Wind and Solar in the Nordic Reserve Markets

Challenges and Possibilities of Weather Dependent Production

ENERGINET FINGRID Statnett SVENSKA KRAFTNÄT

Contents

Background

The power system must always be in balance. That means that the sum of production, consumption and net import/export must be zero at any time to maintain system stability.

The electricity market has several purposes. The electricity market ensures that the power system is balanced before delivery and produces a common price based on the balance between planned production and demand each hour. However, there will always be some deviations in actual production or consumption, and outages can occur. This leads to imbalances. Imbalances in the operation hour are more expensive than trading and this incentivizes every participant to plan themselves into balance.

These imbalances must be handled by the Nordic TSOs (transmission system operator) that purchase different products on the reserve markets. The participants in the reserve markets get paid to adjust their consumption or production if needed. Some reserve markets require automatic activation, fast responses and short duration, while others require more energy for a longer period of time. Reserves can be procured either on capacity markets or energy activation markets.

The power system is changing with increased renewable energy production, which creates new challenges for the system stability. At the same time, it also creates new possibilities. Today the reserves are mainly delivered from resources whose active power is largely controllable (e.g. hydropower). Resources with variable production, such as wind and solar, participate to a very limited extent.

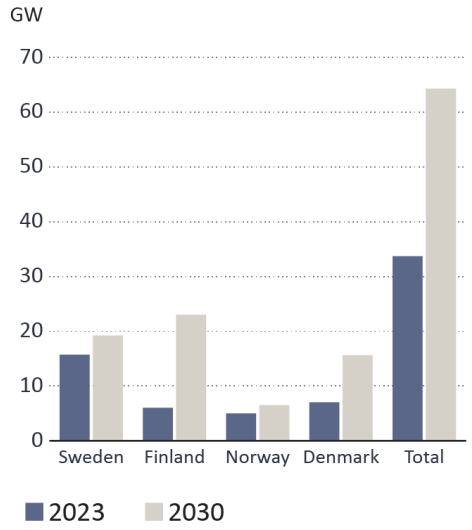
The purpose of this document is to provide guidance to the Nordic reserve markets, with the aim of increasing the participation of wind and solar. It also highlights the initiatives and different approaches made in the four Nordic countries to introduce more wind and solar. The document summarizes the main possibilities and barriers for wind and solar on the markets, presents the Nordic reserve markets and further development.

Reasons to participate

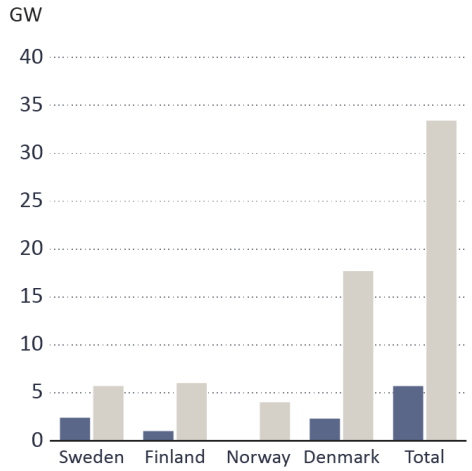
Enabling the energy transition

The green energy transition with increasing share of weather dependent electricity production and the electrification of the society put unprecedented challenges on the power system. TSOs need to be prepared for increasing balancing needs and producers and consumers are urged to utilize their flexibility even more. Electricity market prices are expected to become more volatile creating price signals and incentives to actively participate in the electricity and reserve markets. Wind and solar participating in the reserve markets is crucial for an efficient energy transition and secures system stability. An active market participant could also publicize their support of the energy transition through their involvement in the reserve markets.

Installed wind power in the Nordics



Installed solar power in the Nordics



A reserve product for everyone

There are several different reserve products for different needs in the power system. Some reserves are activated automatically, and some manually, some require more power while others require more energy, some activate fast and some more slowly. The wide selection makes it possible to find reserve products that are attractive to wind and solar production and for the individual market participant. Reserve trading is well defined, trading client is provided by the TSO, and the communication is standardized. High degree of automation is also possible.

Additional income for the market participants and more efficient markets

Selling and providing reserves to TSOs generates additional revenues that do not depend only on the Day-ahead market prices. One can also provide reserve products that do not restrict normal production. When the wind or solar park plans to produce, it can deliver down regulation. The production is sometimes curtailed due to low or negative energy prices, which makes it possible to deliver up regulation. High demand for capacity can make it profitable to curtail production to be able to provide reserves.

Active participation and higher supply promotes competition, makes the markets more efficient, and makes extreme balancing prices less likely. In addition, it lowers the overall costs for procuring reserves.

TSOs have the responsibility to keep the electricity system operational

Ultimately, TSOs need to secure system operations. Reserves are procured market-based but if there isn't sufficient supply to meet the demand, TSOs, as system operators, have the right to order market participants to provide the capacity needed. Participating in the markets increases the liquidity which makes such measures unlikely.

Market principles

In this section some market principles for reserve markets are presented.

Most reserve markets are asymmetrical which means that a bid is only used in one direction, up or down regulation. In case of up regulation, the provider must increase the production from the current production or decrease consumption, if activated. In case of down regulation, the opposite applies: the provider must decrease the production or increase consumption, if activated. The reserves can be procured either on capacity markets or energy activation markets. To be allowed to participate in a market, the reserve provider must undergo a prequalification to verify compliance with the technical requirements for the relevant reserve.

The capacity markets

The capacity markets ensure that there are sufficient available resources to respond when needed during the purchasing period. Entities with an accepted capacity market bid must react automatically or commit to participate in the subsequent activation market.

