European Network of
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# Test Program for Prequalification of FCR in the Nordic Synchronous Area

29 June 2021

**Version for the pilot phase**

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## Introduction

This document describes the tests that shall be performed for prequalifying providing entities in the Nordic power system, for FCR-N, FCR-D upwards and FCR-D downwards respectively. The document contains a step-by-step instruction on how to perform the testing.

- Section 1 contains a summary of the process to plan for prequalification. This process is recommended to initiate well in advance of the prequalification testing.
- Section 2 describes preparations to perform just prior to performing the tests.
- Section 3 specifies the tests to perform for FCR-N, if applicable.
- Section 4 specifies the tests to perform for FCR-D upwards, if applicable.
- Section 5 specifies the tests to perform for FCR-D downwards, if applicable.
- Section 6 outlines situations where certain tests can be omitted and where test results can be reused.
- Section 7 indicates tasks to perform after the testing, to handle the test results and to prepare for the formal application.

Sections 3, 4 and 5 are presented independent of each other so that the provider only needs to refer to the test section corresponding to the service they wish to prequalify for.

For a description of the technical requirements, how the results will be evaluated, etc., please refer to the main and supporting document.



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# 1. Planning for prequalification

Prior to performing the prequalification tests, the applying reserve provider should ensure compliance with the following items. When necessary, contact with the reserve connecting TSO should be established well in advance.

- ❑ Take note of the current regulations and technical requirements.
- ❑ Ensure that all documents used for reference are the most recent provided by the relevant TSO.
- ❑ Perform analysis of the ability of the entity to be prequalified to comply with the technical requirements and aim to find suitable controller parameters.
- ❑ Ensure that the TSO provided IT-tool, where the provider chooses to use it, is the latest version.
- ❑ Ensure that uncertainties and/or possible derogations/exceptions from testing are approved by the relevant TSO.
- ❑ Ensure that the relevant TSO is informed about the testing according to established processes for prequalification.
- ❑ Plan which operational ranges the unit is to be qualified for, and associated range for capacity/droop. This determines the operational conditions where the tests have to be performed.
- ❑ Ensure that the measurement system complies with the requirements for accuracy and resolution, summarized in Table 1.

**Table 1: Minimum requirements for data logging**

| Measured quantity | Category | Rated power[1] | Accuracy[2] | Resolution |
|---|---|---|---|---|
| Active power | 1 | < 2 MW | ± 5 % | 0,01 MW or 0,025%[3] |
| | 2 | 2–10 MW | ± 1 % | |
| | 3 | < 10 MW | ± 0,5 % | |
| Grid frequency | N/A | N/A | ± 10 mHz | 1 mHz |
| Applied frequency | N/A | N/A | ± 10 mHz | 1 mHz |

- ❑ Ensure that the sampling rate of the measurements in Table 1 is high enough to achieve the required measurement accuracy and measurement resolution and to supply the controller with a suitable update interval. The sampling rate shall be at least the same as the logged data interval values, i.e. 10 Hz for FCR-D and 5 Hz for FCR-N.
- ❑ Ensure that the logged data and real-time telemetry (if required by the TSO) can be provided during FCR provision.
- ❑ Investigate the need for performing additional tests due to special considerations. This may when applicable include:
    - Separate frequency measurement loop when using internal governor software for testing.
- ❑ Become familiar with the tasks to perform after the testing in Section 7.

[1] Rated power of the resource being measured.
[2] The value shall include the total inaccuracy of instrument (measurement) transformer, measurement transducer and any other equipment in the measurement system.
[3] For new installations it is recommended to use a 16-bit transducer and thus have a resolution of 0,0015%.



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## 1.1. Operational conditions

During testing compliance must be confirmed for the endpoints of the relevant operational ranges. Generally, it is required to complete one test set at a minimum of four operational conditions for FCR-N, FCR-D upwards and FCR-D downwards:

1) *Maximum active power setpoint* where the entity will provide FCR, and *maximum droop*, and corresponding controller parameter sets, where the entity will provide FCR
2) *Maximum active power setpoint* where the entity will provide FCR, and *minimum droop*, and corresponding controller parameter sets, where the entity will provide FCR
3) *Minimum active power setpoint* where the entity will provide FCR, and *maximum droop*, and corresponding controller parameter sets, where the entity will provide FCR
4) *Minimum active power setpoint* where the entity will provide FCR, and *minimum droop*, and corresponding controller parameter sets, where the entity will provide FCR

Please refer to Section 6 for possible test exemptions and guidance as to where it is possible to reuse test results between FCR-N and FCR-D, assuming the same parameter set is used for both products.



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## 2. Preparations for testing

Prior to performing tests, the following points should be checked.

- ❑ The unit or group should be set up such that normal frequency measurement input is replaced by an artificial frequency source.
- ❑ Ensure that the data outlined below is logged.
- ❑ Ensure that logging equipment is correctly time synchronized (if applicable).
- ❑ Ensure that logged data can be formatted and reported after the test as required in Section 7.2.

