Case no.: Svk 2017/3551

Final report Pilot project in demand response and energy storage

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Contents

Abbreviations

Abbreviation	Explanation
UPS system	Uninterruptible Power Supply system
FCR-D	Frequency Containment Reserve – Disturbance
FCR-N	Frequency Containment Reserve – Normal
aFRR	automatic Frequency Restoration Reserve
mFRR	manual Frequency Restoration Reserve
SCADA system	Supervisory Control And Data Acquisition system

Abstract

This report describes and evaluates the pilot project in demand response and energy storage, which Svenska kraftnät conducted together with Fortum. Svenska kraftnät's purpose with the project was to test new flexibility resources for the frequency controlled disturbance reserve (FCR-D), and the aim was to gain increased knowledge in order to be able to develop the reserve markets and enable for new types of resources in the balancing markets.

The test period for the project was carried out from the middle of March until the end of May 2018. During this test period, Fortum delivered 0.1 MW frequency controlled disturbance reserve to Svenska kraftnät by using an Uninterruptible Power Supply (UPS) system[1] with energy storage. The result shows that UPS-systems can contribute to balancing the power system.

The UPS-system could be controlled by using two different control modes, central and local control. When using central control, Fortums' control centre monitored the frequency[2] and sent control signals to the UPS-system. For local control, the UPS-system monitored the frequency locally and responded automatically on frequency deviations. When using local control, the UPS-system was activated fast enough to fulfil the technical requirements for FCR-D. Also when using central control the UPS-system was activated fast enough, when activated. However, when using central control, the UPS-system did not activate on all of the occasions that the reserve should have. According to Fortum this was most likely due to the way they collected frequency measurement to the control centre. Improvements regarding this is planned in the near future. A conclusion from the project is that local control is preferred in this case, since the result with local control was better. The project also shows that the UPS-system is a potential future resource for FCR-D delivery.

During the pilot project the UPS-system started to charge its energy storage almost immediately after a frequency regulation. This could have a negative impact on the power system if the charging is initiated directly after a frequency regulation. Therefore, further investigation is needed on how charging of the energy storage should be done in the best way in order to minimize the impact on the power system at the same time as the life span of the energy storage is taken into account.

In order for the UPS-system to be able to participate as a reserve and contribute in balancing the power system, all the requirements from Svenska kraftnät needs to

be fulfilled. As new technical solutions such as energy storage and demand response are participating in different system services, the importance of clarification of the functional requirements from Svenska kraftnät increases.

1 Introduction

The power system is changing with an increasing proportion of weather-dependent power generation and a decreasing proportion of plannable power generation. This brings challenges, for example in maintaining the balance between electricity production and consumption in the power system. Svenska kraftnät is the system operator for electricity in Sweden, which includes the overall responsibility to ensure that there is always momentary balance between production and consumption of electricity throughout the country. The frequency, a measure of the balance between production and consumption, should be 50Hz in the Nordic synchronous area. In order to maintain the frequency, there are different types of reserves with different requirements for endurance and speed.

Today, these reserves are mostly comprised of hydro power. The introduction of new types of resources, for example demand response or energy storage, would increase competition in the reserve markets and allow access to automatic reserves in more bidding areas[3]. If demand response and energy storage were to play a bigger part in the markets for reserves than today, capacity from hydro power could be used as a base of electricity production to a greater extent. The combined regulating power of the power system would also increase. The ability to provide flexible resources for the power system in the future will be crucial for handling the challenges posed by the changes it is undergoing.

By conducting pilot projects within demand response and energy storage, it is possible to test new types of resources on a small scale, so that the reserve markets can be developed and new flexibility resources can be used for efficient balancing of the power system.

At present, it is not possible for demand response or energy storage to participate in all markets for reserves. Today, demand response can be handled on the regulating power market and in the peak load reserve. The main factor that limits the possibility of demand response to participate in other markets is that the regulations are not adapted to consumption and that Svenska kraftnät's IT system for operation, trade and invoicing cannot handle these resources in a correct way.

In 2017, Svenska kraftnät carried out a pilot project "Flexibla hushåll"[4], which aimed to test new types of resources for the automatic frequency-controlled reserve for normal operation, FCR-N. In this pilot project, Svenska kraftnät focussed on testing new types of resources for the automatic frequency-controlled disturbance reserve, FCR-D.

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[3] Predefined area for the division of trade in the electricity market. A geographical definition can be found at www.natomraden.se.

[4] https://www.svk.se/siteassets/om-oss/rapporter/2017/slutrapport-pilotprojekt-flexibla-hushall.pdf

2 Purpose

Svenska kraftnät is engaged in research and development activities in several strategic areas. In one are there is a particular focus on demand response and energy storage with the aim of investigating how flexibility resources can participate in balancing the power system by supplying different types of reserves.

The purpose of this pilot project was to investigate how demand response and energy storage can function as a regulating resource in the automatic frequency-controlled disturbance reserve FCR-D.

Svenska kraftnät's aims for the project were:

a) increased knowledge about demand response and energy storage as a frequency-controlled disturbance reserve, and

b) to contribute to the development of the reserve markets so that new flexibility resources can be used to balance the system more efficiently.

Fortum's aim for the project was to test and evaluate the market solution, the technical solution and the prerequisites for an attractive commercial product.

Pilot projects within demand response and energy storage can also contribute to faster commercialisation of the service by spreading knowledge to operators interested in offering similar services. These operators are the report's main target group.

3 Background

This section provides background information on regulating resources and requirements. Readers who are already familiar with this can skip to Section 3.

3.1 Reserves

Below is a brief description of the different types of reserves available. The purpose of reserves is to provide upwards[5] and/or downwards[6] regulation to maintain balance in the power system.

3.1.1 Primary regulation

In the event of frequency deviation, automatic primary regulation is used in the first instance. In a number of power stations – currently only hydro power plants – electricity production increases automatically when the frequency drops and reduces when the frequency increases. The reverse occurs for consumption, which decreases when frequency drops and vice versa. Primary regulation is essential for maintaining the balance and stabilising the frequency when it changes. The reserves are-traded in advance and are available to respond to frequency at each moment, every hour. This means they are activated automatically and stabilizes the frequency when it changes within the reserves assigned frequency range. Primary regulation includes:

> FCR-N (Frequency Containment Reserve – Normal) – stabilises the frequency in the event of small changes in production and consumption. Activated within the normal operating range 49.90–50.10 Hz.

> FCR-D (Frequency Containment Reserve – Disturbance) – stabilises the frequency in the event of disturbances, which cause the frequency to drop below 49.90 Hz.

