTED	Measurement Feedback	*Energinets is expecting aFRR delivery from the participant*
Require-ment	*SETPOINT EXPECTED*	*Setpoint*	*The setpoint signal from Energinet. Is sent as one signal, with +/-.*

Table 1 – Signal list

Version	Valid from
2.1	19-04-2024
2.0	01-09-2023
1.0	-