The testing shall preferably be performed by using external equipment as the artificial frequency source, connected to the frequency measurement equipment. If an external signal is not feasible, an internal signal may be generated in software, but then additional testing of the frequency measurement loop has to be performed as described in subsection 3.4.

The sampling rate for data logging during the tests shall be at least 10 Hz for FCR-D and at least 5 Hz for FCR-N.[4]

**Signals to be continuously logged during the tests:**

- Instantaneous active power in [MW]
- Measured grid frequency in [Hz]
- Applied frequency in [Hz]. The resolution and accuracy shall be as stated in Section 1.
- Status ID indicating which controller parameter set is active, if it can be automatically changed during the test.

In addition, it is recommended that important states affecting the FCR response are logged as well. Such data includes but is not limited to:

- For hydro power units
  - Controller output signal
  - Guide vane opening
  - Runner blade angle (Kaplan units)
  - Upstream water level above sea level [m]
  - Downstream water level above sea level [m]
- For thermal units
  - Controller output signal
  - Turbine control valve opening
- For batteries
  - Charge level
- For entities without a predefined setpoint

  Calculated baseline

[4] In cases where the data logging requirement during test is prohibitive, the reserve connecting TSO may grant an exception to use a sampling rate for data logging of at least 1 Hz. This exception only applies in cases where the higher data rate is not needed for the evaluation, i.e. the response is fast, stable and with low noise levels.



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# 3. FCR–N Prequalification tests

This section contains a specification of the tests to be performed in a test set, for FCR-N. The entire test program consists of one or more test sets. A single test set is designed to verify the properties associated with FCR provision under a specific operational condition. Each test set consists of:

- 1 step response sequence
- 1 sine response sequence of 7 period times
- 1 linearity test, for entities with non-continuous responses

The testing shall be repeated at the endpoints of typical operational conditions and for maximal and minimal droop[5]. In addition, the following tests shall be performed for each tested entity:

- 1 test of the frequency measurement loop, for entities tested with internal frequency signals
- 1 hour of active FCR-N provision, using measured grid frequency

Results from the tests shall be attached to the application along with logged test data. The test results are evaluated by utilising the IT-Tool provided by the TSOs.

## 3.1. Step response test

The step response test sequence shall be performed for all FCR-N providing entities.

1. Perform the frequency step-response sequence as in Figure 1. Ensure that the active power response has clearly stabilised and reached its steady state value before applying the next step.

50.00 Hz → 50.05 → 50.00 → 49.90 →50.00 → 50.10 → 50.00 Hz

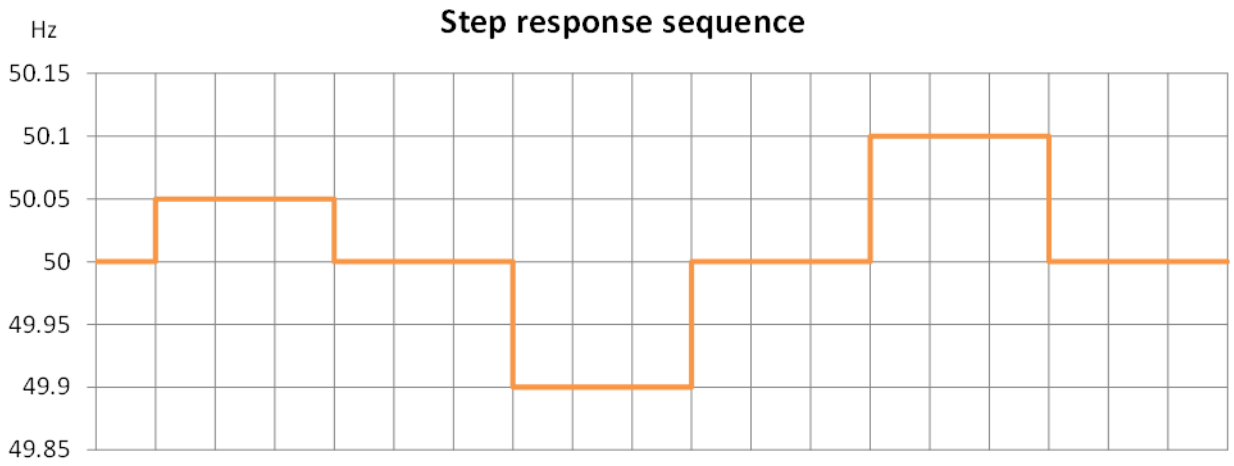


**Figure 1. FCR-N step-response sequence.**

[5] Sine tests only need to be performed at the most challenging operating point in terms of stability. The choice of the operating point must be motivated by prior knowledge and approved by the TSO. Units that do not have droop control should refer to maximal and minimal capacity.



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## 3.2. Sine response test

The sine response tests shall be performed for all FCR-N providing entities.

1. Perform the sine response testing as in Figure 2. Inject a sinusoidal frequency disturbance varying between 49.9 Hz and 50.1 Hz.