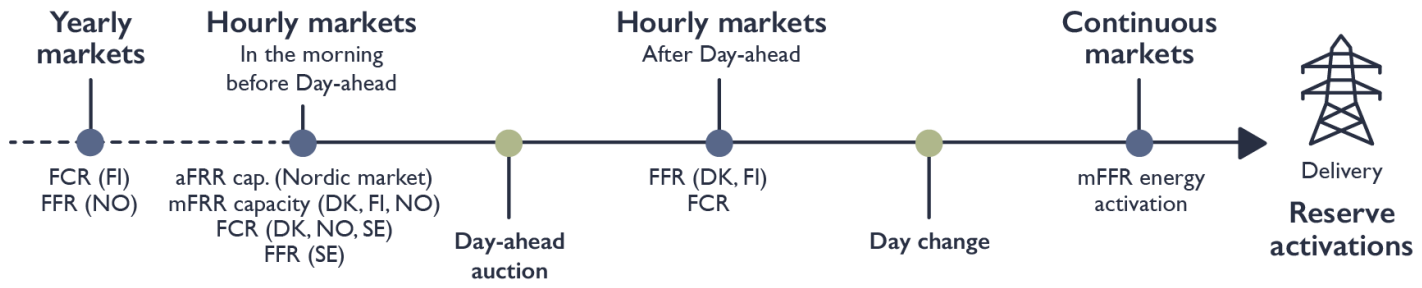
Energy activation markets

Energy markets are used to activate bids that involve an up or down adjustment of consumption or production in real time. Upon activation, the resource shall deliver according to the market requirements. The accepted resource gets paid only if the resource was activated.

Principle of pricing

For most reserves, marginal price principle applies when participating in the reserve markets. That means that all bids are marginal cost for changing production. That also means that no one will be activated unless the market price is higher* than the producer's marginal cost. For the common FCR market in Sweden and Denmark, marginal price will be implemented but today pay-as-bid pricing is used.

- Valid for capacity markets and for up regulation in activation markets



Closing time for reserve markets

Capacity markets are cleared before the delivery day, some reserves before and some after the Day-ahead auction. Energy activation (currently mFRR) happens closer to real time, after Intraday market closure time.

Roles in the reserve markets:

There are two main roles in the reserve markets defined by the European grid codes: Balance responsible party and Balance service provider.

Balance responsible party (BRP) is responsible for imbalances and deviations between the traded volume and the actual production and consumption on the electricity market. A BRP can be a Balancing Service Provider as well.

Balancing service provider (BSP) is an entity that has made a contract with the TSO to bid their resources on the reserve capacity and energy markets. The BSP is responsible for delivering the purchased reserves.

Reserve Products and Markets

Wind and Solar in the Reserve Markets

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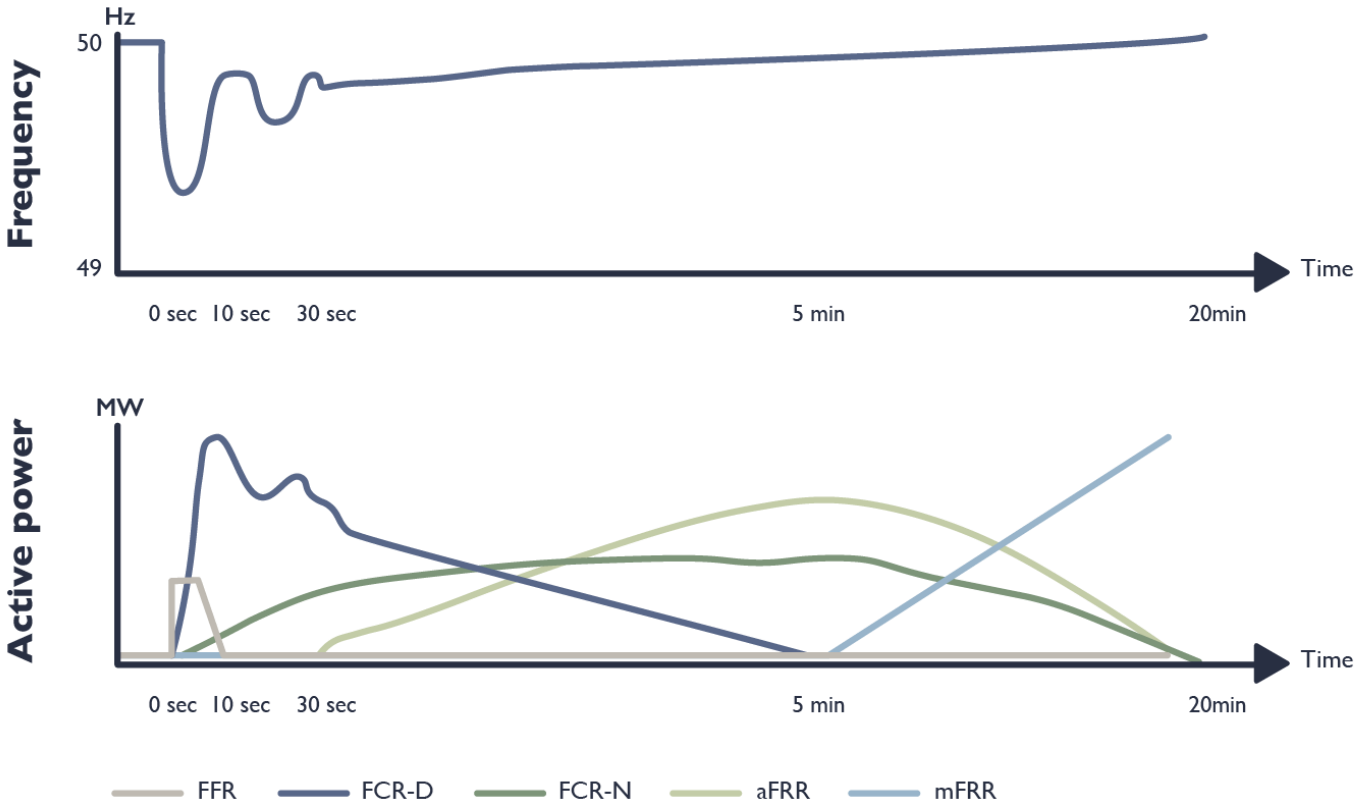
Introduction of the reserve products



To keep the balance in the power grid, the TSOs need several reserve products, which all have different purposes. Some products are responsible for stopping a frequency fall or rise in case of a disturbance, while other reserves are to restore the frequency back to 50 Hz after a disturbance. The figure to the left shows the activated reserve products in case of a disturbance in an illustrative way.

