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Final report from the pilot study: Provision of ancillary services from resources with variable production or consumption

SVENSKA KRAFTNÄT

Svenska kraftnät

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Note that this is a translation of the Swedish document "*Slutrapport från Pilotstudien Leverans av stödtjänster från variable production och förbrukning"* in case of any inconsistency between the Swedish and English version, the Swedish version shall prevail.

1 Terms and abbreviations

This section explains commonly used abbreviations and terms.

Abbreviation/term	**Explanation**
aFRR	Automatic Frequency Restoration Reserve.
Curtailment	Means a deliberate reduction in power below what could have been produced.
Fictitious bids	Fictitious or notional bids are the bidding capacity that would be bid in if resources participated in the market.
FCR-N	Frequency Containment Reserve Normal.
FCR-D	Frequency Containment Reserve for Disturbances.
FFR	Fast Frequency Reserve.
Freezing method	Method that can be used to improve the baseline. The freezing method adjusts the baseline at the time of activation, which minimises initial deviations and thus ensures correct initial provision.
Mean (Average)	The sum of all values divided by the number of values.
Median	The middle value in a data series sorted in ascending order. The median corresponds to the 50th percentile (Perc 50).
mFRR	Manual Frequency Restoration Reserve.
Percentile (Perc)	The value above which a certain percentage of the values fall.
Baseline	Also known as, reference power or reference value. A baseline is calculated and must show what production/ consumption would have been if the ancillary service had not been activated. This report refers to a technical baseline and not a financial baseline.

2 Objective and scope

2.1 Background

Svenska kraftnät procures ancillary services and remedial actions to stabilising and balancing the power system. These categories include FFR, FCR-D, FCR-N, aFRR and mFRR. These are used for both disturbances and continuous balancing. The costs of ancillary services and remedial actions have increased significantly in recent years. Moreover, the need and hence the volumes will increase for certain ancillary services in the next few years, which is due to factors such as new principles for balancing, an increased proportion of variable power production and a reduced proportion of synchronously connected production. Svenska kraftnät therefore perceives a need to increase the number of providers of ancillary services and to utilise the potential of technologies that today participate to only a very limited extent. One important source for this purpose is provided by resources with underlying power variations, such as wind power, solar power or variable consumption plants. There is an interest from both providers and Svenska kraftnät to make it possible for these resources to provide ancillary services. However, this requires a prequalification process adapted to these resources, which has not existed to date.

Historically, resources whose active power has been more or less fully controllable (mainly from hydropower) have provided ancillary services. This has meant that both the initial value before regulation and the final value after regulation have been well-defined, and thus the delivery of ancillary services has been clear and definable. For variable resources to be able to provide ancillary services, a method is required that handles the natural power variations where it can be ensured that the capacity sold to Svenska kraftnät is provided. There is thus a new type of issue that Svenska kraftnät has not dealt with previously in the context of ancillary services and which requires both clear and specific requirements, as well as suitable methods for verifying fulfilment of requirements for variable resources.

Briefly, the new challenges can be divided into two categories. More detailed information can be found in *Guidance for variable resources for the provision of ancillary services and remedial actions* [1]:

> **Baseline for regulation**. For a resource with underlying variations to provide an ancillary service, a baseline is required used as a basis for regulation, both so that the provision is correct but also so that Svenska kraftnät can distinguish provision from underlying power variations. The baseline can be calculated for many variable resources such as solar and wind farms. The question then is how accurate this calculation has to be in order for the resource to reliably provide the various ancillary services.

> **Guarantee available power.** For most variable resources, there is uncertainties in what power will be available at the operating hour since the ancillary services are procured in advance. A key issue here is the level of certainty required in the forecasts when bidding.

2.2 Project aim

The pilot study aims to develop prequalification requirements and evaluation methods for requirements verification for variable resources wishing to provide ancillary services and/or remedial actions.

2.3 Project goal

The pilot study targeted resources with underlying power variations. Before the pilot study, there were no specific requirement and no prequalification process for these resources. The goal of this project was to develop clear requirements and methods for requirements verification to make it possible for variable resources to prequalify and provide ancillary services. The purpose of this pilot study was also to find an appropriate requirement level ensuring a good balance between liquidity, the risk of unavailability and the quality of ancillary service provision, in dialogue with providers.

2.4 Limitations

The prequalification requirements developed in this pilot study do not replace existing prequalification requirements but serve as a complement for resources with underlying power variations. Requirements for response time, endurance, measurement accuracy, etc. therefore remain unchanged. Note that this pilot study merely addressed resources with underlying power variations. Resources with constant power or plannable production/consumption were not considered in this pilot study.

3 General approach

Svenska kraftnät invited providers with variable resources to participate in the pilot study and permitted them to test principles for the provision of ancillary services in practice, i.e. during operation. After an approved initial prequalification, providers were given the opportunity to participate in the ancillary service markets during the pilot. During the pilot study, Svenska kraftnät evaluated data from the resource and discussed difficulties and improvements regarding the provision of the ancillary service with the providers. In this way, the threshold for participating in the ancillary service markets was lowered, and both providers and Svenska kraftnät were given the opportunity to try new principles and build expertise in the area. The providers continuously logged measurements and sent monthly logged data to Svenska kraftnät for review. The data collected formed the basis for the evaluation and development of requirements and evaluation methods for prequalification for these types of resources. The pilot study concluded with the pilot study participants undergoing a full prequalification and the existing prequalification documents being updated and adapted to better suit variable production and consumption. The pilot study lasted from January 2022 to October 2023.

This report is structured as follows: the next chapter presents a summary of participation in the pilot study. This is followed by a description of the data analysis that was carried out. The last chapters present the prequalification requirements and evaluation test methods established in the pilot study to handle baseline and bidding.