3.1.2 Secondary regulation

Secondary regulation, aFRR, is activated after primary regulation. Secondary regulation is used to relieve primary regulation. Secondary regulation is also activated automatically; what is different from the primary regulation is that secondary regulation *restores* the frequency to 50 Hz instead of simply stabilising it. Secondary regulation includes:

> aFRR (Automatic Frequency Restoration Reserve) – restores the frequency to 50.00 Hz when it deviates from 50.00 Hz.

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[5] Upwards regulation means increased production or reduced consumption.

[6] Downwards regulation means reduced production or increased consumption.

3.1.3 Tertiary regulation

Tertiary regulation relieves the automatic reserves and restores the frequency to 50.00 Hz. For mFRR (manual Frequency Restoration Reserve), there is a Nordic regulating power market known as RKM. There, power is purchased and sold every hour to make sure that the frequency in the Nordic power system is maintained within the limits 49.90–50.10 Hz. Manual regulation is performed by Svenska kraftnät's balancing service.

For unforeseen disturbances in the power system there is a disturbance reserve, a long-term reserve consisting of a number of gas turbines which can support the power system for short periods.

In order to secure the power balance even during hours when Swedish electricity consumption is very high, the peak load reserve is available during the winter months. The peak load reserve is a strategic reserve, which is procured in advance.

3.2 Regulations for FCR-D

The procurement procedure for primary regulation is based on the balance responsible party[7] submitting bids for Frequency Containment Reserve –Normal (FCR-N) and Frequency Containment Reserve – Disturbance (FCR-D). This is done for the next day and for two days ahead. This means that the bids are submitted on D-1 and D-2in relation to operating day D and that Svenska kraftnät purchases the regulating resources on these occasions.

A total of approximately 1200 MW FCR-D is purchased in the Nordic region, depending on the dimensioning error, of which approximately 280–450 MW is procured in Sweden (most often about 400 MW). The minimum bid size permitted for FCR-D is 0.1 MW. To participate in primary regulation, the resource needs to be prequalified by Svenska kraftnät. During prequalification, a test is performed to verify that the requirements are met.

Activation of FCR-D shall take place if the frequency falls below 49.90 Hz. When the frequency changes from 49.90 down to 49.50 Hz, FCR-D shall be activated to 50% within 5 seconds and 100% within 30 seconds.

Each company that supplies FCR-D must compile and report real-time measurements to Svenska kraftnät in accordance with the document "Regler för upphandling och rapportering av FCR ", which is available on www.svk.se.

For FCR-D, the pay-as-bid model is applied for power compensation of sub ordered bids. Average price/MW per hour for primary regulation is published on https://mimer.svk.se/.

[7] An electricity supplier must supply as much electricity as its customers consume. This is called balance responsibility. The electricity supplier can either take responsibility or hire a company that takes the responsibility in its place.

4 Description of the project

In order to develop the reserve market and facilitate new solutions which can help maintain the balance in the power system, Svenska kraftnät issued a call for proposals for a pilot project on demand response and energy storage in autumn 2017. The call for proposals concerned the Frequency Containment Reserve - Disturbance, FCR-D, which automatically responds to the frequency in the power system.

During the autumn 2017, Svenska kraftnät received several interesting applications, and after an assessment, Svenska kraftnät chose to proceed with Fortum Sverige AB's project proposal. Fortum's project proposal aimed to test how data centres' Uninterruptible Power Supply (UPS) system[8] can contribute to the reserve market. During the pilot project, Fortum delivered 0.1 MW FCR-D to Svenska kraftnät. The basic idea behind using the UPS system as a reserve is to disconnect a portion of the data centre's consumption from the power system in the event of a drop in frequency, and instead allow the UPS system and its energy storage to provide the date centre with power. However, in the pilot project, the UPS system was connected to a multi-load centre at the facility and the power system was offloaded when the UPS system provided these loads with power. One of the strengths of the UPS system is that it can provide power for both upwards and downwards regulation. During the pilot project, power was only provided for upwards regulation.

In the project, Fortum received strong technical support from Eaton EMEA, the manufacturer of the UPS system and energy storage used in the project. Fortum and Eaton had identified data centres as the primary owners of UPS systems globally and considered that they were one of the most suitable customer segments for demand response. The main purpose of the UPS system and the energy storage is to secure the power supply to data centres' critical systems during a power failure. However, according to Fortum many data centres have an excess capacity, making them suitable for use in the reserve market. Fortum also hoped that the project would demonstrate how demand response could be implemented with high data security, one of Svenska kraftnät's focus areas during the project. The security aspect is also a top priority for data centre owners.

A schematic description of the pilot project is shown in Figure 1:

[8] A UPS system is a system capable of supplying emergency power to an electricity consumer when an interruption to the power source or power system occurs by using the batteries of a UPS system.

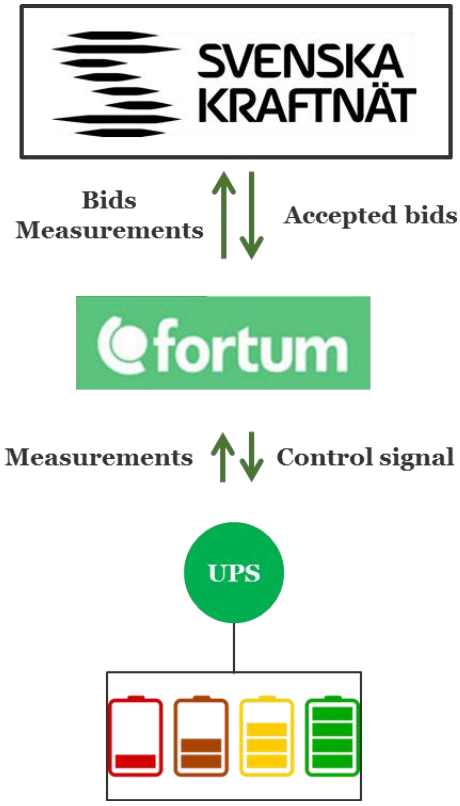

Figure 1. Schematic description of the structure of the pilot project.

The various phases of the project are listed below and described in more detail in Section 5.

- Choice of data centre (December 2017 – January 2018)
- Installation of interface for controlling the UPS system (January 2018 – February 2018)
- Prequalification of regulating resource (February 20, 2018)
- Bidding and activation of bids (March 16 –May 30, 2018)
- Evaluation

4.1 Control of the UPS system

Fortum and Eaton developed a function in UPS systems for demand response, which they call "UPS-as-a-reserve". The functionality includes the necessary interfaces with external systems (e.g. the balance responsible party's SCADA system). Activating the "UPS-as-a-reserve" function requires an upgrade of the UPS system software. Once this is done, the UPS system is integrated with Fortum's system via the developed interface, and communication between the resource and Fortum's operating centre is tested. The interface allows Fortum to send control signals/control commands and collect measurements. During the project, the "UPS-as-a-reserve" function was programmed to regulate according to the technical requirements of the pilot project.