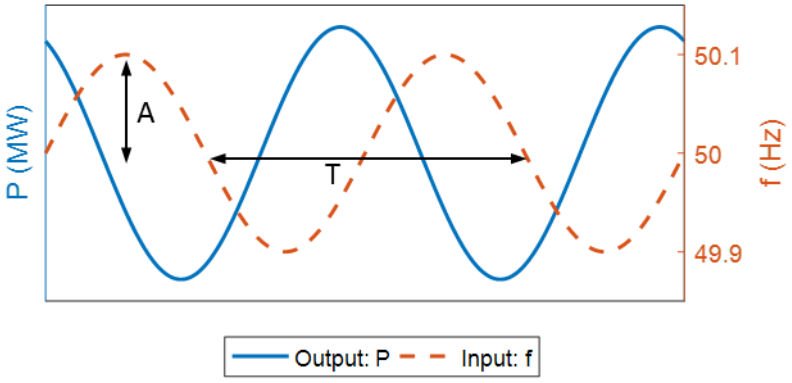


**Figure 2. FCR-N sine response testing.**

2. Repeat the test for all of the following period times:

| 10 | 15 | 25 | 40 | 50 | 60 | 70 |
|---|---|---|---|---|---|---|

For each period time, five periods shall be recorded after reaching a stable sinusoidal active power output. Time periods shorter than or equal to 40 seconds may be omitted if they are not needed to verify compliance with the stability requirement, see Section 4.4.2 in the main document.

## 3.3. Linearity test

If the unit or group has a non-continuous response, e.g. is stepwise controlled, an additional linearity test shall be performed.

1. Perform the linearity test as in Figure 3. Both activation and deactivation shall be tested in the upwards and downwards direction respectively. The ramp rate shall be between 0.5 mHz/s and 2 mHz/s, i.e. a full activation from 50.0 Hz to 49.9 Hz shall be made between 200 seconds and 50 seconds.



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50.0 Hz → 49.9 Hz → 50.0 Hz → 50.1 Hz → 50.0 Hz

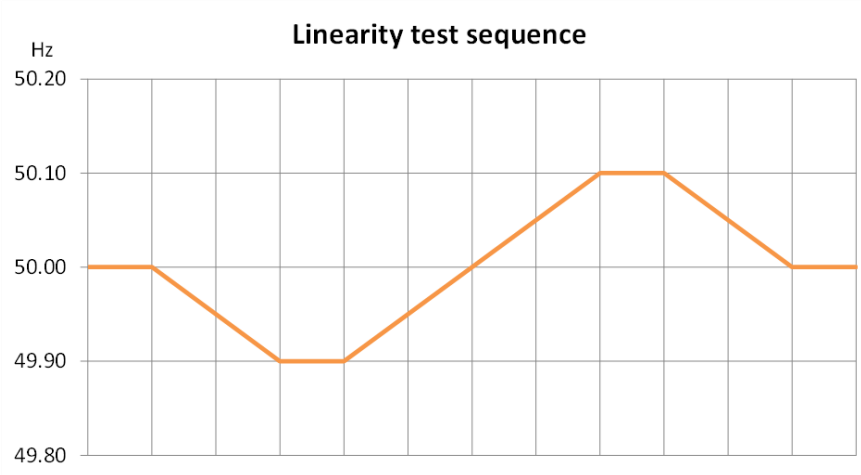


**Figure 3. FCR-N linearity test sequence.**

## 3.4. Test of the frequency measurement equipment

If the frequency measurement loop is omitted from the test process by e.g. applying an internal frequency signal to the controller, the time delay of the frequency measurement loop needs to be separately determined using one of the below four options;

1. Separate test of the frequency measurement loop, by inserting an externally generated frequency step response to measure the time constant of the response.

