Analysis of aFRR and mFRR Balancing Capacity & Energy Demands and Bid Curves

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***Abstract*—Balancing markets in Europe are under transformation from regulated balancing services procurement and uniform activation operated on national level towards fully market-based and Europe wide operation. The European institutions are pushing towards technology neutral markets where all players are participating on equal footing, including small distributed energy resources. The markets are developing in the direction of gate closure times closer to delivery, smaller bid and price resolutions etc. Such conditions are opening gates to new participants but are at the same time more complex to correctly position market bids. The first part of this paper will discuss current status of balancing services and their markets in Europe. The second part provides analysis of demands and bids for frequency restoration reserves in Germany as the leader in balancing services liberalisation. Such analysis is extremely important for forecasting and bidding algorithms for both balancing capacity and energy markets.**

***Index Terms*—Balancing Capacity, Balancing Energy, Frequency Restoration Reserve, Reserves, Electricity Markets**

I. Introduction

Power systems are leading the global economy transformation towards low-carbon and climate neutral society. Still, the generation of heat and electricity makes the highest share in global greenhouse gas emissions of around 42% [1]. The coal power plants are the highest polluter with almost 30% of global GHG emissions [2]. However, more than 25% of today's electricity comes from renewable energy sources (RES) [3] and they have the steepest increase in new installations [1]. The main challenge with RES-based decarbonized power system is that it gradually loses its flexibility since the traditional flexibility providers, controllable coal and other fossil units, are being replaced with uncontrollable RES units.

To replenish the missing flexibility the power systems are opening towards new technologies such as demand response, smart charging of electric vehicles, battery storage systems (BSS) etc. For example Germany, as the leader in BSS installations, had in 2018 125 thousand household-level BSS (415 MW, 930 MWh), 700 industry-level BSS (27 MW, 57 MWH) 59 utility-level BSS (400 MW, 550 MWh) [4]. The large projects are mostly installed to provide frequency ancillary services whereas the behind-the-meter batteries (both household and industry level) are focusing on boosting the solar self-consumption and cutting the overall electricity bill of the consumption facility. To enable the new technologies to provide flexibility such as frequency ancillary services the procurement schemes must be market-based and adjusted for new types of flexibility providers. The adjustments can include: transparent pricing mechanism must be in place, the procurement horizons and the market resolution must decrease, gate closure times (GCT) must come closer to real-time, the bid volumes must also decrease etc. The European Union set the foundation for these adjustments through *Energy for all Europeans* package of energy measures [5], [6].

Some countries already have open markets for different types of frequency ancillary services with several years in operation where bidding data is publicly available. In order to build efficient bidding algorithms for participation on those markets, it is necessary to systematically analyse available data and prepare it to be further used as inputs for mentioned algorithms. In this paper we will provide and overview of frequency ancillary services in Europe and especially Germany and analyse the demands and anonymous bids on:

- both automatic and manual frequency restoration markets,
- for both positive and negative direction,
- for both balancing energy and balancing capacity.

The paper is organised as follows. Section II explains the main principles of European-style frequency ancillary services and their markets. Additionally it also explains the status of new technologies on those markets on the example of BSS. Section III provides insights in publicly available demands and bids on frequency restoration reserve markets in Germany, while the Section IV provides insight in authors future steps.

II. Frequency Services and Markets in Europe

A. Types of Frequency Ancillary Services in Europe

Frequency ancillary services in Europe are divided into four main reserve categories [7]: Frequency Containment (FCR), automatic (aFRR) and manual (mFRR) Frequency Restoration, and Replacement Reserve (RR). The FCR and aFRR are automatically activated reserves (activated upon a frequency deviation and an automatic generation control signal, respectively) with fast response and short but more frequent activation events. The mFRR and RR are manually activated reserves (based on a signal directly sent by the TSO's dispatch center) with slower response, longer and less frequent activation events.

FCR is used to intervene automatically within seconds in the entire synchronous area to restore the balance between the

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supply and the demand [8]. A provider must be able to ramp up/down its generation/consumption to the full power within 30 seconds after a disturbance. After successful FCR activation the frequency is at a stable value below or above nominal value. The task of restoring the frequency to its nominal value is performed by aFRR and, if necessary, additionally by mFRR. The aFRR acts on a Load Frequency Control (LFC) area level where it replaces local LCF FCR activations and mitigates power flow imbalances on the LFC interconnection lines. The activation time for aFRR provision is 30 seconds to 7.5 minutes (5 minutes after 2024) [9]. As the aFRR provision is gradually increasing, the FCR is released and can be used for new imbalances. The mFRR is manually activated to release the activated aFRR capacity or to provide additional frequency restoration power. Full activation time of mFRR is 12.5 minutes [9]. As the mFRR provision is gradually increasing, the aFRR is released and can be used for new imbalances. Further on, a TSO can additionally use RR to free the activated capacities in mFRR. RR is not obligatory and only few TSO use it across Europe. Full activation time of RR is 30 minutes.