In the Nordic electricity system, there are five different reserve products:

1. FFR – Fast frequency reserve
2. FCR-D – Frequency containment reserve for disturbances
3. FCR-N – Frequency containment reserve for normal operation
4. aFRR – Automatic frequency restoration reserve
5. mFRR – Manual frequency restoration reserve

The products are explained on the following slides. The possibilities and barriers for wind and solar are highlighted.

One note to take is that Denmark is split into two synchronous areas, DK1 being a part of the Central European synchronous area and DK2 being a part of the Nordic synchronous area. There are minor differences in the reserve setup in the two areas, which will not be explained in this report.

Market participation for solar and wind today

Wind and solar power participate in the reserve markets to varying extents in the Nordic countries. Solar power is still only available on the Swedish and Danish FCR market, while wind power is participating to a greater extent. The most common market for wind power today is the mFRR energy activation market for down regulation.

The table on the right presents how much wind and solar is prequalified in different countries, the values are in MW.

For Norway, Finland and Denmark, the volume stated for the mFRR energy market is the maximum hourly bid volume offered until summer 2023.

Finland changed the mFRR capacity up market from weekly to hourly resolution in December 2022 and introduced a new hourly mFRR capacity down market in January 2023.

Sweden did not have a capacity market for mFRR previously*, hence there is no wind and solar power participating during summer 2023. A large part of the prequalified volume in Sweden is in the ongoing pilot study for variable resources.

*go live was in October 2023 (both up/down).

	Svenska kraftnät	Fingrid	Statnett	Energinet
Wind				
FFR	0	0	0	9
FCR-D up	170	0	0	150
FCR-D down	320	0	0	150
FCR-N	150	0	0	120
aFRR up	0	0	0	224
aFRR down	250	0	0	224
mFRR energy up	10	290	100	410
mFRR energy down	1440	860	1200	2850
mFRR capacity up	-	0	0	150
mFRR capacity down	-	340	0	-
Solar				
FCR-D down	10	0	0	15
FCR-D up	0	0	0	5

Manual Frequency Restoration Reserve
mFRR

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About mFRR

Manual Frequency Restoration Reserve (mFRR) is needed for managing the balance in the Nordic system in normal operations and during disturbances. mFRR is primarily used to restore the Nordic frequency to 50 Hz and secondarily to manage regional balances and transmission line congestions.

Main tool for system balance management

The mFRR product is needed for both directions. Up and down regulation are offered to the market and activated separately. mFRR regulation is activated, by the decision of TSO operators, on the energy activation market.

There are now mFRR capacity markets in all the four countries. Sweden has just implemented its capacity market for mFRR in October 2023. The capacity markets have a marginal pricing method. The mFRR capacity market secures enough submitted mFRR energy activation market offers. In the capacity market, the BSP/BRP commits to submitting offers to the energy activation market. The BRP/BSP gets paid for the capacity independently of the activation of the bids in the energy activation market.

mFRR energy activation market is the last open reserve market before the delivery hour starts. It is rational for a market participant to offer their full available capacity upwards and downwards to the markets. Balancing needs can occur suddenly and without submitting mFRR offers, the market participant gives up income opportunities. It is also unfavorable for the system if available flexibility is not utilized, and more expensive offers are selected instead.

Technical requirements

Market participants submit mFRR energy activation offers for each individual hour separately. The gate closure time for submitting the offers is 45 minutes before the delivery hour. The TSOs choose offers in price order and send activation requests electronically to the market participants who then need to regulate their assets within 15 minutes. Minimum bid size varies between 1 and 10 MW in different countries.

Common Nordic mFRR market

The current hourly mFRR energy activation market is Nordic, and the pricing method used is marginal pricing. The Nordic TSOs run their local marketplaces, but the activation is done by combining the Nordic bid lists and optimizing the cost of activation and utilizing the transmission lines between different bidding zones.

Up regulation offers are activated from the cheapest upwards until the balancing need is covered. Down regulation offers are activated from the most expensive downwards. The price of up regulation is equal or higher than the Day-ahead (DA) price and down regulation price is equal or lower than the DA price. The mFRR activation price to the dominating direction also sets the imbalance price in the area. Regulation area can consist of more than one bidding zone when there are no congestions in the connecting transmission lines. Imbalance of a balance responsible party is the difference between their trades and their net production or consumption.

TSOs can also activate mFRR offers as special regulation for other purposes than balance management. In this case, the activated offers are settled pay-as-bid. Special regulation doesn’t affect the imbalance price.

mFRR in different Nordic countries

Denmark

mFRR Capacity market
In DK2 60% of the capacity is procured on a monthly market and 40% is procured on an hourly market. The minimum bid size is 5 MW. There is no capacity market for down regulation.

mFRR Energy activation market
Assets are not yet prequalified for the energy activation market but will be when joining the Nordic mFRR EAM market. The minimum bid size is 5 MW.

Finland

mFRR Capacity market
The minimum bid size is 1 MW.

mFRR Energy activation market
Finnish energy activation market has a minimum order size of 1 MW. Assets are not prequalified for the energy activation market – what is needed is a real time production or consumption measurement and manned control room for the hours a market participant submits orders. Asset owner, balance responsible party of the asset or an aggregator can act as a mFRR balancing service provider.

Norway

mFRR Capacity market
From fall 2023 the capacity market is an hourly market for the next day. Minimum bid size is 1 MW.

mFRR Energy activation market
Today the Norwegian activation market (called RK - regulerkraftmarkedet) has a minimum bid size of 10 MW, except in the areas NO1 and NO3, where it is 5 MW. The minimum bid size will be reduced to 1 MW and will also be part of the Nordic mFRR energy activation market in the future. The real-time communication system must be tested as part of the qualification process.

Sweden

mFRR Capacity market
From fall 2023 the capacity market is an hourly market for the next day. Minimum bid size is 1 MW.

mFRR Energy activation market
The Swedish energy activation market has a minimum bid size of 10 MW, except in SE4 where the minimum bid size is 5 MW. There is an ongoing pilot study where 1 MW bid size is allowed for new market participants. To be allowed to participate in the market, assets need to be prequalified and have real time communication in place.