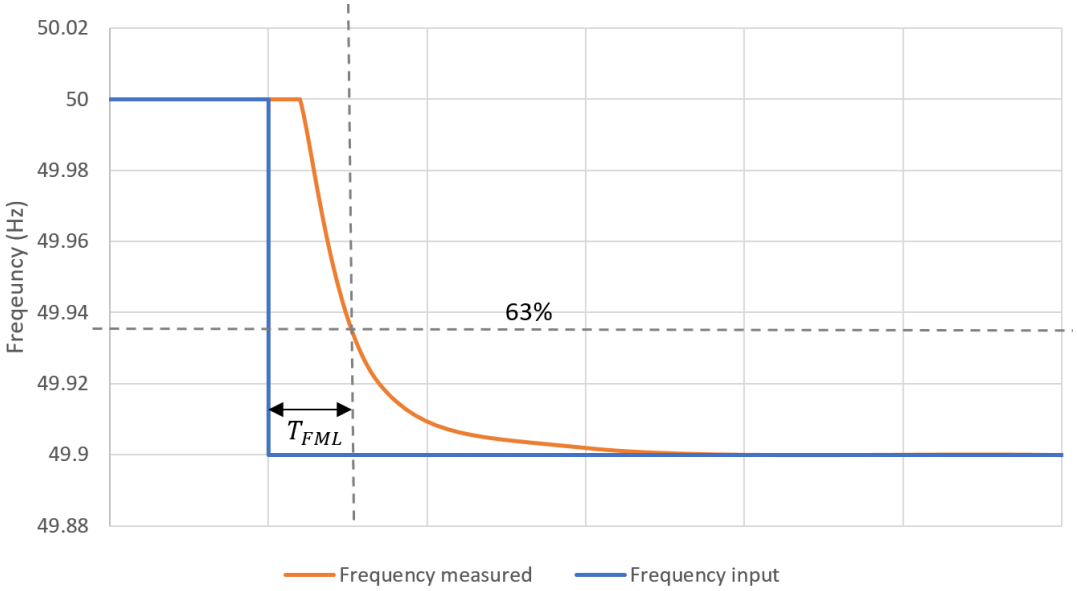


**Figure 4. Example response (orange) from a separate test of frequency measurement loop, by applying a step frequency change (blue)**

2. Documentation from supplier of the equipment.
3. References to previous tests of equal equipment.



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4. If no testing is performed, the default value provided by the TSOs[6], $T_{FML} = x$ second (TBD)[7] will be applied

## 3.5. Active frequency control

All FCR-N providing entities shall perform a test with 1 hour of active frequency control based on measured grid frequency. It is recommended to perform the active frequency control test at maximal FCR-N capacity.

[6] The default value is purposefully set to a high value to ensure a margin.
[7] The Nordic TSOs are currently working to define the value.



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# 4. FCR–D upwards Prequalification tests

This section contains a specification of the tests to be performed in a test set, for FCR-D upwards. The entire test program consists of one or more test sets. A single test set is designed to verify the properties associated with FCR provision under a specific operational condition. Each test set consists of:

- 1 stationary performance test
- 1 ramp response test
- 1 sine response sequence of 5 period times

The testing shall be repeated at the endpoints of typical operational conditions and for maximal and minimal capacity[8]. In addition, the following tests shall be performed for each tested entity:

- 1 test of the frequency measurement loop, for entities tested with internal frequency signals
- 1 hour of active FCR-D upwards data logging, including measured grid frequency

Results from the tests shall be attached to the application along with logged test data. The test results are evaluated by utilising the IT-Tool provided by the TSOs.

## 4.1. Stationary performance test

The stationary performance test sequence shall be performed for all FCR-D upwards providing entities.

1. Perform the frequency ramp-response sequence as in Figure 5. Ensure that the active power response has clearly stabilised and reached its steady state value before applying the next ramp
2. Both activation and deactivation shall be tested in the upwards direction. The ramp rate shall be between 2 mHz/s and 10 mHz/s, i.e. a full activation from 50.0 Hz to 49.5 Hz shall be made between 250 seconds and 50 seconds.
3. For FCR providing entities with switching of parameter sets between FCR-N and FCR-D, the initial ramp from 50.00 Hz to 49.50 Hz is used for compliance evaluation, and in that case FCR-N needs to be active. This switchover is only necessary to test (i.e. to keep FCR-N active) at a single power setpoint, but for maximum and minimum droop settings. The ramp sequence remains the same even if switchover testing is not performed.

[8] Sine tests only need to be performed at the most challenging operating point in terms of stability. The choice of the operating point must be motivated by prior knowledge and approved by the TSO.



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50.00 Hz → 49.50 → 49.70 → 49.90 → 49.70 → 49.50 → 49.70 → 49.90

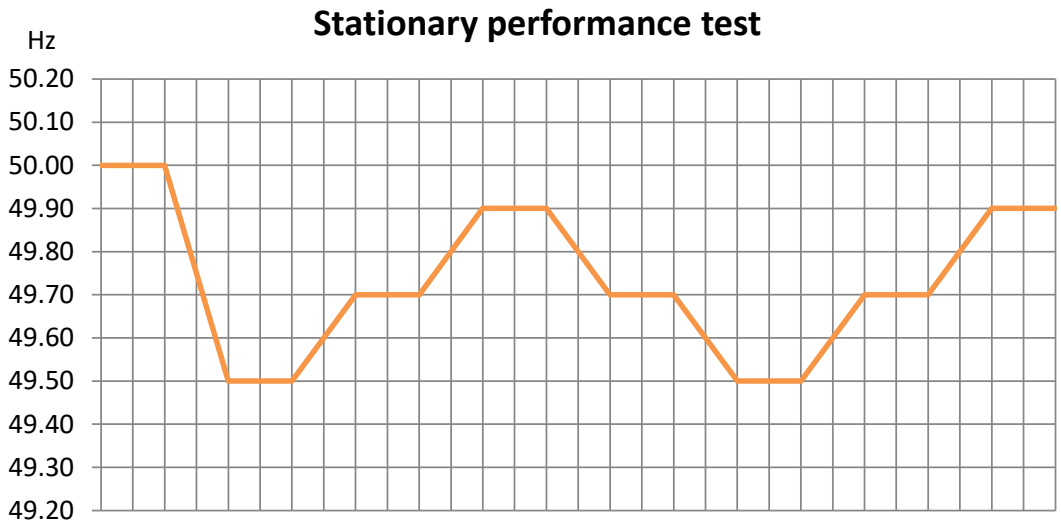


**Figure 5. Input frequency signal for FCR-D upwards stationary performance response tests**

## 4.2. Ramp response test

The ramp response test sequence shall be performed for all FCR-D upwards providing entities.

