Study Committee C5

ELECTRICITY MARKETS AND REGULATION

Paper 10824 2022

Possible wind farm earnings from frequency regulation markets in Nordic power system – Issues, examples, and policies

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Motivation

As the cost of frequency regulation in the Nordic region keeps increasing new actors are considering entering the market. This increasing cost is illustrated in Figure 1 where it can be observed that the total cost for ancillary services (AS) is expected to increase by 50% in the coming four years in Sweden.

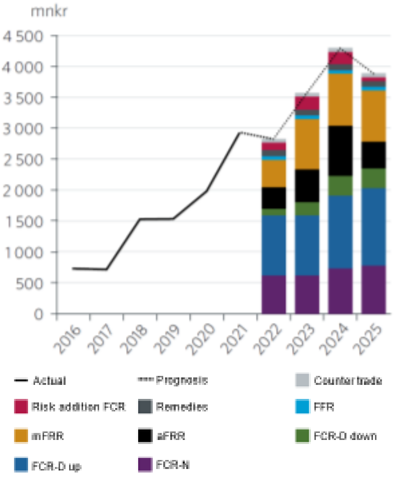

Figure 1. Historical and prognosis of costs for different ancillary services in Sweden.

Several research papers indicate that it is technically possible for wind turbines to deliver AS of various types FFR [2], FCR [3], [4], FRR [5] [6].

The aim of this paper is to provide an evaluation framework for the potential revenues that wind power owners in Sweden can make by being active on AS markets. The current market structure for AS related to frequency control in the Nordic synchronous area is presented, focusing on the Swedish case. A methodology used in this work for estimating profitability given realistic technical requirements and production forecasting errors is presented. Finally, potential revenues for a real wind power plant and discuss what services are deemed to be most suitable for wind turbines to participate in.

Method

Currently mainly hydro is responsible for AS in the Nordic synchronous area.

Table 1. Overview of ancillary services (AS) in Sweden in 2021.

AS	Compensation	Gate closure
FFR	For capacity (marginal pricing)	Yearly qualification
FCR-N	For capacity (cost-based bids and pay-as-bid*) and energy (up- and down-regulation prices)	16:00 D-2 and 18:00 D-1
FCR-D up	For capacity (cost-based bids and pay-as-bid*)	16:00 D-2 and 18:00 D-1
aFRR up	For capacity (pay-as-bid**) and energy (up- and down-regulation prices)	On Thursdays (for Saturday to Friday)***
aFRR down	For capacity (pay-as-bid**) and energy (up- and down-regulation prices)	On Thursdays (for Saturday to Friday)***
mFRR	For energy (marginal pricing). Capacity compensation for the part of the capacity that is procured in advance.	h-1

* Will change to free bids in 2022 and marginal pricing in 2024

** Will change to marginal pricing in 2022

*** Will change to day-ahead procurement in 2022

The paper presents individual methodologies on for example:

- Forecasting of energy and capacity.
- How to acquire quantile forecasts for ancillary services
- FFR capacity computations
- Forecasting of FCR capacities
- Activation based on actual frequency data

Furthermore, the overall methodology is aimed at being modular.

[2] M. Persson, "Frequency Response by Wind Farms in Power Systems with High Wind Power Penetration," Chalmers University of Technology, Gothenbug, 2017.

[3] J. Zhao, X. Lyu, Y. Fu, X. Hu and F. Li, "Coordinated Microgrid Frequency Regulation Based on DFIG Variable Coefficient Using Virtual Inertia and Primary Frequency Control," IEEE Transactions on Energy Conversion, 2016.

[4] M. Persson and P. Chen, "Frequency control by variable speed wind turbines in islanded power systems with various generation mix," IET Renewable Power Generation - Special Issue: Active Power Control of Renewable Energy Generation, 2017.

[5] A. Oshnoei, R. Khezri, S. M. Muyeen and F. Blaabjerg, "On the Contribution of Wind Farms in Automatic Generation Control: Review and New Control Approach," Applied Sciences, 2018.