During the project, there were two possible methods for controlling the resource:

1 Central control

2 Local control

Both methods were tested during the pilot project.

In the case of **central control**, also known as remote control, the frequency in the power system was monitored by Fortum's operation centre. In the event of a frequency drop, a control command was sent to the UPS system via the integrated interface so that the energy storage of the UPS system was controlled to regulate the correct power to the servers according to Svenska kraftnät's technical requirements for the FCR-D reserve. The power system was supported as the frequency drop decreased. For example, if the frequency fell to 49.70 Hz, a power command of 50% was sent to the UPS system, which meant an upwards regulation of 0.05 MW, as a result of the batteries reducing the load on the power system by 0.05 MW.

Local control meant that measurement and monitoring of the frequency in the power system took place directly at the UPS system, which automatically responded to frequency drops based on the sub ordered FCR-D bid. This meant that if Fortum sent an FCR-D bid for the hour 4:00 am to 5:00 am and the bid was sub ordered, the UPS system monitored the frequency from 4:00 am to 5:00 am to regulate according to the technical FCR-D requirements, if the frequency dropped below 49.90 Hz.

The technical FCR-D requirements for the project are listed below:

- Activation of FCR-D would take place if the frequency fell below 49.90 Hz.
- In the event of a frequency change from 49.90 to 49.50 Hz, FCR-D would be activated to 50% within 5 seconds and 100% within 30 seconds.
- If linear regulation was not possible, the resource would be activated partly linearly within the frequency band 49.90–49.50 Hz, as instructed in the call for proposals. In the pilot project, an alternative to linear or partial linear activation was also permitted. The alternative meant disconnecting the reserve in one or more disconnection steps as instructed in the call for proposals.

Since it was possible to activate the UPS system linearly, this was the type of regulation applied.

If no control signals were sent to the UPS system, it was passive and only monitored the local energy storage status while waiting for commands. Although the UPS system was passive on the reserve market, it still performed its primary function of ensuring that the private loads (servers) could be supplied and protected in case of potential interruptions in the power system. If the energy storage was unable to maintain the available capacity offered, a message was sent to Fortum's system so that Fortum could ensure that any submitted and sub ordered bids from the UPS system could be replaced by hydro power.

4.2 Security

When new technical solutions are used to balance the system, IT security is an important area to evaluate and was therefore a key part of the project. Examples of risks that need to be minimised are unauthorised disconnection, broken communication routes, etc.

In the project, security for controlling the UPS system was managed through Eaton's and Fortum's internal procedures for data and electrical security. All communication between Fortum's system and the UPS system was encrypted and took place through protected access points and in protected private networks with local safeguards.

5 Evaluation

This section presents Svenska kraftnät's evaluation of the various phases of the project such as choice of data centre, installation of interface for UPS system management, prequalification of regulating resource, as well as bidding and activation. The section on bidding and activation evaluates, among other things, whether the power supply (i.e. the regulation), activation time and quality of measurements met the requirements imposed by Svenska kraftnät on the reserve.

5.1 Choice of data centre

Fortum's goal was to use a data centre belonging to an external customer and when they applied for the pilot project, they had several customers who had shown interest in participating. The challenge was to find the most suitable customer who had an Eaton UPS system within the SE3 bidding area, which was also under Fortum's balance responsibility.

This was more challenging than expected and Fortum had difficulties finding a suitable UPS system in an external data centre under its balance responsibility within the project's time frame. The test period for the project was also short (two months) and it was not possible to change the balance responsibility for any of the data centres that were identified as suitable, which were not under Fortum's balance responsibility. In order to prevent the test period from being postponed, a UPS system for Fortum's internal servers at their headquarters was selected.

5.2 Installation of interface for controlling the UPS system

After deciding to use an existing UPS system at Fortum's headquarters, they needed to update the existing UPS system interface to enable the "UPS-as-a-reserve" function. However, when this was done, Fortum discovered that the UPS system in their headquarters was not technically suitable for use in the pilot project. This was because the UPS system was an older version which was not manufactured by Eaton and it was incompatible with the developed control interface.

The solution was to borrow a UPS system from Eaton which was compatible and had been tested. In the tests, Fortum had ensured that it could control the UPS system through their systems and that the UPS system responded to frequency deviations in both control methods. The borrowed UPS system was connected to a central connection point at the headquarters which was connected to multiple loads that could use power from the UPS system in the event of a frequency drop. Installation of the new UPS system encountered some unforeseen complications, which resulted in the prequalification and test period being postponed. These complications are listed below:

- Installation had to be done outside of office hours to minimise the risk of making the servers unavailable for longer periods during working hours.
- Fortum wanted to use an installation company that had carried out previous installations because they had the required skills.
- The lift down to the server room was too small for the UPS system, which forced Fortum to dismantle the energy storage and then reassemble it after it had been moved to the server room.

This meant that the prequalification and test period were postponed by about one month compared to the original plan.

5.3 Prequalification of regulating resource

Before bids can be submitted for FCR-D trade, the resource, in this case the UPS system and energy storage, must be prequalified. Prequalification is always carried out for the automatic regulating resources to ensure that the resource meets Svenska kraftnät's requirements and can deliver as agreed. Prequalification of the resource took place on February 20, 2018.

Svenska kraftnät had not prequalified demand response for supply of FCR-D before but had experience of prequalification of demand response for FCR-N from the "Flexibla hushåll" pilot project. Templates for the test and report used in the prequalification were specifically adapted for the pilot project based on Svenska kraftnät's requirements for FCR-D, see Appendix 1 and 2.

Prequalification was conducted on two occasions, one for each control method, central and local control. On both occasions, Svenska kraftnät performed the same tests to ensure correct control according to the requirements for FCR-D. During the tests, a frequency signal was simulated based on which the UPS system's power was regulated. The tests included two step response tests which both verified the speed of control and that the resource acted linearly or partly linearly within the requirements. The stabilisation time and supplied power for the two different control methods are shown in Table 1 and Table 2.