1. Perform the frequency ramp-response sequence as in Figure 6. The ramp shall be at a rate of 0.24 Hz/sec. Ensure that the active power response has clearly stabilised and reached its steady state value before applying the next ramp

50.00 Hz → 49.80 → 49.90 → 49.00→ 49.90

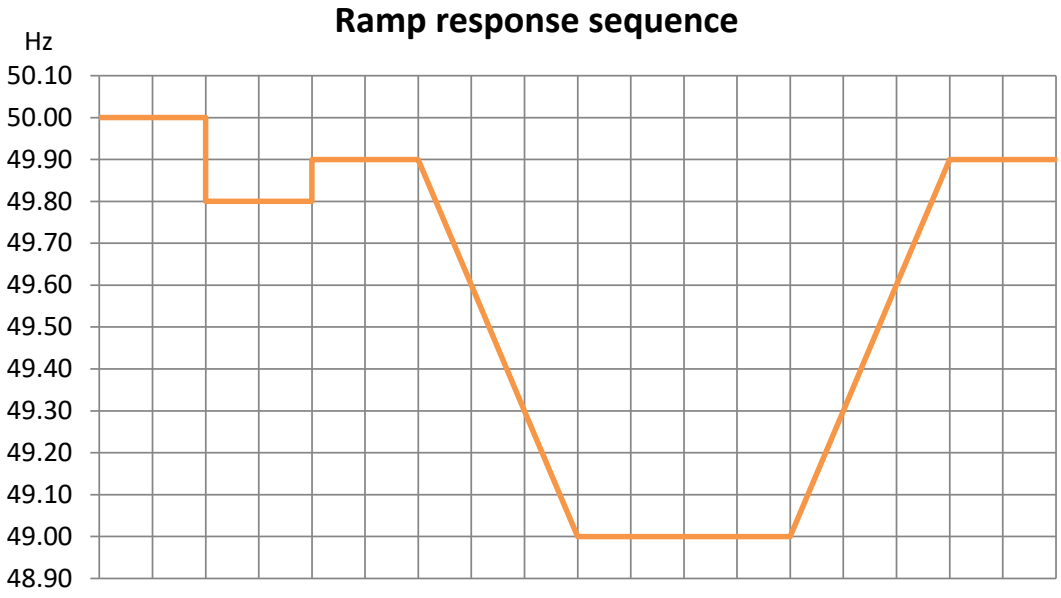


**Figure 6. Input frequency signal for FCR-D upwards ramp response tests**



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## 4.3. Sine response test

The sine response tests shall be performed for all FCR-D upwards providing entities. If the same parameter set is used for FCR-D upwards as for FCR-N, the test results from test in section 3.2 may be reused. Entities providing FCR-D with separate parameters for high performance and high stability shall perform separate sine testing for each parameter set, with parameter switching disabled.

1. Perform the sine response testing by injecting a sinusoidal frequency disturbance around 49.70 Hz with an amplitude of 0.1 Hz.

   Alternatively, if agreed to with the reserve connecting TSO, the test may be performed by a frequency input oscillating around 50.00 Hz whilst providing FCR response continuously and symmetrically around 50.00 Hz, i.e. by deactivating deadbands/insensitivity used in the control loop for FCR-D.

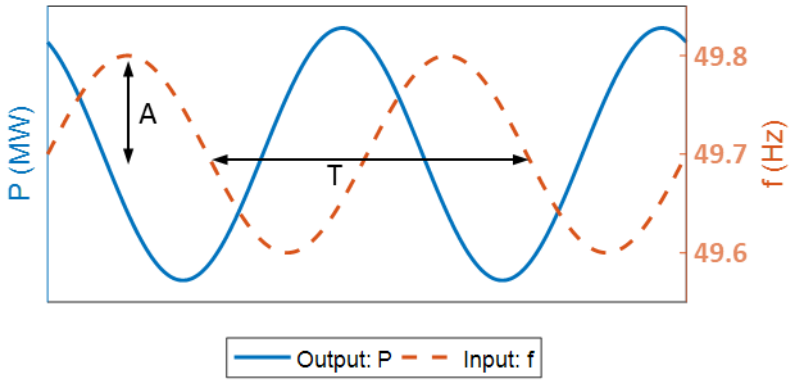


**Figure 7. FCR-D upwards sine response testing.**

2. Repeat the test for all of the following period times:

| 10 | 15 | 25 | 40 | 50 |
|---|---|---|---|---|

   For each period time, five periods shall be recorded after reaching a stable sinusoidal active power output. Some of the shortest time periods may be omitted if they are not needed to verify compliance with the stability requirement, see Section 4.5.5 in the main document.