4 Participation in the pilot study

There was considerable interest in participating in the pilot study, in total 33 providers expressed interested in participating in the pilot study. Of these, ten eventually submitted an initial simplified prequalification application. The majority of applications came from wind power, but solar power and variable consumption were also among the approved applications. Table 1 presents an overview of how participation in the pilot study was distributed by technology and ancillary service.

Table 1. Overview of participation in the pilot study by technology and ancillary service.

Technology	Ancillary service	Prequalified capacity (MW)
Consumption	FCR-N	0.2
Solar power	FCR-D down	10
Wind power	FCR-N	150
	FCR-D up	167
	FCR-D down	324
	aFRR up	150
	aFRR down	200
	mFRR up	150
	mFRR down	150

5 Data analysis

Data was collected on a monthly basis from the approved resources during the pilot study and used as a basis for data analysis. The purpose of the data analysis was to evaluate the quality of the baseline, i.e. how well the baseline reflects actual production or consumption, and to evaluate the accuracy of forecasted bid capacity at the time of bidding for each resource.

The results of the data analysis were discussed with each provider at bilateral meetings to identify potential solutions to further improve the results. The analysis also served as a basis for finding an appropriate level of requirements for variable resources.

The data analysis is divided into two different categories:

> Evaluation of the baseline

> Evaluation of forecasted power and forecasted bid capacity

5.1 Evaluation of the baseline

The baseline must show production/consumption if no ancillary service is activated. How well the baseline represents production/consumption is evaluated by the difference between the resource's baseline and measured power ($p_{reference} - p_{measured}$, which in this report is referred to as *deviation*. A good baseline is a baseline which leads to negligible deviations during periods when the resource is not activated, i.e. $p_{reference} - p_{measured} \cong 0$. If the deviations are negligible the baseline accurately reflects the production/consumption profile and hence can guarantee the correct provision upon activation.

Variable resources can use either a dynamic or a static baseline. More detailed information on the various baseline methods can be found in *Guidance for variable resources for the provision of ancillary services and remedial actions* [1]:

A dynamic baseline, which the majority of providers in the pilot study used, continuously follows the natural power variations of the resource. As this is a calculation, it will not be 100 per cent consistent with actual measured active power. The deviations may vary over time and be both positive and negative. The size of these deviations depends on the precision of the calculation of the baseline.

A static baseline means that the resource limits its power set point at a static value for a shorter or longer periods, i.e. the regulator forces the measured active power to follow the baseline. The baseline and thus the ancillary service provision will then be clearly defined upon activation. Whatever the method chosen, it is important to make a quantitative evaluation of the deviations.

The following assumptions were made in the evaluation of the baseline:

> Periods when the resource was activated were excluded from the analysis. For example, the periods when the frequency exceeded 50.1 Hz were excluded for FCR-D down resources.

> Hours without production or consumption, i.e. when both baseline and measured active power were zero, were excluded from the analysis. The deviation was zero here, but this was not an indication of an accurate baseline.

> It was assumed that the logged baseline was the one used by the regulator for regulation of active power when activating the ancillary service.

> It was assumed that the logged baseline is not affected by ancillary service activation or measured power. This is necessary for the baseline to be useful and the provision to be definable.

Figure 1 shows an example of the instantaneous deviation during one month for a provider in the pilot study that was prequalified for FCR-D down. The deviations varied over time but were almost exclusively positive, which here means under-delivery upon activation. The deviations and hence the under delivery were large at times; e.g. percentile 1 was approximately 2.4 MW, which means that 1 % of the deviations during the month were greater than 2.4 MW. A high percentile value can be particularly problematic for fast ancillary services such as FCR-D, where accurate instantaneous provision is important.

Figure 2 shows the deviations versus the actual measured power, as well as a curve adaptation. The graph shows that the baseline had higher deviations at higher production levels. For the majority of the hours when the provider was bidding the production levels were high, and for this reason the same analysis was performed but only during hours were the provider placed bid: the results are summarised in Table 2. The table shows that the deviations were higher during hours of bids than if the analysis is performed during all hours. The table also shows that the mean value of the deviations was positive, which is an indication here that there were mostly positive deviations, i.e. an average under delivery. Similar observations were made for several providers in the pilot study.

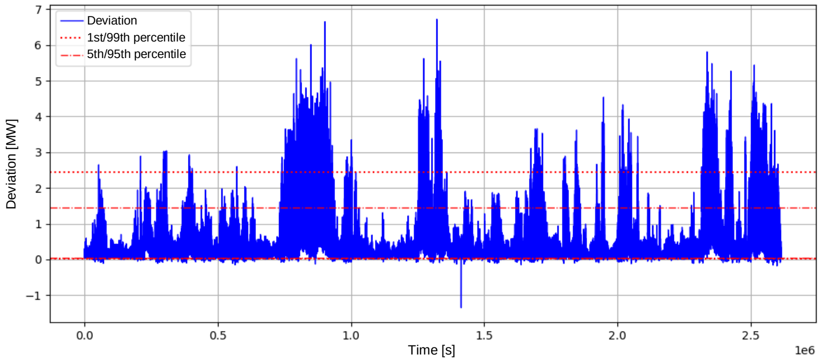

Figure 1. Example of instantaneous deviations between measured power and baseline [MW] and percentiles 1/99 and 5/95.