Wind and solar in mFRR

With increasing wind and solar production, it is important to get the producers to offer their flexibility to the markets. Technically mFRR regulation is relatively easy to provide. The full activation time requirement for the regulation is 15 minutes. In many cases, regulation activation can use the same technical functionalities as when curtailing production due to e.g. negative Day-ahead prices.

Continuous mFRR energy activation market enables the use of up-to-date production forecasts which minimizes forecast errors. The need for mFRR energy activation also affects the imbalance price which is a significant cost factor for weather dependent production. More supply in the markets increases competition, makes the markets more efficient, and thus reduces the likelihood of extreme regulation and balancing prices.

Remote regulation capabilities are needed

Being able to control the production of an asset remotely to provide flexibility will increase in value in the future as price volatility increases and negative prices become more common. This can also help avoiding high balancing costs even if the asset is not participating in the mFRR markets. Some older or smaller wind and solar assets might be missing commercially usable remote control capabilities that are needed for activating the regulation. When new or additional investments are planned, this remote control should be included.

Including reserves in operational agreements

If a wind or solar producer does not participate in the reserve markets, it is possible that the participation possibility is not taken into account in the operational agreements of the asset. These are typically balancing agreements and PPA contracts. To be able to operate flexibly and market based, one needs to have this possibility included in the agreements. Renegotiating them later is a clear delaying factor when aiming to participate in the markets.

mFRR energy activation price levels becoming more attractive

In the past, mFRR down direction energy activation prices have rarely been negative. This has made it economically unprofitable for wind and solar production to participate in the mFRR markets. Down regulation activation means curtailing production and buying the energy from the TSO. Buying energy that cannot be stored becomes relevant at around zero or negative prices.

In the first half of 2023 there has been a significant increase in the number of negative priced down regulation hours in the Nordics. Also, the price sensitivity downwards has increased. Prices have been down to hundreds and even thousands of euros negative.

In Denmark there has been notable demand for special down regulation. Wind producers have had an active market to provide down regulation at profitable prices. This has normalized the mFRR market participation in Denmark.

mFRR capacity market – great opportunity for wind and solar

Another way to make mFRR markets more attractive to weather dependent production are the capacity markets. Finland has introduced mFRR capacity market for down regulation in the beginning of 2023. This hourly market traded before Day-ahead auction for the next day enables income possibilities for wind and solar producers even if the energy activation orders are not activated. Denmark procures only up direction mFRR capacity.

Automatic Frequency Restoration Reserve aFRR

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About aFRR

The aFRR reserve's major task is to restore the frequency towards 50 Hz. The aFRR market has gradually grown over time and hydropower has predominantly participated in it. Wind parks participate in aFRR in Sweden and Denmark today, however solar parks are not currently providing aFRR.

Technical requirements

aFRR is an *asymmetrical* product which means that it consists of two products, one for up regulation and one for down regulation. Each product (up and down) has its own price. The minimum bid size is 1 MW.

Activation

aFRR is an automatic reserve that actives by a control signal from the TSO. The control signal is based on power system frequency. The provider must react and have a full response within 5 minutes. The activated energy is compensated with the mFRR price (except for DK1). When aFRR energy activation market (PICASSO*) is established, energy is compensated with a marginal price principle from its own energy activation market.

Today the activation is pro-rata, which means that the total activated volume is proportionally and equally distributed between the participants in the capacity market. When joining PICASSO, there will be an energy activation market where activations will be done in price order.

How to participate?

New providers are obligated to do a signal test, while the prequalification is sufficient for existing providers with new assets. A signal test is conducted together with the TSO to verify that the necessary real-time signals are correct. Then the prequalification test is done which consists of a physical self-response test performed by the provider.

In Norway, the physical power response test (prequalification) is done before the communication test. The prequalification is done based on local test signals.

* PICASSO is explained here: https://www.entsoe.eu/network_codes/eb/picasso/

New Nordic capacity market since December 2022

Until December 2022, each country bought aFRR separately with different market design. Today there is a common Nordic capacity market for aFRR, except for DK1. The market clears one day before delivery (D-1) with a gate closure time at 7:30 CET. Market results are normally published around 9:00 CET.

The capacity prices are priced to the marginal price principle ("pay-as-cleared"). Bids and market clearing are separate for each hour for each direction.

The Nordic aFRR demand is published each quarter. The procurement is hourly for the period, and reserves for both up and down regulation are purchased.

The total need of aFRR is split between the bidding zones in the Nordics. However, some areas buy aFRR from other bidding zones due to lack of providers.

Deviation from the common Nordic market in DK1

In DK1 the aFRR market is a monthly market. In periods with low liquidity on the market, the auction can become a weekly market to increase liquidity. The capacity market of aFRR in DK1 is pay-as-bid.

Wind and solar in aFRR

Possibilities

For wind or solar parks, there are possibilities to earn money for intermittent production in the aFRR market, especially for down regulation. The volumes for aFRR have increased in the recent years along with the prices.

When the energy activation market (PICASSO) is realized, new opportunities for wind and solar will be applied.

Barriers

The providers need to be able to receive the control signal continuously from TSO and have real time communication in place. This barrier is higher for small wind and solar parks.

Furthermore, aFRR, still being only a capacity market, is seen as economically unprofitable to participate in upward regulation at current market prices since this requires curtailing production and foregoing potential Day-ahead revenues. Whereas downward regulation is unprofitable as the purchase price of energy is mostly positive, and thus buying back wind power is not profitable.

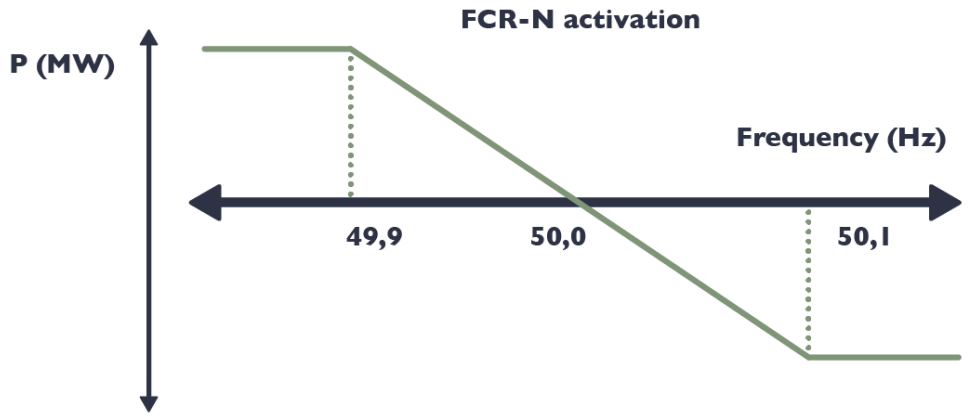
Frequency Containment Reserve for Normal operation FCR-N

About FCR-N

The purpose of FCR-N is to counteract to the continuous frequency deviations during normal operation (hence the letter N). All Nordic TSOs procure FCR-N to stabilize the frequency.