B. Frequency Ancillary Services Markets in Europe

The new EU legislation [5], [6], [10] sets the basis for the creation of market-oriented (as opposed to regulated) and Europe-wide integrated (as opposed to each country for itself) reserve procurement schemes. All reserves types in Europe have two directions: up/positive and down/negative. They can be procured symmetrically (both directions with one bid) or asymmetrically (two separate markets for each direction). The latest European regulation states that the FCR is procured symmetrically, while all other reserves must have separate markets for each direction. Reserve markets are organised in a two-stage fashion, first being the market for reservation of the balancing capacity (price in EUR/MW) and the second one for activation of the balancing energy (price in EUR/MWh). Only FCR reserve does not have subsequent balancing energy market (BEM) but only the balancing capacity market (BCM). FCR balancing energy is, therefore, activated proportionally among all accepted capacity bids. For other reserve types (aFRR, mFRR and RR), the participants who are cleared in the balancing capacity stage must submit their offers in the balancing energy stage at a desired price.

The wholesale energy markets, namely day-ahead (DAM) and intraday (IDM), are already well established and coupled throughout Europe [11], [12]. The FCR BCM internal market is termed as FCR cooperation and already includes many countries: Austria, Belgium, the Netherlands, France, Germany, Switzerland, Slovenia and West Denmark. The BEM for aFRR (PICASSO platform), mFRR (MARI platform), and RR (TERRE platform) are currently at the end of development process and are in the go-live process at present. The expected coupling of national balancing energy markets is in the next few years [9]. Germany and Austria are pioneers in BEM coupling and already have joint aFRR/mFRR BEM markets. The BCM for aFRR, mFRR and RR are at the initial phase of development Europe-wide and there are only several actions in force, to name some: FARCROSS EU Horizon project - BCM coupling algorithm development; aFRR Nordic - aFRR BCM coupling in Nordic countries [13]; aFRR/mFRR Germany/Austria - aFRR/mFRR BCM coupling between Germany and Austria [14], aFRR already live, while mFRR starts in following months.

C. Battery Storage Systems Providing Reserves

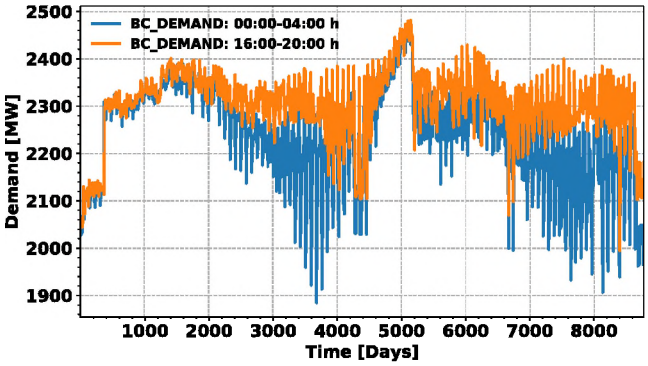
The utility-level BSS is mostly used for frequency containment reserve (FCR) provision since they have fast responses and the FCR provided the highest remuneration. In FCR cooperation, currently more than 1.4 GW of FCR is being procured every day [15]. According to [16], up to the end of 2020 477 MW were being provided by BSS (87% located in Germany), while additional 209 MW was on the way. However, high share of dedicated FCR BSS and other suppliers decreased the FCR price from an average of 26 EUR/MW/h in 2015 and 18 EUR/MW/h in 2017 to as low as 7 EUR/MW/h in 2020. In 2021 first the FCR prices recuperated due to increasing overall energy prices to average of 10.87 EUR/MW/h in the first half of 2021 and to 25.34 EUR/MW/h in second half of 2021.

Regardless of the recent energy price jumps, the FCR market alone could no longer justify BSS investment viability by itself, and new new revenue streams are required. It should be pointed out that this market experienced significant changes in order to ease access to new technologies. Until July 2019 the auctions were on weekly basis, while after July 2019 they shifted towards daily products procured one day-ahead of delivery. The last change happened in July 2020 when the products changed from daily to 6 4-hour products in a day (still procured in day-ahead auctions). Those changes allows the reserve providers to diversify their strategy and provide multiple services though day, depending on their state-of-energy (in BSS case) and depending on different prices for different services at different timesteps.