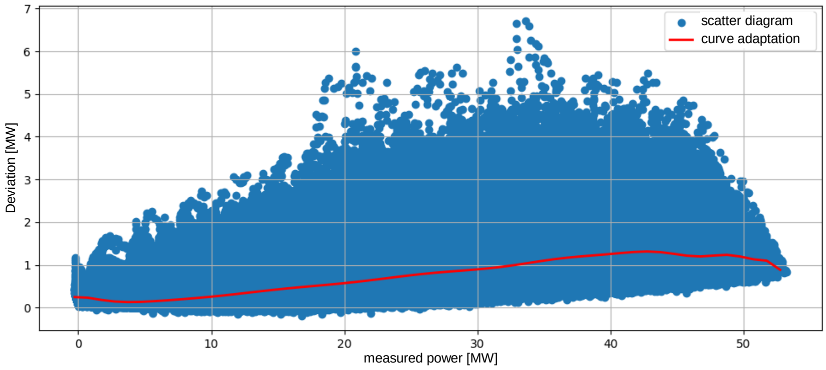

Figure 2. Measured power vs. corresponding deviation with curve adaptation. The red curve shows that the size of the deviation varies at different production levels (greater deviations at higher production levels).

Table 2. Quantitative summary of the instantaneous deviations $(p_{reference} - p_{measured})$ for one provider in the pilot study over one month, both during all hours and only during hours of bids.

	All hours [MW]	**Only hours of bids [MW]**
Mean	0.4	0.8
Percentile 1	2.4	3.2
Percentile 99	0.0	0.0
Percentile 5	1.5	2.3
Percentile 95	0.0	0.1
Max	6.7	6.7
Min	-0.2	-0.2

Some seasonal variations could also be observed in the deviations, as the deviations were greater at higher production levels and during bidding hours. For example, solar farms showed higher deviations in summer than in winter during both hours of bids and non-bid hours.

Besides, to the normal deviations shown, there was another challenge affecting the weather-dependent resources: icing on wind turbine blades or snow cover on photovoltaic surfaces. Electricity production was greatly reduced due to snow and ice on cold winter days. However, the baseline did not reflect this and showed production as if there were no snow or ice, resulting in greater deviations during certain hours/days. Figure 3 shows the deviations ($p_{reference} - p_{measured}$) for a wind farm in December that was affected by icing on the turbine blades. Figure 4 shows the same wind farm in July. From the figures, it can be seen that normal deviations were between ± 1 MW in July while increased to more than 10 MW during in December. To provide ancillary services from wind or solar power under such weather conditions, the baseline should be adapted to provide an accurate representation of the power under these conditions. If this is not possible, the resource cannot provide ancillary services in the event of icing and the provider is responsible for ensuring that this does not happen, such as by trying to forecast icing and/or avoid bidding when there is a risk of icing.

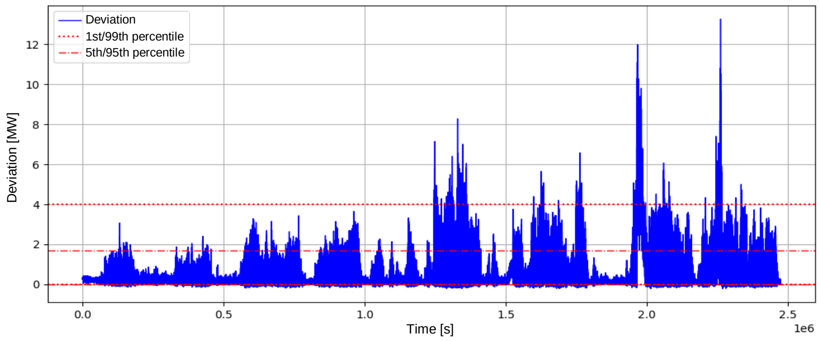

Figure 3. Deviation ($p_{reference} - p_{measured}$) for a wind farm in December. In December, deviations reached over 10 MW at times due to icing on the turbine blades.

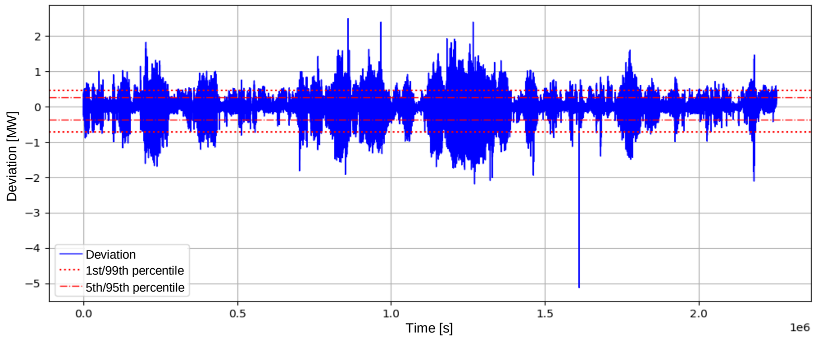

Figure 4. Deviation ($p_{reference} - p_{measured}$) for a wind farm in July. Normal deviations are between ± 1 MW.

5.2 Evaluation of forecasted power and forecasted bid capacity

Part of the analysis focused on the accuracy of the forecasts. The analysis was carried out on both forecasted power and forecasted bid capacity. This report focuses on forecasted bid capacity as the forecasted bid capacity is what will be sold to Svenska kraftnät, and this must be available at the operating hour.

Forecasted power and forecasted bid capacity are normally not the same. Forecasted power means the provider's expected power (produced or consumed) during the operating hour. Forecasted bid capacity refers to the minimum capacity that the provider guarantees will be available for provision throughout the hour. This is the maximum for how much the provider estimates can be sold, on the basis of the forecast and margin of uncertainty. Besides forecasts, providers used various methods to further increase margins and reduce the risk of unavailability, such as margin factors and threshold values. Figure 5 shows the forecasted power and forecasted bid capacity from a provider as an example of the differences between the two. This clearly shows that the forecasted bid capacity is lower than the forecasted power.