Technical requirements

FCR-N is a *symmetrical* product which means that the product must be able to handle both up and down regulation. FCR-N activates in the range from 49.9 to 50.1 Hz. The response in power is proportional to the frequency as shown in the figure. FCR-N shall be 63% activated within 60 seconds and at least 95% within 3 minutes.



Market procurement

FCR-N is a capacity product that is procured from capacity markets which are implemented differently in each Nordic country. More about these specific national procurement models are on the next slide.

Activation

The FCR-N reserves are activated automatically based on the measured grid frequency at each reserve unit. The frequency measurement shall have a specific precision specified in the technical requirements. Activation energy is compensated with the mFRR price. Activated energy for up regulation is compensated with mFRR up regulation price and activated energy for down regulation is compensated with mFRR down regulation price.

The frequency typically fluctuates in the normal range of 49.9 to 50.1 Hz based on the changes in consumption and production. This means that the FCR-N response is constantly changing and maintains system power balance. If the frequency falls outside the normal range, FCR-N will remain fully activated, and Frequency Containment Reserve for Disturbances (FCR-D) begins to support the power system as well.

FCR-N in different Nordic countries

Denmark and Sweden

The Eastern part of Denmark (DK2) and Sweden have a common market for FCR-N, which is an hourly market split into two auctions. One auction before spot market and one auction after spot market i.e. all FCR capacity is procured through auctions one day before operation (D-1). The auctions have *pay-as-bid* pricing*. The minimum bid size is 0.1 MW.

*Marginal pricing by February 2024.

Finland

In Finland, FCR-N is procured from yearly and hourly markets. Most of the volume is currently procured from the yearly market. The yearly auction held in fall determines a fixed price for maintained yearly capacity share.

The auction for the hourly market is held the day before delivery, after the Day-ahead auction (gate closure time is 17:30 CET). The capacity price is cleared for each hour and is based on marginal pricing. The minimum bid size is 0.1 MW, and the maximum bid size is 5 MW.

Norway

In Norway, the first auction is two days before operation (D-2), and then some adjustment is traded the day before operation (D-1) after the spot market is closed. Most of the volume is bought in the D-2 auction.

Wind and solar in FCR-N

How to participate?

Contact the relevant TSO and participation can start after the prequalification process is finished. The prequalification contains tests that show that the frequency response is according to the necessary requirements.

Wind and Solar in FCR-N

From a technical point of view, solar and wind are suitable to participate due to their ability to easily adjust production.

There is no need for expensive communication systems since the activation is based on local frequency measurement. To deliver bids to the TSO is still necessary, however this is usually handled by the BSP or BRP.

Participation has been slowed down because it requires curtailment of production beforehand.

The frequency changes constantly but is usually within the normal band of 49.9 to 50.1 Hz which is where the FCR-N reserves shall respond. Therefore, units participating must constantly change and adjust their production.

Frequency Containment Reserve for Disturbances FCR-D

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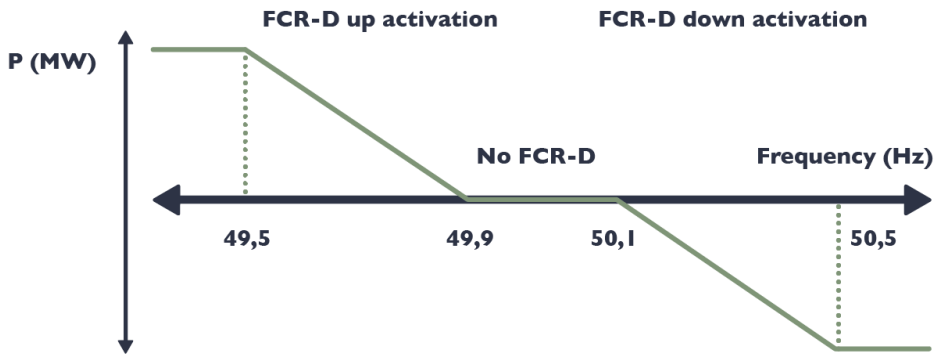
About FCR-D

The frequency containment reserve for disturbances (FCR-D) must ensure the containment of frequency in case of any disturbance. In other words, the reserve must stop the fall or rise of the frequency, if the frequency goes outside the normal band (49.9-50.1 Hz). All Nordic countries must have FCR-D reserves ready to handle disturbances.

Market setup

FCR-D is procured from national markets in the Nordic countries. The FCR-D is separated into two products: up regulation and down regulation. It is possible to participate in both directions at the same time if the reserve unit has available capacity to both directions. In order to participate in the market, the provider must prequalify their assets to ensure they meet the requirements. Contrary to FCR-N, FCR-D providers are only compensated for the capacity and there is no energy compensation for the activated energy.



Technical requirements*

FCR-D is a fast-regulating product, which must secure the stability in the power system. Therefore, the technical requirements are more advanced compared to other services. The providers are obligated to measure the frequency locally and activate the reserve based on this. This means that there is no activation communication between the provider and the TSO.

The provider can choose from two different options. The overall requirements are stated below.

1. Dynamic FCR-D

The activated power must be at least 86% within 7.5 sec.

Deactivation must have same behavior as activation (no grace period).

Must be able to control power continuously to ensure sufficient damping (fulfill a sinus test).

2. Static FCR-D

The activated power must be at least 86% within 7.5 sec.

A grace period after activation of maximum 15 minutes is allowed.

The providers must be able to deliver FCR-D for 20 minutes if necessary.