Table 1: Results for central control in the step response test performed at the prequalification

Step	Frequency [Hz]	Start time of step	Stabilisation time [s]	Power, ∆P [MW]
1	50.00→49.90	T1 = 08:33:30	N.A.	0.0
2	49.90→49.70	T2 = 08:33:45	< 2	0.054
3	49.70→49.90	T3 = 08:34:00	< 2	0.054
4	49.90→49.50	T4 = 08:34:15	< 3	0.108
5	49.50→49.90	T5 = 08:49:15	< 3	0.108

Table 2. Results for local control in the step response test performed at the prequalification

Step	Frequency [Hz]	Start time of step	Stabilisation time [s]	Power, ∆P [MW]
1	50.00→49.90	T1 = 11:34:54	N.A.	0.0
2	49.90→49.70	T2 = 11:35:16	< 1	0.047
3	49.70→49.90	T3 = 11:35:30	< 1	0.050
4	49.90→49.50	T4 = 11:35:53	< 1	0.1
5	49.50→49.90	T5 = 11:51:00	< 1	0.1

Prequalification showed that the UPS system's available capacity, which Fortum could supply as a reserve, reached the bid volume of 0.1 MW. In Table 1, the data shows that the stabilisation time when using central control differs from local control, see Table 2, and that the UPS system seemed slower with central control. The reason for this was that in the central control tests, there was no external oscilloscope connected, which there was for local control tests. Hence, the measurements on which the stabilisation time was based had a certain delay. The actual stabilisation time can be assumed to be the same for the UPS system regardless of the control method. During prequalification, Svenska kraftnät also tested that the UPS system could provide full regulation[9] (0.1 MW for the UPS system in the pilot project) for at least 15 minutes, a requirement that the resource met.

In the local control tests, an external oscilloscope was connected to the UPS system, which showed that the reaction and stabilisation time with local control was less than 1 second. Figure 2 shows an image from the oscilloscope for frequency simulation during local control tests. Without the oscilloscope, it would have been difficult to detect the rapid reaction and stabilisation time since the UPS system could only log and save test results with one second resolution.

When using central control, the UPS system supplied 0.108 MW at full regulation when the frequency was 49.50 Hz. Also at a frequency of 49.70 Hz, when the UPS system should have delivered 0.05 MW, the UPS system regulated too much power, 0.054 MW. The difference in regulated power between central and local control was, according to Fortum, due to the fact that different measurement points were used for the different control methods. In the case of local control, the UPS system read the measured values in the power connection point, whereas the battery connection was used as a measurement point when using central control. Between the UPS system and the energy storage, the conversion from AC (alternating current) to DC (direct current) took place, which led to losses. According to Fortum, the power that the energy storage supplied was 0.108 MW, but the actual supply to the central connection point (and thus the balancing of the power system) was 0.1 MW at full regulation. An attempt was made to update the embedded software to obtain

[9] Fully regulate means that the reserve supplies 100% of the power that has been sub ordered.

measurements from the power connection point also in the case of central control. However, the problem was not resolved during the pilot project, which means that providers wishing to participate with UPS systems in the reserve market need to investigate and resolve this issue in order to verify that the UPS system regulates the correct power also with central control.

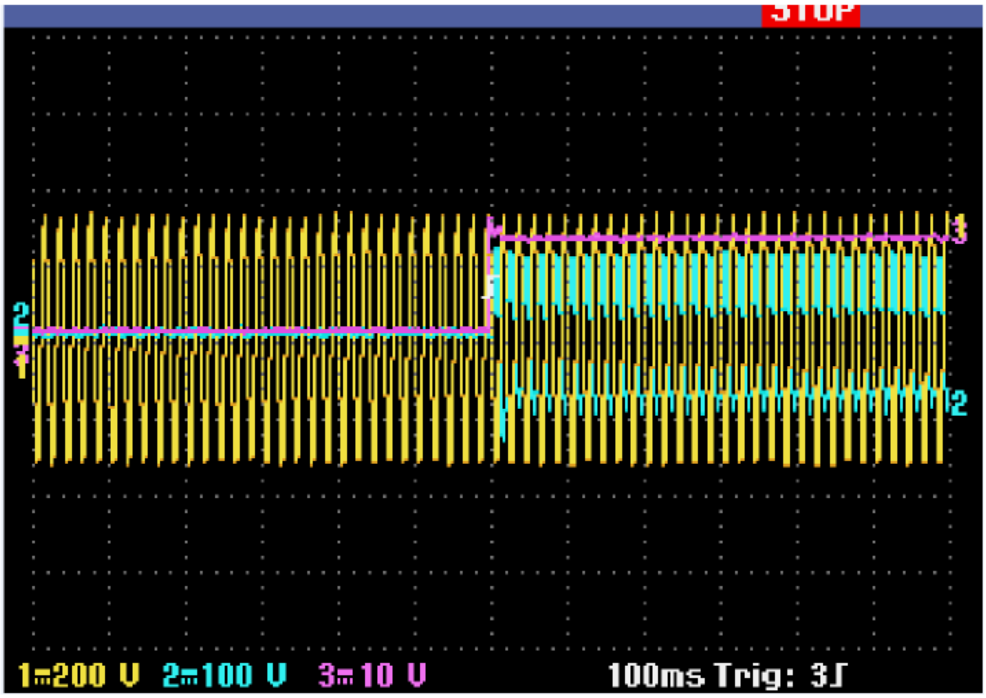

Figure 2. Oscilloscope image from an activation that shows input voltage (yellow), input current (cyan), battery power (purple).

The prequalification of the UPS system was approved by Svenska kraftnät with requirements for completion and follow-up of the following points:

1 Measurements were not reported with one second resolution (instead, approx. 55 measurements were reported per minute).

2 ΔP when using central control deviated somewhat from the requirements.

Item 1 is discussed in more detail in Section 5.4.

5.4 Bidding and activation of bids

The test period for the pilot project was from mid-March to the end of May and included bidding and activation of the bid. The test period was divided into two parts, test period 1 for central control and test period 2 for local control. The first bid for the test period with central control was submitted and sub ordered at the D-2 trade on March 14 and participated in frequency regulation on March 16.

During the first few days of test period 1, Fortum only submitted bids for one hour per day (12:00–13:00). In order to increase the probability of activation and to give the project access to more data to evaluate, Svenska kraftnät allowed Fortum to submit bids with the UPS system for several consecutive hours. This was despite the fact that full regulation for more than 15 minutes, would risk making the UPS system unavailable the subsequent hour if the energy storage needed to be charged. However, Fortum always has real-time monitoring of its FCR resources and in case of unavailability, the operator at Fortum is warned and able to take necessary actions. This ensured that Fortum would replace the UPS system with hydro power if necessary, which allowed Svenska kraftnät to grant Fortum permission to bid for several consecutive hours for a limited period.

At the end of test period 1, it was discovered on one occasion that the connection to the UPS system had been lost and that communication lapsed. This meant that Fortum stopped submitting bids for the UPS system. For hours that had already been sub ordered, the capacity was replaced with hydro power. The problem was that the communication box lost the connection to Fortum's system, which meant that Fortum could not send control signals to the UPS system. One likely reason was that the antenna of the communication box was not strong enough and therefore did not receive a signal in the basement where the UPS system was located. The problem was resolved before test period 2 started, by connecting an additional antenna and placing it in a better location to ensure good reception. Test period 1 ran from March 16 to April 9 and test period 2 from April 30 to May 30.