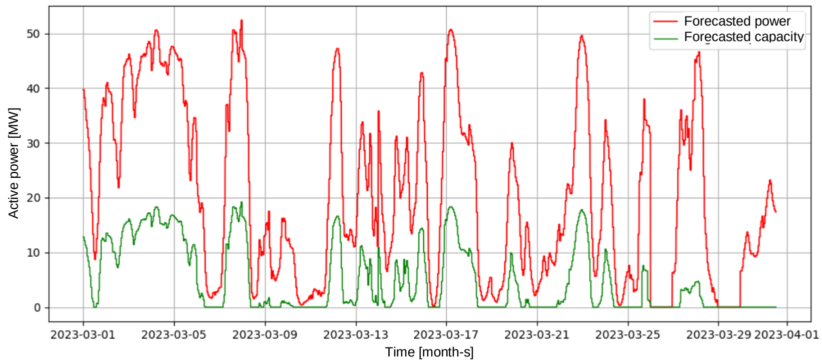

Figure 5. Example of forecasted power and forecasted bid capacity from March 2023. Forecasted bid capacity is lower than the forecasted power.

Ideally, the forecasted bid capacity is the capacity that guarantees the availability of the entire bid capacity during the operating hour, but no forecast can guarantee 100 per cent availability at all times.

The method for evaluating forecasted bid capacity was to calculate the available headroom every second and then to calculate $Deviation\ [\%\ of\ bidding\ capacity]$ as the difference between available headroom and forecasted bid capacity. The evaluation was carried out for all providers every month during the pilot study. Some of the results are shown in figure 6 and Figure 7 from a provider in March 2023 as an example.

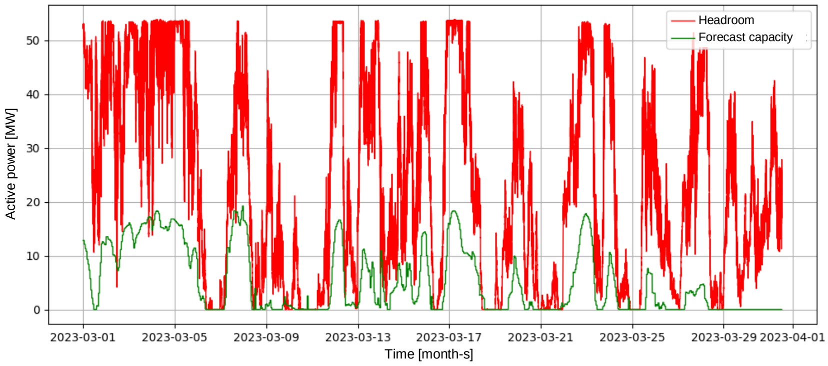

Figure 6. Available headroom and forecasted bid capacity from March 2023. As a rule, the headroom must exceed the forecasted bid capacity, otherwise the resource will not be able to provide what has been sold.

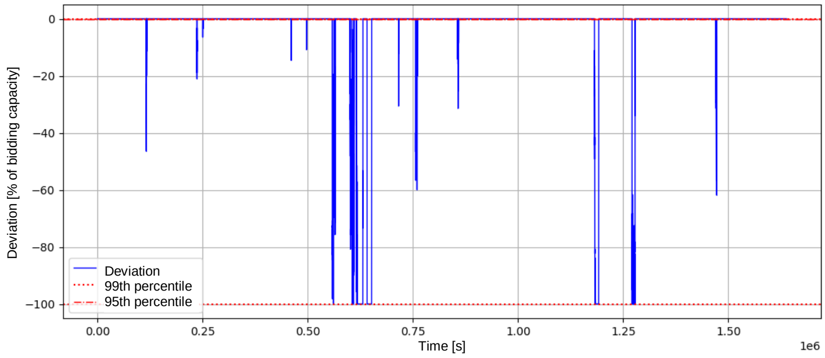

Figure 7. Deviation between available headroom and forecasted bid capacity [% of bid capacity] from March 2023. Most of the time when the forecast was wrong, the provider lost more than 10 % of the bid capacity.

A quantitative summary of the results in Figure 6 and Figure 7 can be seen in Table 3. This table presents the average forecast error calculated for all hours, as well as the average forecast error for those hours when the forecasted bid capacity was less than the actual available capacity. In this case, the resource lost 3 % of the total bidding volume on average in March, and when the provider lost capacity, on average 73 % of the bid capacity were lost. The table also shows how much of the time the available headroom was lower than the forecasted bid capacity and how much of the time the reduced bid capacity was more than 10 % of the bid volume for the resource. According to Table 3, the resource had full capacity available 96 % of the time. More than 10 % of the bid capacity was almost always lost in the 4 % where the headroom was not fully available, which is in line with what was observed in Figure 7.

Table 3. Quantitative summary of the forecasted bid capacity from a provider in March 2023. The analysis was performed with a resolution of one second.

	March
Average forecast error (all hours)	-3.0 %
Average forecast error (only hours with forecast error)	-71.0 %
Percentage of time with reduced bidding capacity	4.0 %
Percentage of time with more than 10 % reduced bidding capacity	3.7 %

Forecasted bid capacity for individual resources in the pilot study was evaluated on a monthly basis. It is observed that a certain level of error in forecasted bid capacity was inevitable. However, this level varied between the different providers. Some providers had less than 1 % hours of reduced bid capacity per month, while for other providers the proportion could be as high as 13 %. Another observation was that during hours with reduced bid capacity, most of these were hours where the reduced capacity was more than 10 %, i.e. the deviations were usually large when the forecast was wrong. This was a general trend among all providers who participated in the pilot study. The average availability of all wind farms participating in FCR-D for 2 months is presented in Table 4. Note that the analysis performed was based on forecasted bid capacity. In reality, providers have to repurchase bids before the operating hour if the forecasts show a risk of reduced bid capacity. In this way, Svenska kraftnät can buy the capacity from other available resources and minimise the risks of imbalance.