[6] E. Rebello, D. Watson and M. Rodgers, "Ancillary services from wind turbines: AGC from a single Type 4 turbine," Wind Energy Science Discussions, 2019.

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Method cont.

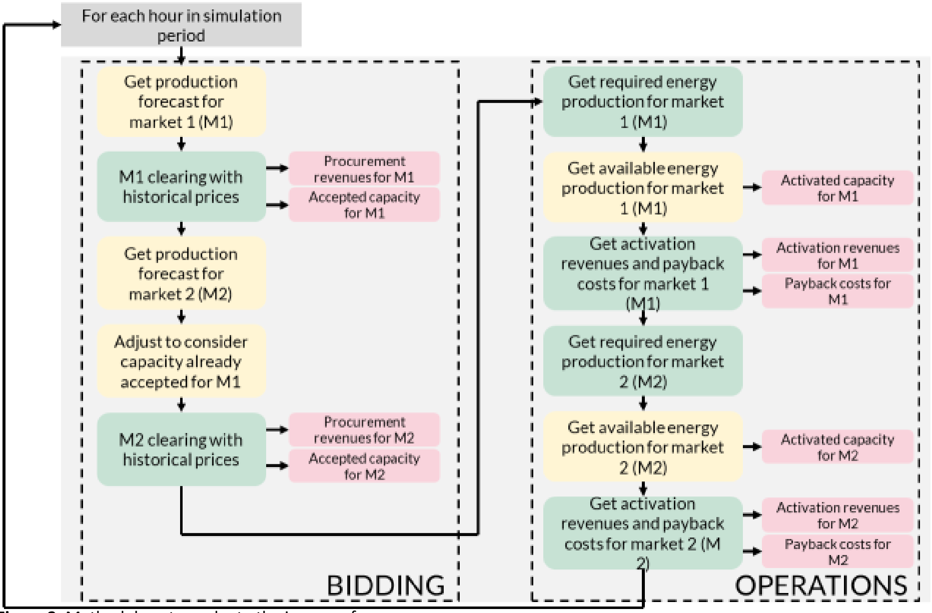

Figure 2. Methodology to evaluate the incomes from an ancillary service market for all hours of a defined evaluation period.

For each market that is part of the evaluation, procurement, and activation revenues (capacity and energy revenues) are computed, as well as so-called payback costs which producers must pay if the available capacity differs from the procured one. For the day-ahead market (DAM), payback costs correspond to imbalance costs and imbalance fees and can be either positive or negative (in which case they become an income). For AS markets, payback costs are always positive (in case of less activated power than requested) or zero (when the requested power could be met).

The requested activation is the energy production (for the DAM and mFRR market) or the minute-to-minute activation (for the other AS markets) corresponding to the procured capacity. For all aFRR and FCR markets, the minute-to-minute activation is estimated from a per-unit signal generated based on historical frequency data sampled at a 3-minute resolution and available on Fingrid's website. This per-unit signal is a linear response to frequency deviations and is designed to request full activation at the frequency interval limits of the different frequency-response products.

Case study – Wind power plant

Using the methodology presented in the previous section, the following cases studies are investigated:

Case 1: Perfect forecast on minute basis. This corresponds to having no uncertainty on either the capacity that will be available for ancillary service or the hourly energy production.

Case 2: Perfect forecast on an hourly basis but uncertainty considered in the capacity forecast. In this case, quantile forecasts are used to generate capacity forecast with the perfect hourly energy production forecast as input.

Case 3: Production forecast both for capacity and hourly energy production.

Case 4: Same as Case 3 but with twice as large forecast errors.

When considering forecast errors in the hourly energy production in cases 3 and 4, the output of the methodology from Figure 2 will be random, since it corresponds to one set of hourly forecasts for the evaluation period. Therefore, in this case, the methodology is embedded in Monte Carlo simulations to evaluate the average hourly incomes. Each Monte Carlo iteration corresponds to one set of hourly forecasts covering the entire evaluation period.