5.4.1 Test period 1 – central control

The table below summarises the number of sub ordered bids from Fortum, how many times the frequency fell below 49.90 Hz at the same time as the bids were sub ordered, and on how many occasions the UPS system was activated/not activated during test period 1.

Table 3. Statistics from test period 1 regarding UPS system activation.

Number of bids sub ordered during test period	Number of times the frequency was < 49.90 Hz (measurement accuracy 0.01 Hz)	Number of times the UPS system was activated	Number of times the UPS system should have been activated but was not
148	33	22	11

Based on the requirement of 0.01 Hz accuracy for frequency measurement, there were 11 occasions when the UPS system was not activated although it should have been. In total, the UPS system should have been activated for 33 of the 148 hours that were sub ordered, giving the UPS system a 67% (22/33) activation rate for the hours it should have been activated.

On all 33 occasions when the frequency was below 49.90 Hz and the UPS system should have been activated, the frequency was below the limit for an interval of 10–

45 seconds. The lowest measured frequency on those occasions when the UPS system was not activated was 49.86 Hz. If these occasions are compared to hours when the UPS system has been activated and delivered FCR-D, it is difficult to draw conclusions about why the UPS system was activated or not since there is no clear pattern. Possible reasons are that the communication between Fortum's control system and the UPS system is insufficient, or the frequency meter used for central control to determine whether the UPS system should be activated has poor measurement accuracy. Fortum thought that the reason why there were so many failed activations most likely had to do with the method used to collect frequency measurements for the control centre. At the start of the pilot project, Fortum had planned to update its frequency measurement but did not manage to implement the improvements during the pilot project.

On the occasions when the UPS system was activated when the frequency was below 49.90 Hz, the UPS system responded quickly, regulated linearly and correctly according to the requirements. Figure 3 below shows a large frequency drop that occurred early in the morning at 4:00–5:00 am UTC (6:00–7:00 am Swedish summer time) on April 9 and how the UPS system responded quickly and correctly to the frequency drop. On this occasion, the frequency fell to 49.794 Hz at its lowest, resulting in the UPS system offloaded the power system by 0.0268 MW.

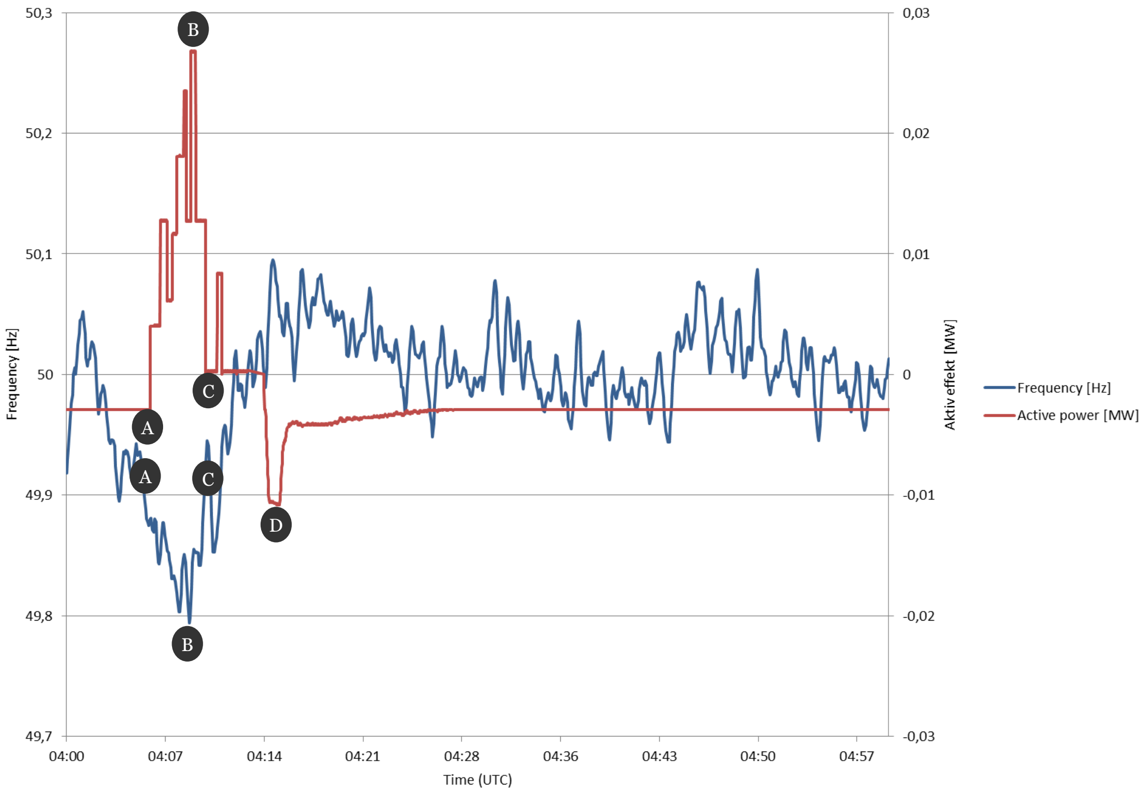

Figure 3: Activation of UPS system due to a frequency drop on 9 April, 4:00-5:00 am (UTC).

Item A in Figure 3 shows when the frequency fell below 49.90 Hz and the UPS system began to regulate. Item B shows when the frequency was at its lowest and the UPS system offloaded the power system most and item C shows when the frequency exceeded 49.90 Hz and the UPS system stopped regulating. Shortly after item C, the graph shows that the frequency fell below 49.90 Hz again for a short period and that the UPS system also responded well on this occasion. Item D shows that the UPS system began to charge the energy storage when the frequency had stabilised. When and how charging should take place in order to have as little impact on the power system as possible is something that needs further investigation.

Overall, the results from the pilot project show that Svenska kraftnät's requirements were not fulfilled with central control of the UPS system. In order to be able to participate with the UPS system in the reserve market using central control, interested players would need to ensure that the activation rate increases. However, in cases where the UPS system responded to frequency drops, it regulated correctly and showed good potential for becoming a new resource in the reserve market.

5.4.2 Test period 2 – local control

The table below summarises the number of sub ordered bids from Fortum, how many times the frequency fell below 49.90 Hz at the same time as the bids were sub ordered, and on how many occasions the UPS system was activated/not activated during test period 2.

Table 4. Statistics from test period 2 regarding UPS system activation.

Number of bids sub ordered during test period	Number of times the frequency was < 49.90 Hz (measurement accuracy 0.01 Hz)	Number of times the UPS system was activated	Number of times the UPS system should have been activated but was not
464	167	164	3

Based on the requirement of 0.01 Hz accuracy for frequency measurement, there were three occasions when the UPS system was not activated although it should have been. In total, the UPS system should have been activated for 167 of the 464 hours that were sub ordered, giving the UPS system a 98% (164/167) activation rate for the hours it should have been activated. The reason there were more activations in test period 2 was mainly that Fortum submitted bids for more hours (464 sub ordered bids) compared to test period 1 (148 sub ordered bids), resulting in more sub ordered hours and therefore more opportunities for activation in the event of frequency deviations.