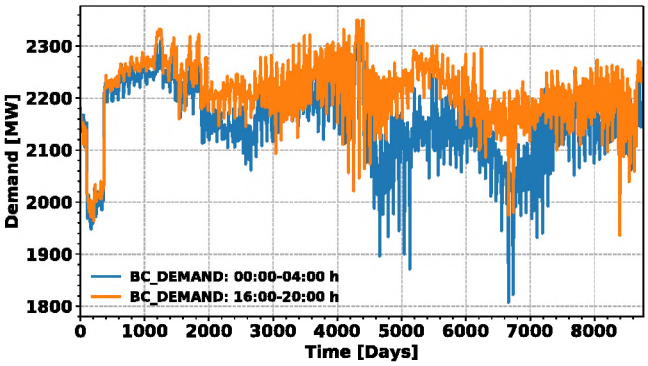
The first addition to the FCR provision is the aFRR market and many countries are working on new regulation to allow new technologies, such as storage, to provide it [17]. While the aFRR BCM market is still not harmonized within Europe and depends on local regulations, the BEM aFRR market is being harmonized and will behave as integrated Europe-wide market on PICASSO platform. The prices on BCM aFRR market are currently in most countries higher than FCR prices, plus there is an addition of BEM aFRR market revenues. The similar processes are expected to happen for mFRR reserve which can be seen as the second addition to BSS diversification strategy. This is the main reason why we choose to analyse aFRR and mFRR bids in this paper. Papers [18]–[23] are proposing different models for participation on BCM, but we believe that there is a lack of general analysis of trends on those markets which can induce further development in this area.

III. Data Analysis

To properly bid on BCM or BEM markets a market player must either directly forecast price (similarly to forecasting energy DAM price) or it must forecast whole supply and demand curves. Only the latter allows creation of price-making bidding models. In this paper, due to publicly available data, we will use German/Austrian data (for services where markets

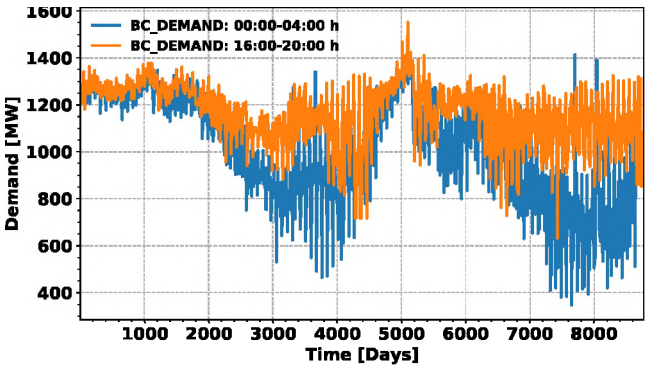


(a) Real aFRR Up BC Demand for 4-hour Periods 1 & 5

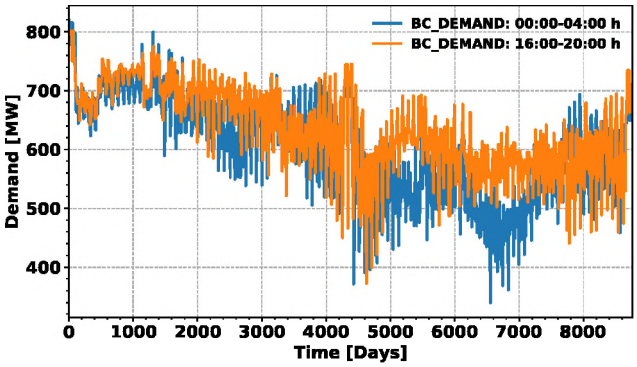


(b) Real aFRR Down BC Demand for 4-hour Periods 1 & 5

Fig. 1: aFRR BC Demand Plots for: 2020-2021



(a) Real mFRR Up BC Demand for 4-hour Periods 1 & 5



(b) Real mFRR Down BC Demand for 4-hour Periods 1 & 5

Fig. 2: mFRR BC Demand Plots for 2020-2021

are not yet coupled only German side will be observed) to analyse the aggregated bidding behaviour on aFRR/mFRR BEM/BCM. All the date is taken from [15]. The analysis is made on 2020-2021 data.

A. Observed Markets in Germany/Austria

The BCM market in Germany/Austria acts in day-ahead timeframe with the gate closure times (GCT): aFRR - 09:00, mFRR - 10:00. The BEM market until 02.11.2020 operated jointly with BCM market where the players were submitting a triplet: volume plus one BCM and one BEM price. After 02.11.2020. the two markets separated where a player which has allocated capacity at the BCM, must bid on BEM up to that volume but can also bid more volume (called voluntary bids) if he sees an additional opportunity. The BEM GCT currently is 1 hour before 4-hour bidding period. Both the BCM and BEM currently have 6 4-hour periods in one day. Note, that BEM is not operating as planned in Picasso/Mari platforms where the bidding will be based on 15-min periods, not 4-hour periods. This is a middle step where the BEM is first cleared for one 4-hour period ahead which means that those cleared bids can be activated in the real-time according to their price. However, contrary to BCM, they are paid only when activated in real-time, not directly after clearing.