Table 4. The result of availability of bid capacity for February and March 2023 from all wind farms participating in FCR-D down.

	Availability
February	95 %
March	95 %

6 Suggested improvements and principles

This section presents a few suggestions of methods for improving the quality of the baseline found in the pilot study. Note that these are merely suggestions; there is no requirement to use any of these methods. The suggestions are written on a general level and, if used, they must be adapted to the resource. It is up to the provider to decide whether or not a solution is suitable for the resource. Combinations of different solutions may also be considered in order to achieve the best results. Note that methods for improving the baseline are not limited to the methods described to below, providers can use other methods to improve the baseline.

Proposal 1: Adjustment of production towards a baseline

The proposal involves adjusting production/consumption against an appropriately calculated baseline in order to produce/consume exactly in accordance with the baseline. To be able to use the method, a margin is added to the baseline as production/consumption is adjusted towards the corrected baseline. This margin involves curtailment.

An example from a provider in the pilot study is presented here in Figure 8 and Figure 9 in order to demonstrate this proposal. The baseline is the focus here, rather than the step response test. Figure 8 shows the baseline and measured power. The original baseline is the green line labelled *Old baseline* in the figure. The updated reference value when the proposal is implemented is the red line labelled *New baseline* in the figure, and this is the *Old baseline* with 2 MW subtracted. Both reference values are the same until shortly after 4000 seconds. Then *New baseline* is activated and production is adjusted towards the corrected baseline. The step response test uses the *New baseline* and reduces production from there. However, what is interesting are the deviations between the baseline and the measured power before and after implementation of the proposal as shown in Figure 9. It can be observed that deviations almost disappear completely by curtailing only a small portion of production.

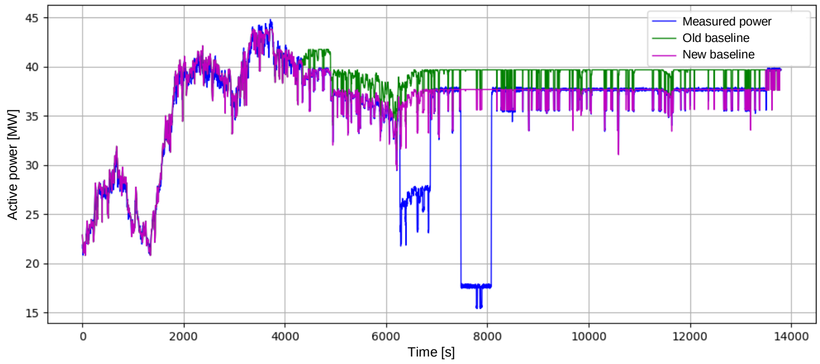

Figure 8. Demonstration of adjusting production against the baseline (Step response tests from an application in the pilot study).

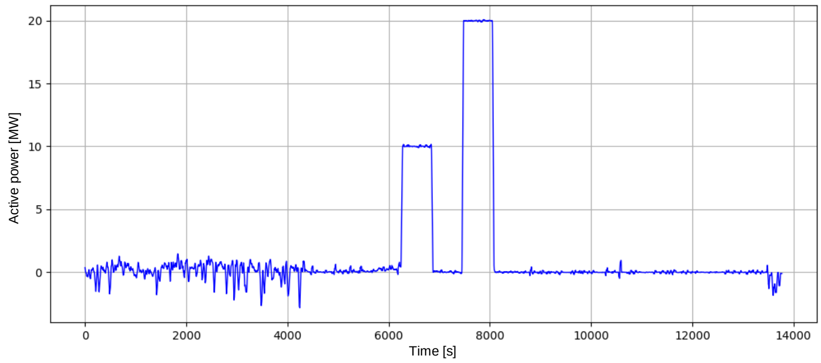

Figure 9. Demonstration of adjusting production against the baseline (Step response tests from an application in the pilot study). It can be observed that deviations disappear almost completely by curtailing only a small proportion of production.

Proposal 2: Calibration of baseline

The proposal involves calibrating the baseline to get rid of the constant shift between active power and the baseline, i.e. to reduce the mean value of the deviations to zero.

One way of applying calibration is based on analysis of historical data on production or consumption and calculation of the deviations. A calibration table can be developed on the basis of these data – for different production/consumption ranges and/or seasonal variations, for example – showing how the reference value should be calibrated on the basis of the factors that are most crucial for the resource in question.

An example from a provider in the pilot study is presented in Figure 10 and Figure 11 to demonstrate calibration. Figure 10 shows the instantaneous deviations from July 2022. The deviations varied over time but are almost exclusively positive, as shown in the figure. Following discussion with the provider, upgrades were carried out with the primary emphasis on calibration in order to reduce the deviations. Figure 11 shows the result after calibration. The mean value is now around zero for all production levels instead and percentile values were also improved, e.g. percentile 99 was reduced from 2.4 MW to 1.8 MW.