All of the three missed opportunities for activation were connected to the night between May 5 and 6 from 3:00–6:00 am UTC (5:00–8:00 am Swedish summer time). According to Fortum, the reason that the UPS system was not activated during any of these hours was because the network connection between the UPS system control logic and the platform failed. This meant that Fortum could not send the command to ask the UPS system to monitor the frequency and supply FCR-D in the event of a frequency drop, which explains why the UPS system was not activated. The connection was restored during the day and the UPS system supplied FCR-D correctly later the same afternoon on May 6.

It can be noted from the analysis of the data that the UPS system was activated more times than the number of times the frequency fell below 49.90 Hz. On a total of 20 occasions, data from the test period showed that the UPS system offloaded the power system by 0.0004 MW continuously, despite the fact that the frequency was higher than 49.90 Hz. This always happened after the UPS system had supplied FCR-D. 0.0004 MW is not a large amount of power and was not something Fortum could explain.

With local control, the UPS system measured the frequency locally with internal sensors which had a higher measurement accuracy than 1 mHz, exceeding Svenska kraftnät's requirements for measurement accuracy of 10 mHz.

The UPS system responded well to both smaller and larger frequency deviations when using local control. In Figure 4, the hour 2:00–3:00 pm UTC (4:00–5:00 pm

Swedish summer time) is shown on May 8 when the frequency suffered several minor deviations below 49.90 Hz and one major deviation where the frequency (blue graph) dropped to 49.729 Hz. The red graph shows the active power of the UPS system and how it responded to the frequency deviations. The graph shows that the UPS system responded quickly and correctly to all deviations below 49.90 Hz.

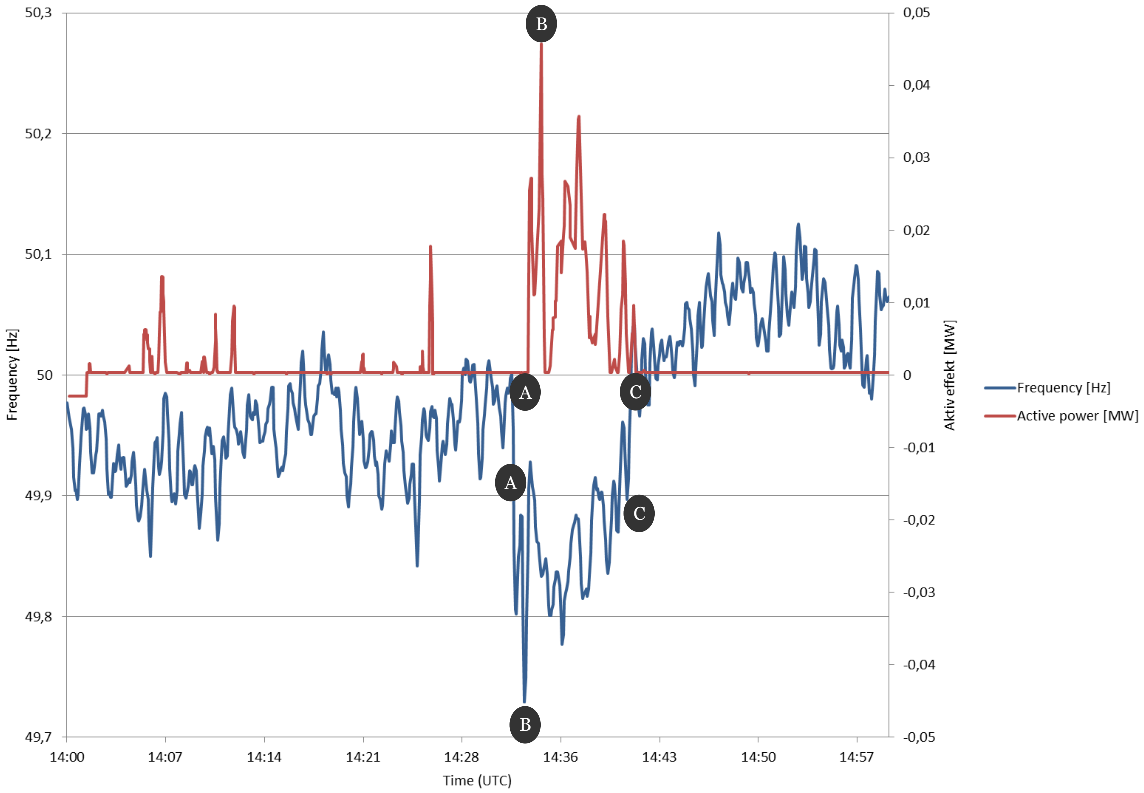

Figure 4: Activation of UPS system due to a frequency drop on May 8, at 2:00-3:00 pm (UTC).

Item A in Figure 4 shows when the frequency fell below 49.90 Hz, during the largest frequency drop in the hour, and the UPS system began to offload the power system. Item B shows when the frequency was at its lowest, 49.729 Hz, and the UPS system offloaded the power system by 0.0457 MW. Item C shows when the frequency exceeded 49.90 Hz and the UPS system stopped regulating.

Svenska kraftnät believes that the results from test period 2, when the UPS system used local control, meet the requirements well and show that UPS systems have great potential for participating as a resource in the Swedish FCR-D market. With local control, the UPS system responds quickly and correctly to both large and small frequency deviations.

5.4.3 Measurement reporting

When the bid was sub ordered, Fortum needed to report data to Svenska kraftnät to show how the regulating resource was activated. This section describes which measurements were reported and how. The quality of measurement reporting is analysed in Section 5.4.4.

Fortum reported the following measurements to Svenska kraftnät in real-time:

> Active power for the UPS system.

> Momentary value for aggregated available capacity FCR-D per bidding area.

This reporting must take place at least every three minutes.

In addition to this, the pilot project also required that the active power of the resource was logged and saved locally with one second resolution, data which Svenska kraftnät could request for more careful follow-up, if necessary.

However, during prequalification, it became apparent that there were deviations regarding the locally stored data with second resolution. In the tests performed during prequalification, fewer than 60 measurements per minute were obtained.

Possible reasons for this:

1 Logging of measurements had lower priority compared to other activities performed by the UPS system, resulting in a certain loss of measurements.

2 The communication/connection between the UPS system and Fortum's system was weak, which meant that certain measurements were lost due to temporary loss of communication.