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Results

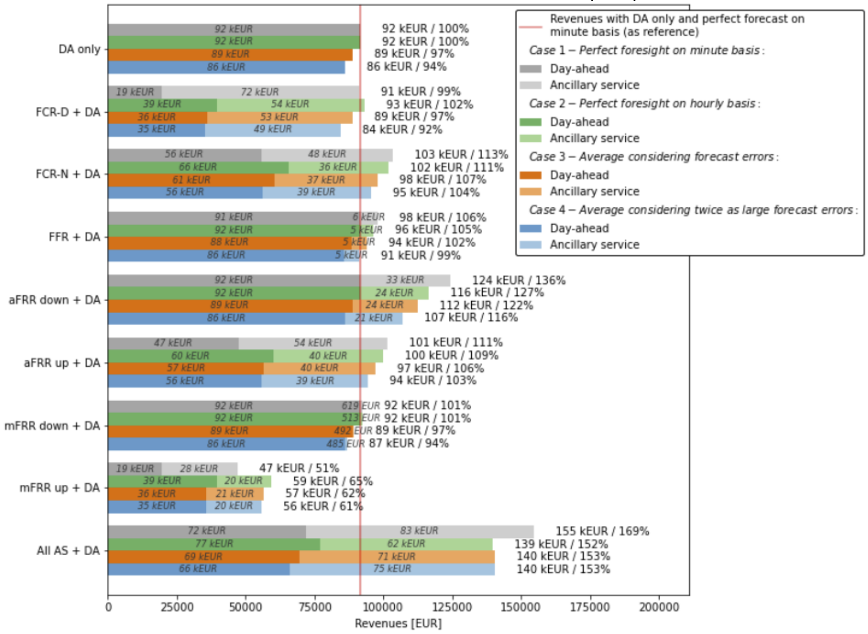

Figure 3. Yearly income from participating in different ancillary service markets for a 2 MW wind power plant. The total for each AS and case is given as both absolute value in EUR and percentage of the DAM only revenues with perfect foresight on minute basis.

Assumption and Input data

The evaluation is done for 2020 and all input time series (wind power production, frequency, prices) are collected for this year and synchronized. Data from a real 2 MW wind power plant located in SE3 (price area in Southern Sweden) is used.

The imbalance fee is set to 1.15 EUR/MWh, which is the current level in Sweden. The prices received on pay-as-bid markets are the average prices available at MIMER.

For ancillary service markets, the payback cost per MWh is set to 1.2 times the procurement price. For quantile forecasts, the 5% quantile is used.

The available capacity for FFR provision is computed considering a maximum FFR capacity of 10% of the installed capacity.

In addition to each AS market, a “All AS + DA” alternative is simulated using the same methodology. This alternative evaluates all AS markets at once and chooses the most profitable for each hour. This can be used as a best-case reference of the best possible revenues with perfect price information on all markets when choosing on which market to bid.

Conclusions

The economic analysis points out to aFRR down as the most profitable market today with additional income of as much as 35% compared to day-ahead only in case of perfect production forecasts, and as much as 22% with consideration of standard production forecast errors. aFRR is today procured on a weekly basis but will be procured daily in 2022. This should make it even more interesting for wind power owners. Furthermore, it is shown that decreasing the production forecast errors by half reduces the income loss due to forecast errors by half, thus showing the value of improved forecast methods. Finally, it is also shown that developing bidding strategies based on price forecasting to act on several AS markets may increase the incomes by 70% compared to DA only. The development of such strategies is left for future work.

The analysis of this work assumes that wind power owners entering the AS markets are price takers and do not impact the price formation in these markets. This will not hold true if a large capacity of bids from wind power starts participating in AS. Future analyses are needed to quantify this effect.