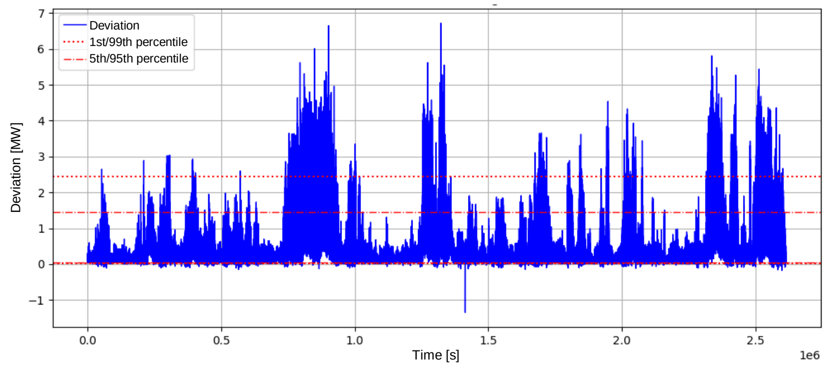

Figure 10. Instantaneous deviations from July 2022, before calibration.

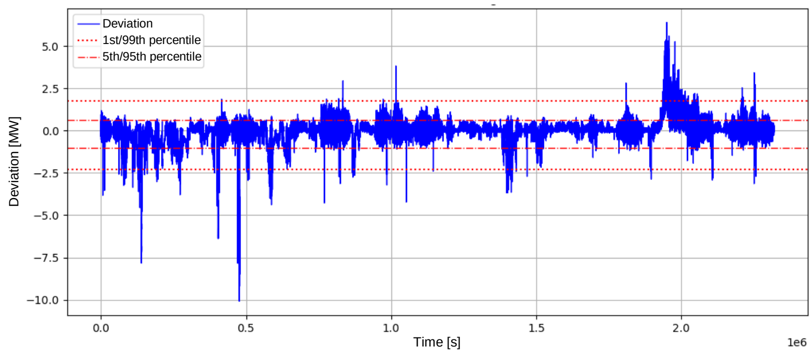

Figure 11. Instantaneous deviations from April 2023, after calibration.

Proposal 3: Freezing method

A method referred to here as the *freezing method* can be used for precise provision at the time of activation. The idea of the *freezing method* is to calculate the deviation at the time of activation and adjust the baseline to match the active power. The adjustment value will be frozen and added to the baseline throughout the activation (i.e. fixed offset). Once the activation is complete, the adjustment value will be reset to zero until the next activation. Note that the freezing method does not freeze the baseline during the activation period, but adjusts the baseline by a fixed adjustment value based on the deviation at the time of activation. This principle is best suited for ancillary services that are usually activated for shorter periods, such as FFR and FCR-D. The freezing method does not work for FCR-D up for wind power, solar power or other resources that need to limit their production in order to provide FCR-D up.

As the *freezing method* corrects the baseline upon activation, an alternative method is needed in order to evaluate the baseline among resources using this principle. This is done by calculating the deviations that would have occurred if this principle had been used by the resource. The primary focus of this evaluation will be to study how deviations vary over time. As the freezing method calibrates the initial deviation, and thus ensures the correct initial response, studying how large the deviations become during the activation is key instead. If the deviations vary strongly and rapidly, the freezing method becomes less reliable than if the deviations vary slowly. To be able to evaluate the freezing method, therefore, two different time intervals are examined; 10 seconds (to represent short activations) and 20 minutes (to represent longer activations). For 10-second time intervals, the deviation is selected at the start of the first 10-second time interval and all deviations within the first 10-second time interval are reduced by the initial deviation. The process is repeated for the next 10-second time intervals until all deviations are updated. The calculation for 20-minute time intervals is performed in a similar way, but with 20-minute time intervals instead.

An example is shown in Table 5 to illustrate the result of the freezing method. The *deviation* was calculated, as above, for both 10-second and 20-minute time intervals and is presented in the table together with the result if no freezing method was used. The table clearly shows that both the mean and the percentiles of the deviations become smaller by applying the freezing method.

Table 5. Example of when the freezing method was used on data from a provider in the pilot study.

		Deviation (MW)
Without freezing method	Mean	2.3
	Percentile 95	6.0
	Percentile 95	-0.1
10-second freezing time	Mean	0.0
	Percentile 5	0.9
	Percentile 95	-1.1
20-minute freezing time	Mean	0.0
	Percentile 5	1.7
	Percentile 95	-1.9

The freezing method described here is intended to provide guidance and inspiration to providers on how to improve the baseline during activation. Note that the freezing method is not a strict method; operators are free to choose the exact solution. There are many different ways of implementing freezing/correction. The solution must be clearly described in the prequalification application if the provider chooses to use the freezing method.

7 Additional requirements and evaluation for variable resources

This section contains a description of the data collection, requirements for baseline and forecasted bid capacity and the evaluation process for variable resources. The data analysis was used to support these requirements. The requirements presented in the following section will be evaluated during the prequalification process.

7.1 Data collection requirements for prequalification

Logged historical data are required to be able to evaluate the quality of the baseline and forecast bid capacity. At least two consecutive months of data (e.g. March and April) must be logged and submitted in the prequalification. More information about data logging can be found in *Reporting of measurements for units and groups with variable production and consumption [2]*. Evaluations described in this section are only performed only on forecasted hours of bids. Data collected must therefore include at least 300 hours of bids for FCR and FFR and at least 150 hours of bids for aFRR and mFRR. Furthermore:

- If two months are not enough to cover the minimum number of hours of bids, the provider must extend the period until the required number of hours of bids is reached. However, the period must be continuous, e.g. March, April and May and not March, April and July.
- Providers who are active in any of the ancillary services markets and wish to undergo prequalification (e.g. for a different type of ancillary service, or to renew a prequalification) must pause their participation and not provide ancillary services during the data collection period[1]. As the resource does not participate in the market, the bids will be fictitious and fictitious bids must will correspond to the bid capacity that would be bided if resources participated in the market.
- The provider must clearly describe its bidding strategy so that Svenska kraftnät can understand why bids are placed for certain hours and not others; by clearly describing when bids are made and the thresholds and safety margins used, for example. Fictitious or notional bids are the bid capacity that would be bided if resources participated in the market.
- During bidding hours, resources that are not prequalified must behave as if they have been in the market for real, i.e. if the control system has a specific adjustment algorithm or baseline calculation that is used only during procured

[1] Exceptions can be given to FCR-D down.

hours, this adjustment must be activated with zero procured capacity during the fictitious bidding hours.