3 The communication unit was not fast enough to both log and send all measurements.

On several occasions, Fortum received measurements every second but without actual values (zero values), indicating that item number two above was not the actual cause of the problem. From previous tests, Fortum and Eaton had checked that the UPS system was able to log and save data locally with one second resolution and they attempted to investigate this problem together during the pilot project. However, they did not manage to determine the exact cause of the problem during the project period. Based on the requirements set for the pilot project, actors wishing to participate in the reserve markets need to ensure that the resource can log and save measurements locally with one second resolution.

5.4.4 Data quality

Real-time reporting of measurements from Fortum to Svenska kraftnät's operations monitoring system worked well during test period 1 of the pilot project. The measurements reported in real-time to Svenska kraftnät corresponded to Fortum's locally stored data with high time resolution. This contributed to the fact that frequency drops could be easily and accurately matched with activations of the UPS system to check whether the regulation had been correct.

However, in test period 2, Svenska kraftnät did not receive any measurements for active power. This was not detected by Svenska kraftnät and Fortum until the end of the test period when monitoring of supply and activations took place. The reason for this was that after test period 1 when remedying the lost connection and communication to the UPS system, Fortum forgot to make an update so that the new communication unit sent data to Svenska kraftnät. Instead, the old communication unit was still set to report measurements to Svenska kraftnät but reported only zeroes. However, data for active power was still stored locally by Fortum and this data could be used for monitoring supply and activation.

5.4.5 Security

Control of the FCR-D which is currently supplied from hydro power takes place locally in the power stations' control facilities, which are industrial environments with industrial communication protocols, independent from the outside world.

The UPS system's local control method can be compared to the control of hydropower. The local control of the UPS system is not as dependent on the outside world as central control. Local control of the UPS system requires only a yes/no signal that tells the UPS system whether to participate, and then the UPS system acts independently based on the frequency in the supply network that the UPS system monitors independently.

Central control of the UPS system has more dependencies, in which a constant connection between the operating centre and the UPS system is required to send control signals and participate with the UPS system on the reserve market. This was put to the test during the test period when this connection was lost, which meant that Fortum could not participate with the UPS system and the sub ordered hours had to be replaced by hydro power. This indicates that more centrally controlled resources entail new risks from a system perspective, something that Svenska kraftnät had identified earlier.

Svenska kraftnät still needs to evaluate and work on developing requirements that can help minimise the risks of centrally controlled resources in the reserve market in order to increase security from a system perspective.

5.4.6 Pricing

In the pilot project, Fortum was paid according to the existing market model. This means that Svenska kraftnät pays a fixed capacity compensation to Fortum for the hours the bid have been sub ordered.

Today's rules for calculating the bidding price for FCR are based on hydro power as the primary regulating resource. The bids must be cost-based, which means that they are based on the actual costs of regulation, but it is permitted to add a certain risk premium.

During the pilot project, Fortum priced the bids at a level that ensured that they were sub ordered for all the hours they placed bids. This was to maximise data collection and learnings for the project. Fortum received no further compensation in addition to payment for sub ordered bids and the project was therefore not economically viable for Fortum. Instead, it aimed to help develop the reserve market for new types of resources. Hence, it is difficult, based on the pilot project, to draw any conclusions about financial incentives.

5.4.7 Impact on the data centre

Since the UPS system used in the pilot project was not directly connected to Fortum's servers but to a central connection point at the headquarters with multiple connected loads, it is difficult, based on the pilot project, to determine whether servers are affected by the UPS system participating as a reserve. Fortum believes that they could participate with the UPS system without compromising the security of the servers. UPS systems in data centres often have an excess capacity to ensure that the data centres are never without power and this excess capacity could be used in the reserve market.

Another factor that needs to be investigated further is how to charge the UPS system's energy storage without affecting the power system and data centre, while taking account of the technical life span of the energy storage.

6 Conclusions

The pilot project has been very instructive and improved knowledge of the challenges facing the development of the reserve market in order for new types of resources to participate, especially regarding the FCR-D reserve. Some conclusions from the pilot project:

> Prequalification showed that the UPS system was activated fast enough and meets the requirement that Svenska kraftnät set for the speed of the FCR-D reserve with a good margin, in the case of both local and central control.

> Prequalification also showed that UPS systems with energy storage have a good capacity for regulating linearly within the desired frequency range.

> Prequalification showed that the UPS system had difficulty logging and saving measurements locally with second resolution, which needs further investigation.

> The results from test period 1 indicate that the connection between the UPS system and control centre can be lost due to poor reception in enclosed spaces, such as a basement. This indicates that additional receivers/transmitters may need to be connected to guarantee the connection if the UPS system is located in a space where reception is limited.

> Analysis of data from test period 1 (central control) shows that when the central control method was used, the UPS system was not activated on all occasions when the reserve should have been activated. At the same time, the analysis shows that when the UPS system was activated, it regulated quickly and correctly in accordance with Svenska kraftnät's requirements.

> Analysis of data from test period 2 (local control) shows that the UPS system was activated quickly in the event of both small and large frequency deviations. The results show that local control was preferable in this case as it resulted in better results compared to central control.

> The results from the project show that the UPS system is a quick resource that can be activated in a few seconds and very accurately, something that Svenska kraftnät believes will be needed in the future.

> How to charge the UPS system's energy storage in as safe and efficient a manner as possible to ensure minimal impact on the power system needs further investigation.

> The results from the project show that UPS systems are a potential future resource for supplying FCR-D in the reserve market.

- As more and more new technical solutions for storage and demand response begin to deliver different system services, Svenska kraftnät needs to clarify the functional requirements that a reserve must meet.

Appendix 1 Test program prequalification FCR-D

Testprogrammet för prekvalificeringen var i pilotprojektet på engelska.

Introduction

This document outlines the tests needed to verify the compliance of FCR-D providing entities. The document also serves as a template for a test program.

Preparations

1. Set up the entity so that normal frequency measurement input is replaced by an artificial frequency source.
2. Make sure that the data outlined below is logged according to the requirements below. If applicable, limitations regarding the requirements below should be described in the FCR Application Document
    - Instantaneous active power in MW with a resolution of 0.01 MW and an accuracy of 1 % of the rated power of the providing entity, or better.
    - Measured frequency in Hz, with a resolution of 1 mHz and an accuracy of 10 mHz or better.
    - Applied frequency signal, with a resolution of 1 mHz and an accuracy of 10 mHz or better.
    - Calculated available capacity.

FCR-D

4 Perform the following frequency step-response sequence. Make sure that the active power response has reached its steady-state value before applying the next step! At 49.50 Hz, the frequency signal should be applied for at least 15 minutes.