*The technical requirements for FCR-D entered into force on the 1st of September 2023 for all Nordic countries, besides Norway, which will have the requirements enter into force on the 1st of January 2024.

FCR-D in different Nordic countries

Denmark and Sweden

The Eastern part of Denmark (DK2) and Sweden have a common market for FCR-D, which is an hourly market split into two auctions. The first auction is before spot, and the last auction is after spot, i.e. all FCR capacity is procured through auctions one day before operation (D-1). The auctions have pay-as-bid pricing*. The minimum bid size is 0.1 MW.

*Marginal pricing by February 2024.

Finland

In Finland, FCR-D is procured from yearly and hourly markets. Most of the volume is procured from the yearly market. The yearly auction held in fall determines a fixed price for maintained yearly capacity share.

The auction for the hourly market is held at D-1 after the Day-ahead trades (gate closure time 17:30 CET). The capacity price is cleared for each hour and is based on marginal pricing. The minimum bid size is 1 MW, and the maximum bid size is 10 MW.

Norway

FCR-D has historically been procured through TSO decision forcing hydropower to deliver FCR-D. Between May 2023 and September 2023, a market-based procurement was tested for FCR-D up. It was done day-ahead (D-1) for each hour. The price was common for all bidding zones.

Wind and Solar in FCR-D

Possibilities

As the market is separated into up and down regulation, it is very well fitted for wind and solar providers.

It is straight forward for wind and solar to deliver down regulation during normal operation of the units. Typically wind and solar providers sell their production in the spot market. They can continue to do so and then afterwards sell the possibility to shut it down in a short period of time, if any disturbances happen. FCR-D is not needed that often, which is an advantage to the provider. If the provider sells 1 MW, they can expect to deliver 0.05% of the capacity as energy (statistical evaluation from 2019–2020).

All production above the sum of minimum production and FCR volume can also offer mFRR down regulation at the same time.

Wind and solar can regulate very quickly, so from a technical point of view there is no issues for these technologies to participate in the market.

As all activations happen based on a local frequency measurement, there is no need for an expensive communication system with the TSO. The only communication the provider needs is related to market bidding, which is typically done by a BSP/BRP.

For wind and solar to deliver up regulation, some other actions must be made. In order to upregulate the unit, one must withhold capacity from the other energy markets. This could naturally happen during hours with negative spot prices. In these situations, it would be preferable for the providers to be active on the up-regulation market for FCR-D if they are still delivering energy.

Barriers

There is a need for the providers to update the control system to be able to activate automatically based on the frequency measurement.

The provider must produce when it is participating in FCR-D even though it hasn't sold the production in spot.

Fast Frequency Reserve FFR

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About FFR

Fast Frequency Reserve (FFR) is the fastest of the automatic reserves. The purpose of FFR is to handle the initially rapid and deep (transient) frequency deviations that can occur in case of low levels of inertia in the Nordic power system. The inertia in the system varies for example with time of the day and season. Because the procurement of FFR depends on inertia, the volumes and hours to be procured may vary. The procurement is typically highest in summer when the inertia is at its lowest.

Market setup

FFR is procured on national capacity markets and the market setup varies between the Nordic countries. The energy volumes for FFR are low and there is no remuneration for activated FFR energy.

Technical requirements

To be allowed to participate in the market, the provider must complete a prequalification process which includes a test to verify compliance with the requirements for FFR. The activation of the Fast Frequency Reserve is automatic, and the provider must be able to adjust the power based on local frequency measurement. The reserve power must be fully activated within the required time when the frequency falls below a certain threshold value. The provider can select any of the activation options listed below:

- 0.7 seconds maximum full activation for the activation level 49.5 Hz
- 1.0 seconds maximum full activation for the activation level 49.6 Hz
- 1.3 seconds maximum full activation for the activation level 49.7 Hz

The delivery time for FFR can be 5 or 30 seconds.

FFR is a new and technically challenging product. The procurement volume is still relatively low but with less inertia in the power system the need will increase. As for today, wind and solar are only participating in the FFR market in Denmark. The possibilities for wind and solar to deliver FFR, inertia response or planned curtailment are investigated further in the Nordic countries.

Nordic market differences for FFR

Denmark

Denmark procures FFR on a national hourly market. The procurement is dynamic and dependent on the inertia level in the Nordics. The auction has marginal pricing. The minimum bid size is 0.1 MW.

Finland

In Finland, FFR is procured from a national hourly market. The bids for each hour are submitted in the previous evening (D-1) before the procurement of FCR reserves (gate closure time 17:00 CET). The minimum FFR bid size is 1 MW, and the maximum is 10 MW. The auction is based on marginal pricing.

BSP may also submit a combination bid for FFR and FCR-D Up for flexible bidding if the BSP also has an FCR agreement. If the combination bid is not used in the FFR market, the bid will be transferred to the FCR-D Up hourly market.

Norway

Norway has two FFR products: flex and profile. FFR profile is procured for all nights and the entire weekend for the whole season (min. bid size 1 MW). FFR flex is procured on seasonable basis but is only active when it is necessary based on a weekly order from the TSO (min. bid size is 5 MW).

Sweden

Sweden has a yearly procurement where providers state their capacity and bid price for the season. Then the actual procurement of needed capacity is done twice a week based on the inertia forecast. The Swedish FFR market is an hourly market with minimum bid size of 0.1 MW. The auctions have marginal pricing.

Wind and Solar in FFR

Barriers

FFR is an up regulation product. This requires curtailing the production beforehand to have the capacity available making it less economically attractive product.

FFR is the fastest of all the reserves used for frequency control and it is used in critical situations. Some of the older technologies have difficulties with the response time.

Historically the inertia in the Nordic power system has been lower in the summer period hence less FFR has been procured during the winter months. This could be a barrier for wind power since the wind production is usually higher during winter.

To be allowed to participate in the FFR, market providers must be able to log and store data for two weeks with a resolution of 0.1 seconds.

Possibilities

FFR is a common Nordic product, and the technical requirements and prequalification process is harmonized in the Nordics. This makes it easy for providers with resources in several countries to enter the markets.