> The baseline must not be affected by ancillary service activation or measured power and must be as used during activations. This is necessary for the baseline to be useful and the provision to be definable.

> Baseline calculation and solutions used (e.g. freezing method) must be clearly described in the application.

7.2 Baseline requirements

The baseline will be evaluated for the various ancillary services according to the requirements specified in Table 6 by calculating the mean value/mean error, 95th percentile and 5th percentile of the instantaneous deviations ($p_{reference} - p_{measured}$) during the hours of fictitious bids.

Table 6. Baseline deviation requirements ($p_{reference} - p_{measured}$).

Ancillary service	Mean value/ mean error	95th percentile (P95) and 5th percentile (P5)	Filtering[2]	K_{red}[3]
FFR	|Mean error| < 5% of FFR Steady state response[4]	|P95-P5|/2 < 20% of FFR Steady state response	No filtering	-
FCR-D	|Mean error| < 5% of FCR-D steady state response[4]	|P95-P5|/2 < 20% of FCR-D steady state response	No filtering	$0.75 \leq K_{red} \leq 1$
FCR-N	|Mean error| < 5% of FCR-N steady state response[4]	|P95-P5|/2 < 20% of FCR-N steady state response	30 s	$0.9 \leq K_{red} \leq 1$
aFRR	|Mean error| < 10% of aFRR steady state response[4]	|P95-P5|/2 < 20% of aFRR steady state response	1 min	$0.75 \leq K_{red} \leq 1$
mFRR	|Mean error| < 20% of mFRR steady state response[4]	|P95-P5|/2 < 50% of mFRR steady state response	5 min	-

A low-quality baseline value leads to an increase in the minimum permitted bid capacity, which means that the capacity range for bidding will be reduced. With a very low baseline value quality, the minimum permitted bid capacity will be equal to or higher than the rated power of the resource, which means that the prequalification cannot be approved. The minimum permitted bid capacity is calculated as follows:

$$\Delta P_{min} = \text{max.}\left(\frac{e_{actual}}{e_{permitted}}\right)$$

[2] After the calculation of deviations, filtering will take place with a moving mean value with the filtering time according to the table. Filtering is not permitted for FFR and FCR-D.
[3] Reduction factor, find out more about the reduction factor in 7.2.1
[4] Steady state response here corresponds to the capacity divided by the reduction factor (i.e. capacity excluding reduction factor).

where ΔP_{min} is the minimum bid capacity in MW, e_{actual} is the actual deviation from the baseline (either mean error or percentile range) in MW, and $e_{permitted}$ are the given permitted deviations as a percentage in Table 6 above. For example, the minimum permitted bid capacity for FCR as shown below:

$$\Delta P_{FCR,min} = max.\left(\frac{|Mean\ error|}{0.05}, \frac{\frac{|P95 - P5|}{2}}{0.2}\right)$$

For example, the minimum permitted bid capacity for the resource in Table 2 is:

$$\Delta P_{FCR,min} = max.\left(\frac{|Mean\ error|}{0.05}, \frac{\frac{|P95 - P5|}{2}}{0.2}\right) = max.\left(\frac{|0.8|}{0.05}, \frac{\frac{|0.1 - 2.3|}{2}}{0.2}\right) = 16\ MW$$

7.2.1 Reduction factor

The minimum permitted bid capacity can be reduced relative to the steady state response by using a reduction factor(K_{red}). The idea is to add extra capacity to the procured capacity to compensate for the deviations. I.e. if the capacity to be provided is ΔP, the capacity bid and compensated is the reduced capacity $K_{red} \cdot \Delta P$. The reduction factor is a way to compensate for the deviations that can lead to underdelivery.

The reduction factor, ΔP, in MW, is calculated as follows:

$$K_{red} = \min\left(\frac{1 - \frac{e_{actual}}{\Delta P}}{1 - e_{permitted}}\right)$$

and for example for FCR:

$$K_{red,FCR} = \min\left(\frac{1 - \frac{|Mean\ error|}{\Delta P}}{1 - 0.05}, \frac{1 - \frac{|P95 - P5|}{2 \cdot \Delta P}}{1 - 0.2}\right)$$

The reduction factor can be a value between 0.9 and 1 for FCR-N, and between 0.75 and 1 for FCR-D and aFRR. Note that no reduction factor is permitted for FFR or mFRR. The minimum permitted bid capacity that can be provided is the capacity that leads to the minimum permitted reduction factor, K_{red}.

The previous equations for the minimum permitted bid capacity that can be provided, including the reduction factor, are rewritten as follows:

$$\Delta P_{min,red} = \max.\left(\frac{e_{actual}}{1 - K_{red,min} \cdot (1 - e_{permitted})}\right)$$

and for example for FCR :

$$\Delta P_{FCR,min,red} = \max.\left(\frac{|Mean\ error|}{1 - K_{red,min}(1 - 0.05)}, \frac{\frac{|P95 - P5|}{2}}{1 - K_{red,min}(1 - 0.2)}\right)$$

Bid capacities lower than $\Delta P_{min,red}$ are not permitted. Note that if other reduction factors are considered, the minimum reduction factor must be selected.