Some FCR-D providing entities will be allowed to exist within a limited quota for entities with a grace period of 15 minutes where the deactivation requirement does not apply, as described in the Main document. Such entities will not be required to perform sine testing. When performing testing on such entities enough resting time shall be applied between each activation in the step and ramp sequences respectively, so that each activation is unhindered by previous activations and the grace period. The detailed testing arrangements for such entities must be agreed with the TSO.

## 4.4. Test of the frequency measurement equipment

The test is the same as for FCR-N and described in subsection 3.4.

## 4.5. Active data logging

All FCR-D upwards providing entities shall perform a test with 1 hour of active data logging, including measured grid frequency.



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# 5. FCR–D downwards Prequalification tests

This section contains a specification of the tests to be performed in a test set, for FCR-D downwards. The entire test program consists of one or more test sets. A single test set is designed to verify the properties associated with FCR provision under a specific operational condition. Each test set consists of:

- 1 stationary performance test
- 1 ramp response test
- 1 sine response sequence of 5 period times

The testing shall be repeated at the endpoints of typical operational conditions and for maximal and minimal capacity[9]. In addition, the following tests shall be performed for each tested entity:

- 1 test of the frequency measurement loop, for entities tested with internal frequency signals
- 1 hour of active FCR-D downwards data logging, including measured grid frequency

Results from the tests shall be attached to the application along with logged test data. The test results are evaluated by utilising the IT-Tool provided by the TSOs.

## 5.1. Stationary performance test

The stationary performance test sequence shall be performed for all FCR-D downwards providing entities.

1. Perform the frequency ramp-response sequence as in Figure 8Figure 5. Ensure that the active power response has clearly stabilised and reached its steady state value before applying the next ramp
2. Both activation and deactivation shall be tested in the downwards direction. The ramp rate shall be between 2 mHz/s and 10 mHz/s, i.e. a full activation from 50.0 Hz to 50.5 Hz shall be made between 250 seconds and 50 seconds.
3. For FCR providing entities with switching of parameter sets between FCR-N and FCR-D, the initial ramp from 50.00 Hz to 50.50 Hz is used for compliance evaluation, and in that case FCR-N needs to be active. This switchover is only necessary to test (i.e. to keep FCR-N active) at a single power setpoint, but for both droop settings. The step sequence remains the same even if switchover testing is not performed.

[9] Sine tests only need to be performed at the most challenging operating point in terms of stability. The choice of the operating point must be motivated by prior knowledge and approved by the TSO.



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50.00 Hz → 50.50 → 50.30 → 50.10 → 50.30 → 50.50 → 50.30 → 50.10

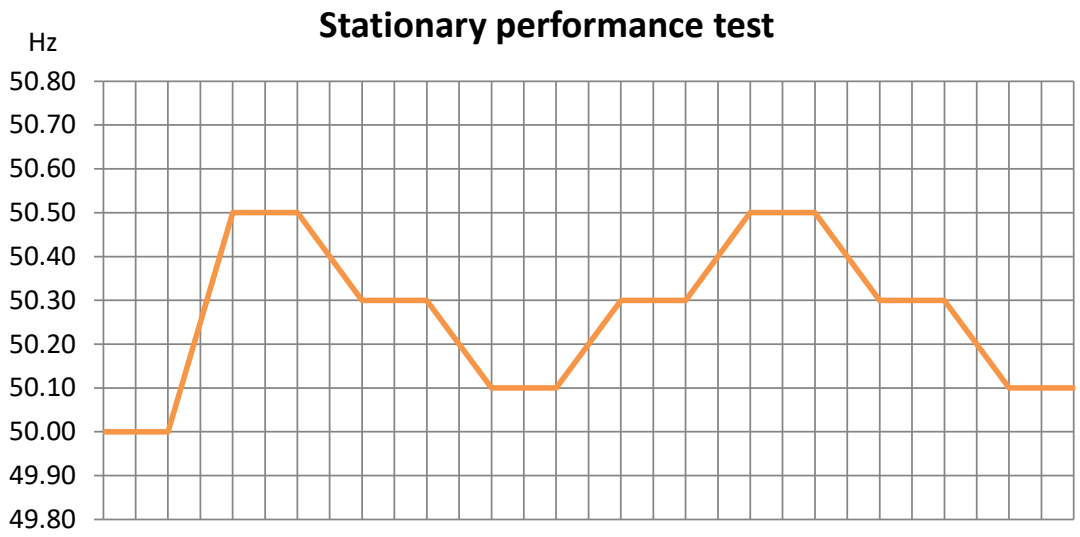


**Figure 8. Input frequency signal for FCR-D downwards stationary performance response tests**

## 5.2. Ramp response test

The ramp response test sequence shall be performed for all FCR-D downwards providing entities.

1. Perform the frequency ramp-response sequence as in Figure 9. The ramp shall be at a rate of 0.24 Hz/sec. Ensure that the active power response has clearly stabilised and reached its steady state value before applying the next ramp.