As all activations happen based on a local frequency measurement, there is no need for an expensive communication system with the TSO. The only communication the provider needs is related to the market bidding, which typically is done by a BSP/BRP.

The inertia in the system today comes from rotating machines such as thermal, nuclear and hydro plants. When the inertia is low, FFR is procured and the majority of the FFR resources comes from batteries and consumption. But in the future, there might be strategies to use wind turbines to provide FFR to the grid by extracting kinetic energy from their rotating masses, also referred to as inertia response.

Historically the inertia in the Nordic power system has been lower in the summer period hence more FFR has been procured during the summer months. This is suitable for solar, where production is highest during summer as well.

Special aspects of wind and solar in the reserve markets

Forecasting wind and solar

Wind and solar are variable sources and are not available all the time. Historically the Nordic markets have relied on long contracts, which fits wind and solar poorly. Over time, the market development has been adapted to fit new technologies better. The time of bidding has moved closer to the operational hour and the delivery periods have been shortened and will most likely be shortened even more in the future.

The TSOs need to secure reserve capacity prior to the operational hour, which creates a high need for good forecasts of wind and solar in order for the TSOs to rely on them as reserves. The further away from the operational hour the provider must predict the production, the more uncertain the forecast becomes. Therefore, the best opportunities for wind and solar are markets with gate closure time 1 day before delivery or closer.

For the TSOs to rely on the reserves, there are specific rules which the providers must respect. The requirements are not harmonized. They are presented for each of the Nordic countries in the following section.

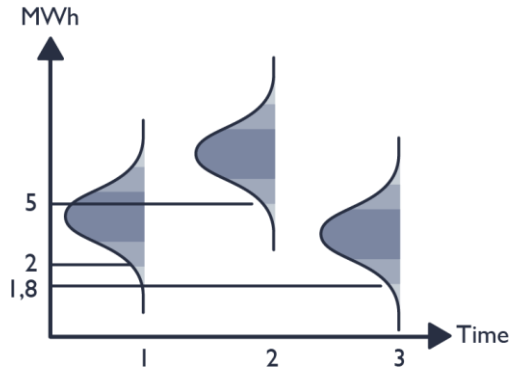
Capacity forecasting requirements

Forecasting production and available capacity are important for weather dependent assets for minimizing imbalances and for guaranteeing reserves. Difficulties in accurate forecasting can make market participation challenging. Energinet has quality requirements for the forecasts and Svenska kraftnät is investigating requirements in the ongoing pilot study. There are no additional forecasting requirements for wind and solar in the reserve markets in Finland and Norway.

Denmark

To allow wind and solar to participate in the capacity markets, Energinet has developed special requirements for the forecasting tools to ensure high enough quality. Through a Danish pilot project, it is concluded that the current forecasting precision and tools have high quality to meet firmness requirements. Energinet requires a prequalification of the forecasting tool to participate in the capacity markets. There is no methodology requirement. The providers are free to choose whichever fit their unit best, but there are certain criteria the forecasting tool must live up to.

- The forecast must be based on minimum 3 months of historical data.
- The forecast confidence level must be above 85%.



The criteria is established to ensure that the capacity is available at almost any time. This level can be changed over time, if the TSO sees a need for it. It is expected that the level can be increased, as the forecasting methods become better.

Energinet does not limit the providers with the remaining energy. The providers are allowed to bid in the energy from the 10% quantile to the median of the forecast to other markets, such as Day-ahead and Intraday.

If updated forecasts closer to real-time reduce the expected power production (but not below the 10% quantile), the provider can restore balance in their portfolio by trading in the Intraday market.

Sweden

It is important for solar and wind providers to have accurate prognoses to be allowed to participate in the reserve markets. However, there are no exact requirements on forecasting today in Sweden. In the ongoing pilot study, forecast data is collected and evaluated. The ambition is to have prequalification requirements on forecasting when the pilot is over. The forecast will then be a part of the prequalification process for wind and solar and will require historical data for power forecast. So far, the pilot has noticed that it is harder to do accurate forecast during winter since it is hard to predict icing on the turbine blades and snow on solar cells. These factors reduce power significantly and it is something to consider when setting requirements.

Validating delivery of reserves

When procuring reserves, the TSO expects to receive the activated power or the maintained reserve capacity. TSOs follow up the realized reserve delivery by validating it based on the data provided by the market participant.

Available reserve capacity is calculated by comparing the *baseline* of an asset with the minimum or maximum possible production or consumption, and the certified reserve capacity of the asset.

> *Baseline is a timeseries, which indicates what a unit had produced if no regulation happened*

With weather dependent production maximum or *available power* value is dependent on the wind speed or solar radiation.

> *Available power is a calculated value that indicates the highest power the asset can produce at the time*
>
> *Minimum power is the lowest power that the plant can operate*

Activated reserve is also monitored. For this, the baseline value is also needed.

> *Provided regulation = Measured power – Baseline*

The baseline is an important calculation and the TSOs are interested in its correctness. TSO specific requirements for the baseline are presented in the next page.

Validation methodologies

Norway

There are no special requirements for wind and solar on validation. The TSOs validate the energy delivery based on reported volumes from the BRPs.

Sweden

In Sweden there are two main methods to obtain the baseline; static and dynamic baseline. *Dynamic baseline*: Regulation with respect to a dynamic baseline that follows the natural variations of the unit. During activation, the active power of the unit is adjusted downwards or upwards in relation to the dynamic baseline. The adjustment should equal the expected delivery. The dynamic baseline can be based on theoretical available power, calculated continuously from appropriate measurements or other methods. *Static baseline*: The production is limited to a set point to obtain a stable and well-defined baseline. For example, a production unit can produce stable (limited) power, instead of delivering full available power. The baseline thus becomes clearly defined and the regulation is performed based on this level.

The baseline should be carefully described in the prequalification application and the potential provider will be required to send in historical data of the baseline. In the ongoing pilot study, baseline data is collected and evaluated. The ambition is to have prequalification requirements on accuracy for baseline when the pilot is completed.