7.2.2 Freezing method

For resources using the *freezing method*, the evaluation will be performed at 10-second and 20-minute freezing time intervals according to the requirements specified in Table 7. The freezing method is best suited to FFR and FCR-D without curtailment. No evaluation after 20 minutes is needed for FFR as FFR is not active for more than a few seconds.

Table 7. Requirements for deviation $(p_{ref} - p_{meas})$ with the freezing method.

Ancillary service	Freezing time	Mean value/ mean error	95th percentile (P95) and 5th percentile (P5)	K_{red}
FFR	10 seconds	|Mean error| < 5% of FFR steady state response	|P95-P5|/2 < 20% of FFR steady state response	-
FCR-D	10 seconds	|Mean error| < 5% of FCR steady state response	|P95-P5|/2 < 20% of FCR steady state response	$0.75 \leq K_{red} \leq 1$
	20 minutes	|Mean error| < 20% of FCR steady state response	|P95-P5|/2 < 50% of FCR steady state response	$0.75 \leq K_{red} \leq 1$

The minimum permitted bid capacity for FCR-D using the freezing method (without reduction factor) is calculated as follows:

$$\Delta P_{FCRD,min,freeze} = max.\left(\frac{|Mean\ error|_{10\ sec.}}{0.05}, \frac{|Mean\ error|_{20m}}{0.2}, \frac{\frac{|P95 - P5|_{10\ sec.}}{2}}{0.2}, \frac{\frac{|P95 - P5|_{20m}}{2}}{0.5}\right)$$

The minimum permitted bid capacity for FCR-D using the freezing method (with reduction factor) is calculated as follows:

$$\Delta P_{FCRD,min,red,freeze} = \max.\left(\frac{|Mean\ error|_{10\ sec.}}{1 - K_{red,min}(1 - 0.05)}, \frac{|Mean\ error|_{20m}}{1 - K_{red,min}(1 - 0.2)}, \frac{\frac{|P95 - P5|_{10\ sec.}}{2}}{1 - K_{red,min}(1 - 0.2)}, \frac{\frac{|P95 - P5|_{20m}}{2}}{1 - K_{red,min}(1 - 0.5)}\right)$$

Bid capacities lower than $\Delta P_{FCRD,min,red,freeze}$ are not permitted.

The minimum permitted bid capacity for FRR using the freezing method is calculated as follows:

$$\Delta P_{FFR,min,freeze} = max.\left(\frac{|Mean\ error|_{10\ sec.}}{0.05}, \frac{\frac{|P95 - P5|_{10\ sec.}}{2}}{0.2}\right)$$

7.3 Availability requirements

The requirements for the forecasted bid capacity relates to availability in percentage. The forecasted bid capacity from collected data is compared with available headroom. All seconds where the available headroom is less than the forecasted bid capacity are added over all hours of bids (total time with reduced bid capacity). The percentage availability is calculated according to the equation below; that is, by subtracting the total number of hours of bids from the total time of reduced bid capacity and dividing by the total bidding time. The availability requirements for each ancillary service are presented in Table 8.

$$Availability\ (\%) = \frac{total\ number\ of\ hours\ of\ bids - hours\ with\ reduced\ bid\ capacity}{total\ number\ of\ hours\ of\ bids}$$

Table 8. Availability requirements for each ancillary service.

Ancillary service	Availability requirements
FFR	95%
FCR	95%
aFRR	90%
mFRR	90%

7.4 During and after prequalification

The requirements presented in this section should be evaluated in parallel with other requirements, i.e. the provider submits all test results, application forms and logged historical data together in the prequalification application. Depending on the accuracy of the baseline, the minimum permitted bid capacity (min-cap) may be adjusted when evaluating the prequalification application.

The baseline and availability presented in the prequalification must be maintained at the approved level also after prequalification. Logged data must be available and provided to Svenska kraftnät upon request according to regular prequalification requirements. Any change in the regulator, baseline calculation or bidding strategy after prequalification that affects the baseline or availability will require a new prequalification. Providers are responsible for informing Svenska kraftnät in such cases and initiating a new prequalification application.

8 Summary

This section presents some of the most important conclusions from the pilot study. Conducting the pilot study enabled providers who had previously participated in the ancillary services market to only a limited extent to enter the market and test ancillary service provision principles in practice. This work gave Svenska kraftnät and providers in the opportunity to discuss difficulties and suggestions for improvement linked to the provision of ancillary services on an ongoing basis. It was also a good opportunity to try out new ideas in operation under controlled conditions. The work and continuous dialogue during the pilot study allowed clear improvements to be made by the participating providers in the calculation of baseline, for example.

The pilot study resulted in a set of prequalification requirements and evaluation methods for resources with variable production and consumption, i.e. a prequalification process adapted to variable resources which did not exist before.

One of the requirements established by the pilot study was a requirement for data collection for prequalification. These data are used to evaluate the accuracy of the baseline and the strategy that will be used for bidding. From the data analysed in the pilot study, it is concluded that the forecast bidding capacity was not always available and was unavoidable up to a certain level of error in the forecasts. When the forecasts were wrong, the errors were usually great. Therefore, one requirement identified by the pilot study was the requirement for available bidding capacity in the prequalification.

Furthermore, a baseline is needed that must fulfil the defined requirements regarding the deviations between baseline and measured power. The fact that the mean value of the deviations at system level is negligible was particularly important, whereas the major deviations (as measured by the outer percentiles) were mostly temporary and did not seem to be correlated between the different providers. The pilot study also found several potential measures that can be used to improve the baseline: this document mentions control of production against the baseline, calibration and the freezing method, for example.

References

[1] “Guidance for variable resources for the provision of ancillary services and remedial actions”, Svenska kraftnät, 2023.

[2] ”Reporting of measurements for units and groups participating with variable production and consumption”, Svenska kraftnät, 2023.