50.00 Hz → 50.20 → 50.10 → 51.00→ 50.10

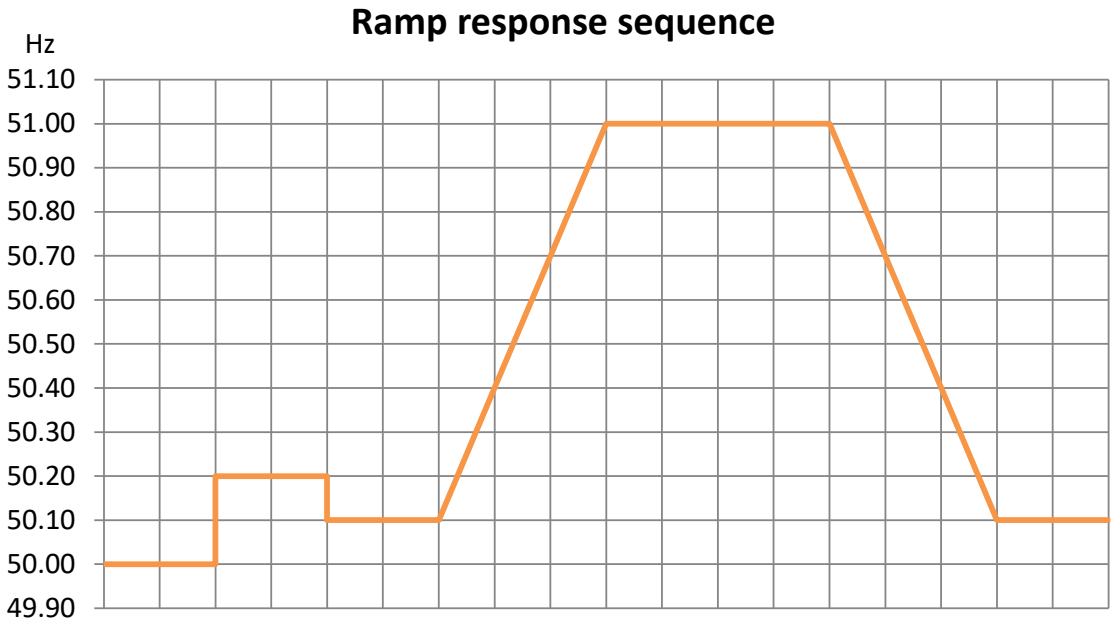


**Figure 9. Input frequency signal for FCR-D downwards ramp response tests**



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## 5.3. Sine response test

The sine response tests shall be performed for all FCR-D downwards providing entities. If the same parameter set is used for FCR-D downwards as for FCR-N, the test results from test in section 3.2 may be reused. Entities providing FCR-D with separate parameters for high performance and high stability shall perform separate sine testing for each parameter set, with parameter switching disabled.

1. Perform the sine response testing by injecting a sinusoidal frequency disturbance around 50.30 Hz with an amplitude of 0.1 Hz.

   Alternatively, if agreed with the reserve connecting TSO, the test may be performed by a frequency input oscillating around 50.00 Hz whilst providing FCR-response continuously and symmetrically around 50.00 Hz, i.e. by deactivating deadbands/insensitivity used in control loop for FCR-D.

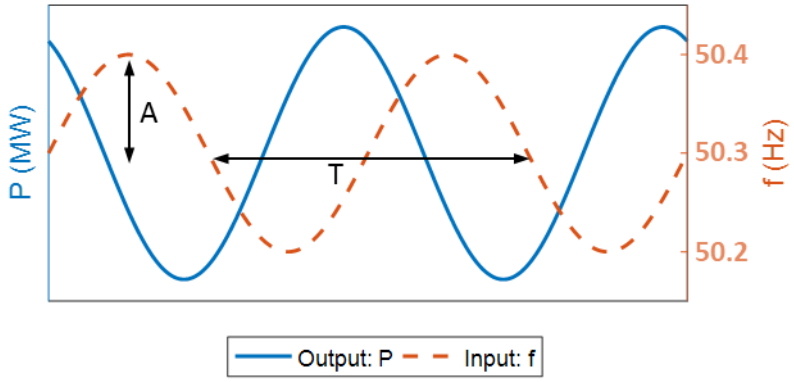


**Figure 10. FCR-D upwards sine response testing.**

2. Repeat the test for all of the following period times:

| 10 | 15 | 25 | 40 | 50 |
|---|---|---|---|---|

   For each period time, five periods shall be recorded after reaching a stable sinusoidal active power output. Some of the shortest time periods may be omitted if they are not needed to verify compliance with the stability requirement, see section 4.5.5 in the main document.

Some FCR-D providing entities will be allowed to exist within a limited quota for entities with a grace period of 15 minutes where the deactivation requirement does not apply, as described in the Main document. Such entities will not be required to perform sine testing. When performing testing on such entities enough resting time shall be applied between each activation in the step and ramp sequences respectively, so that each activation is unhindered by previous activations and the grace period. The detailed testing arrangements for such entities must be agreed with the TSO

## 5.4. Test of the frequency measurement equipment

The test is the same as for FCR-N and described in subsection 3.4.