Denmark

In Denmark it is allowed to calculate the baseline after the operating hour. The reasoning behind that is to give the providers an opportunity to use real measured data in the calculation, which increases the accuracy. Some examples of real measured data used in the calculation are following:

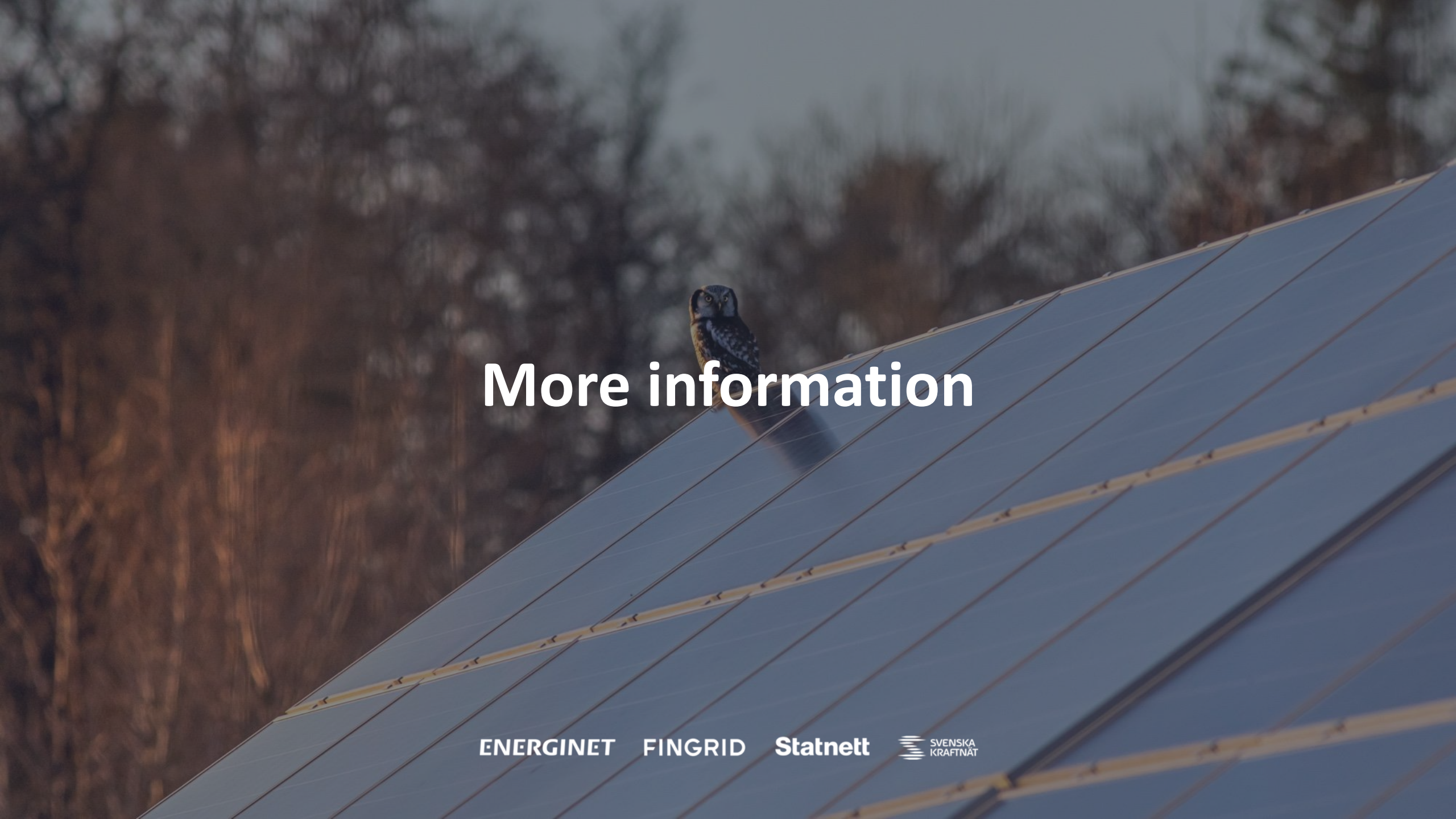
- Wind speed, wind direction
- Solar radiation, solar angle
- Temperature

The Danish TSO monitors the response from wind and solar. A tool has been developed to indicate periods where deliverables have been inadequate.

Finland

In Finland, the delivery of the automatic reserves is validated on one-minute intervals in real time. The calculation of the provided reserves requires the use of the baseline.

The baseline can be fixed to a controllable setpoint, or it can follow the normal variations in the power production of the unit. To achieve a controllable setpoint for the baseline, the production must be limited to a defined setpoint from which the reserves are activated. If a varying baseline is used, the calculation of the baseline must be described in the prequalification process. Fingrid is planning on introducing criteria for the quality of such calculated baselines.



More information

ENERGINET FINGRID Statnett SVENSKA KRAFTNÄT

Relevant pilots in the Nordic countries

Sweden

Sweden has an ongoing pilot for resources with variable production or consumption where wind turbines participate in FCR-N , FCR-D up, FCR-D down, aFRR and mFRR. In the pilot there is also solar parks in FCR-D down. The purpose is to find new ways to evaluate if the technical requirements are fulfilled in the prequalification process and to verify the delivered power.

Finland

Finland has an ongoing project “Wind power for the Reserve Markets pilot”. The goal of the pilot project is to prequalify wind assets and have them participating in the automatic reserve markets. The pilot project is ongoing during 2023.

Denmark

There is no ongoing pilot in 2023, but in 2020 Denmark started a pilot project, which aimed to find specific requirement for wind and solar, for them to participate in the capacity markets. The pilot resulted in new requirements for wind and solar, which allowed wind and solar participation in capacity markets in 2021.

Norway

There are no ongoing pilots for wind and solar in the reserve markets in Norway at the moment.

Further information

In the near future, the Nordic reserve markets for mFRR and aFRR will connect to the European market platforms MARI and PICASSO. Read more about this here: Roadmap and projects – nordicbalancingmodel

To read more about the reserve markets in each country, please follow these link to the national web pages:

Energinet: Ancillary Services

Svenska Kraftnät: Provision of ancillary services

Fingrid: Reserves and balancing power

Statnett: Introduksjon til reservemarkedene

To find prices and procured volumes, please go to the transparency platform: Data view (entsoe.eu)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