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

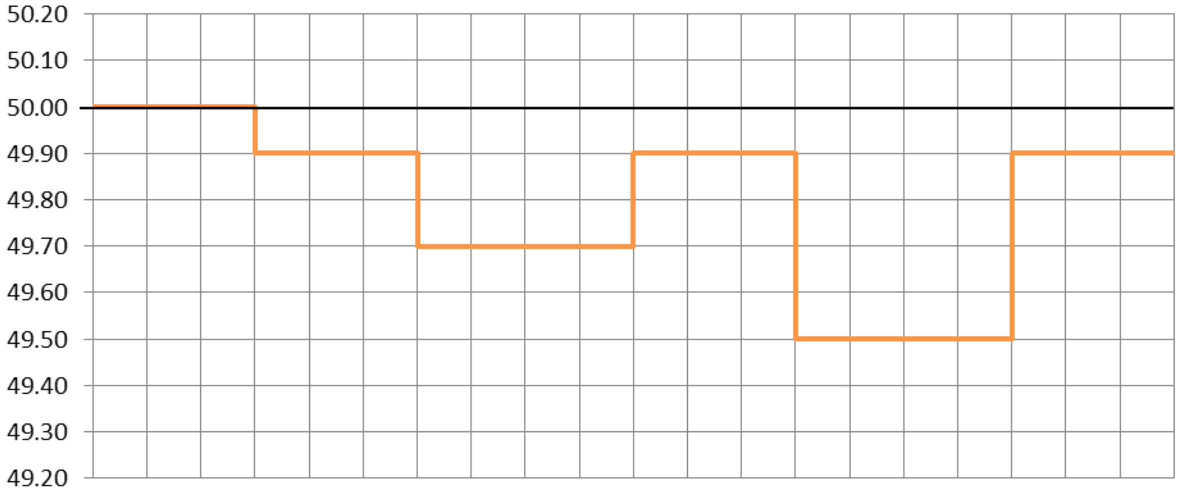

Figure 1: FCR-D upwards regulation step response sequence.

5 If the entity is relay-controlled, verify that the steady-state responses are inside the blue area in Figure 2. The figure shows relay controlled load but from a grid perspective, corresponding power change should be delivered from production and energy storage.

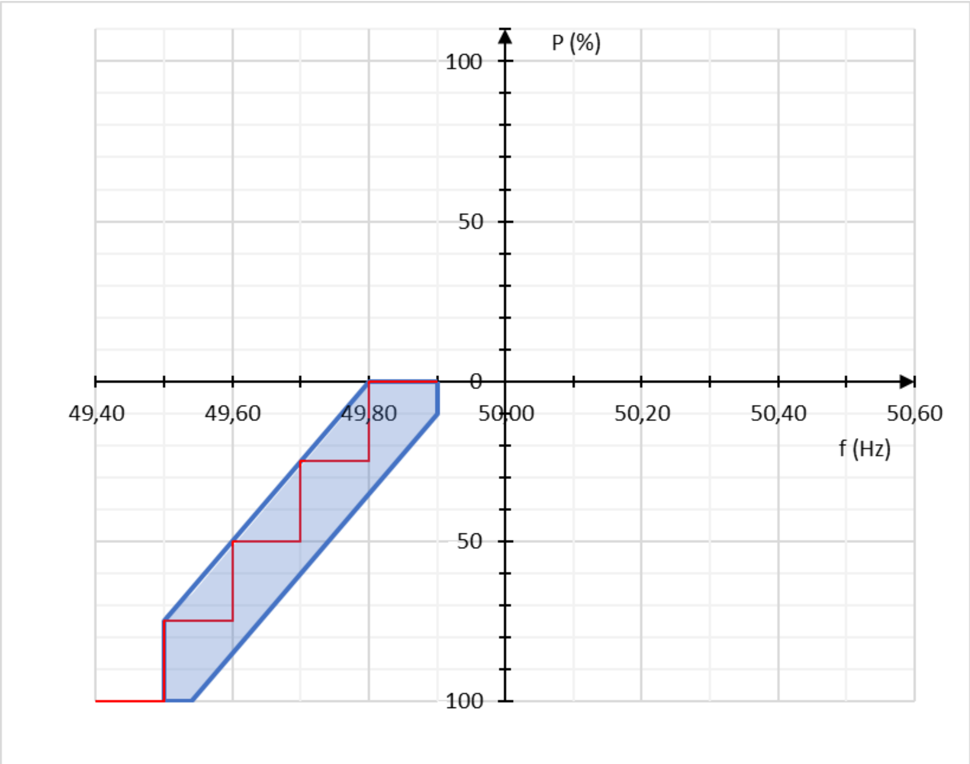

Figure 2: Activation of relay controlled FCR-D resources.

Perform the step-response sequence as shown in Figure 3. The starting frequency should for FCR-D be set to 49.90 Hz and each frequency step should not be larger than 50 mHz. Once 49.50 Hz is reached the frequency should be stepped back in a similar manner until 49.90 Hz is reached. Next step may only be applied once steady-state response has been reached.

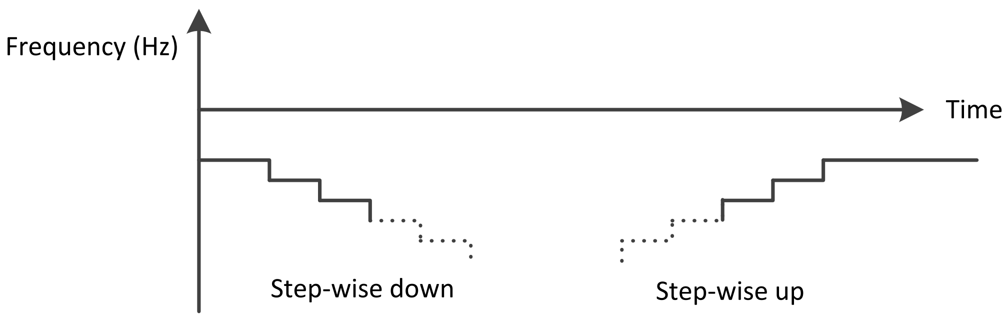

Figure 3. Step-response sequence to verify linear behaviour of the FCR-unit.

Appendix 2. Test report prequalification FCR-D

Introduction

This document serves as a template for documenting the tests performed to verify the compliance with the technical requirements set for the provision of FCR-D. This document specifies the minimum amount of information to be documented. Where needed, the document shall be extended.

Test data

Table 1: FCR-D test data

P_{min}		**MW**
$P_{\max}$		MW
Expected FCR-D capacity		MW
Deadband		Hz

Document controller parameters used

Stationary and dynamic performance

Add a figure of the stationary performance of the entity (from FCR-D step response sequence test).

Step	Step initiation time [hhmmss]	Stabilisation time [s][10]	ΔP [MW] 5 s, 30 s
1			
2			
3			
4			
5			

Step	Step initiation time [hhmmss]	Stabilisation time [s]	ΔP [MW] 15 min
4			

[10] Stabilisation time is the time it takes from applying the step until steady state value is considered to be reached.