## 5.5. Active data logging

All FCR-D downwards providing entities shall perform a test with 1 hour of active data logging, including measured grid frequency.



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# 6. Test exemptions and reuse of test results

## 6.1. Exemptions

With reference to the operational conditions stated in Section 1.1, the following exemptions are allowed:

- If the entity is planned to deliver FCR at a single power setpoint, the tests 3) and 4) can be omitted.

  3) Minimum active power setpoint where the entity will provide FCR, and maximum droop, and corresponding controller parameter sets, where the entity will provide FCR.

  4) Minimum active power setpoint where the entity will provide FCR, and minimum droop, and corresponding controller parameter sets, where the entity will provide FCR.

- If the entity is planned to deliver FCR at a single droop setting, the tests 2) and 4) can be omitted.

  2) Maximum active power setpoint where the entity will provide FCR, and minimum droop, and corresponding controller parameter sets, where the entity will provide FCR.

  4) Minimum active power setpoint where the entity will provide FCR, and minimum droop, and corresponding controller parameter sets, where the entity will provide FCR.

- If a single parameter set is used for all power setpoints, sine testing at multiple power setpoints can be omitted. Maximum and minimum droop setting must be tested. The power setpoint where stability is most challenging, normally the highest, shall be tested. E.g. hydro power using a single parameter set for entire power setpoint range is required to perform stability testing for high loading only.

With reference to FCR-N and FCR-D sine testing:

- For FCR-N sine tests using the test time periods of T = [10, 15, 25, 40, 50, 60, 70] seconds, if the response already crosses the real axis (Im=0) in the Nyquist plane on the right side of the stability requirement circle for tested time periods, the testing of time periods less than or equal to 40 seconds can be omitted
- For FCR-D sine tests using the test time periods of T = [10, 15, 25, 40, 50] seconds, if the response already crosses the real axis (Im=0) in the Nyquist plane on the right side of the stability requirement circle for tested time periods, the testing of shorter time periods can be omitted.
- The FCR provider may choose to perform tests at more time periods to investigate transfer function values in the area otherwise interpolated, see Subsection 4.6 in the Supporting document.

The following exemptions are subject to TSO approval prior to testing:

- For technologies where power setpoint does not influence the FCR provision capabilities, testing at a single power setpoint is sufficient for both steady state, dynamic performance and dynamic stability, e.g. batteries.
- The reserve connecting TSO can give additional exemptions for testing requirements where compliance can be confirmed by the general knowledge of the technology, either from previous



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tests of similar units or other documentation. The potential FCR provider is responsible for clarifying this prior to testing.

## 6.2. Reuse of test results

| Note: For the Pilot phase, Section 6.2 does not apply. |
|---|

Sine testing is similar for FCR-N, FCR-D upwards and FCR-D downwards. Results can where applicable be reused for confirming compliance for several products, assuming the same parameter set is used.

- For example, FCR-N sine test results can be reused for FCR-D upwards and FCR-D downwards



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# 7. Tasks to perform after the testing

This section contains a description of tasks to be performed after the testing has been concluded, and prior to sending in the prequalification application.

## 7.1. Data logging and analysis

Data shall be prepared in the format specified in section 5.2 of the main document, with the exception that a running number of seconds may be used instead of a full time-stamp. Evaluation of the test results shall be performed utilising the IT-Tool provided by the TSOs. The evaluation can preferably be performed continuously while testing to check for compliance during testing with partial test results.

## 7.2. Reporting

For a FCR providing unit, there may be tests performed at various operational conditions. A test set is the entirety of tests needed to prequalify the FCR providing entity at a specific set of operational conditions.

At each test set the following information shall be provided:

- $P_{\max}$ in [MW]
- $P_{\min}$ in [MW]
- Active power setpoint of FCR providing entity [MW]
- Controller parameter set,
- Expected FCR capacity in [MW]
- Dead band for frequency control [Hz]
- Conditions that have an impact on the FCR response, such as
    - Ambient temperature [°C] (thermal units)
    - Cooling water temperature [°C] (thermal units)

The data shall be provided to the reserve connecting TSO in a set of files for the various tests, and named on the format [DateTime]_[Resource]_[Test]_[Test_set].csv
where;

- [DateTime] = The day and time of the day the test is performed in format YYYYMMDDThhmm e.g. 20160310T1210
- [Resource] = Identifier for the resource agreed with the reserve connecting TSO e.g. FCPG1
- [Test] = The test performed named according to one of the following “FCR-N_step”, “FCR-N_sine_[TimePeriod]”, “FCR-N_linearity”, “FCR-D_down_stationary”, “FCR-D_down_ramp”, “FCR-D_down_sine_[TimePeriod]”, “FCR-D_up_stationary”, “FCR-D_up_ramp” and “FCR-D_up_sine_[TimePeriod]”
- [TimePeriod] = One of the time periods for the respective FCR-N or FCR-D sine tests, e.g. “40s”.
- [Test_set] = The test set which was used e.g. “Test-set1”

## 7.3. Calculation of capacity and compliance

Please refer to Section 5 of the Supporting document.



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