When it comes to BCM/BEM the demand curve is fixed vertical line set up by the TSOs. In both cases it is deterministic and known before the GCT closure, but it changes from one 4-hour period to another, and from one day to another. As already mentioned, in the BEM case this deterministic curve does not set the price. The BEM price is set by highly uncertain activation/balancing energy requirement which is set by the current power systems conditions. The required uncertain balancing energy significantly affects the price which makes extremely hard to use direct forecasting tools for the BEM price. This is the main reason why the bidding curves, their analysis and modeling are very important for proper trading on BEM markets. The activated balancing energy is out of the scope in this paper due to page length restrictions.

B. Balancing Market Demands

Since the balancing capacity and energy market demands set by TSOs are almost always the same or at least very similar, in this Subsection only balancing capacity demands will be shown. The German TSOs use probabilistic dimensioning approach where the probability of imbalances is taken into account for each dimensioning period [15]. From December 2019, the dimensioning period is 4-hour period. The historical system imbalances are the basis for the dimensioning. Power plant failures are subtracted out of this basis and taken into account via failure probability of the power plant (all power plants with power higher than 100 MW are considered).

Due to dynamic dimensioning, the demand for different products fluctuates on a 4-hour basis as on Figures 1 and 2 for both services. The subfigures on the left side, subfigures (a), refer to upward, while subfigures (b) refer to downward direction. The figures refer to the demands for first (00:00-00:04 h) and fifth (16:00-20:00 h) 4-hour period in two year period: 2020-2021. The Figures 1 and 2 show significant

differences between the 4-hour periods in the same day, or differences between same 4-hour period of different days. E.g., on Figure 1 (a) around timestep (day) 5200, we can see that in just few days the difference can as high as 200/300 MW for the same 4-hour period. Even though similar, there is significant difference between up and down aFRR reserve demand as may not necessary fallow the same pattern (e.g. compare Figure 1 (a) vs (b)). On the other hand there are stronger similarities between aFRR and mFRR pattern, but the apsolute values are different (e.g. compare Figure 1 (a) vs 2 (a)).

C. Bidding Curves

Each participant submits his price-volume pairs for both BC and BE. After gate closure, the merit order list is created in ascending price order for BC Up & Down and for BE Up direction, while for BE Down direction the list is created in descending order. The positive price for BC Up & Down and for BE Up direction represents payments from TSO toward participants, while for BE Down direction the positive price represents payments from the participants toward TSO.

The bidding curves are represented on figures 3 and 4 for BC and BE of aFRR reserve, and on figures 5 and 6 for mFRR reserve. Left subfigures, a) and c), represent up direction, while right subfigures, b) and d), represent down direction. The first row of subfigures, a) and b), shows typical bid curves for 7 days for one 4-hour period (16:00-20:00 h), while the second row of subfigures, c) and d), shows statistical distribution of bids for different volumes for one 4-hour period (16:00-20:00 h) but during two year period: 2020-2021.

The curves are always monotonically increasing (BC up and down and BE up) or decreasing (BE down) as can be seen on a) and b) subfigures on all figures bellow. Please note that the apparent non-monotonic behavior of curves on c) and d) is only because the bidding behavior of players is different for different demands and in different time periods. This points out that it is important not to model the bidding curves on the large timespans but to always try to forecast future curves based on the behavior characteristic for certain timeframe such as summer/winter, weekday/weekend, day/night etc. After initial low prices for low volumes, both aFRR and mFRR BC bidding curves are almost linearly increasing with volume in most cases. In few cases there is also a high rise when closing to the TSO demand (when closing to high volumes). It means that the curves could be modeled in three stage piece-wise linear fashion. Both aFRR and mFRR BE bidding curves could be seen as exponential, but in the general form they can also be modeled as three stage piece-wise linear. However, their span is significantly wider and they more often reach the highest allowed price (+/- 99999.99).

IV. Discussion & Conclusion

After detail overview of the markets and analysis of demands and bids we can conclude that there are some regularities in the data which can be used as an inputs for forecasting and bidding algorithms. The BC demands are volatility and significant differences can appear between even subsequent hours. However, they are known before the BCM gate closure. On the other hand, BCM bidding curves are unknown before the GCT, but their historic curves are available. It means that we can use known future BC demands and and historic BC bidding curves to forecast future BC prices. BE activation demands are unknown before the GCT, but we can still use their historical values to forecast whole price curves and stochastically model the activation demands. Our future steps are to use all available data to create a recurrent neural networks (RNN) to forecast future bidding curves which will be used as inputs for bidding algorithms based on mathematical linear programming. The idea is to create RNN to forecast BC prices and BE bidding curves for one day in advance and to forecast BE curves for 4-hour ahead. The former will be used for day-ahead bidding algorithms while the latter will be used for intraday bidding algorithms. Both for day-ahead and intraday BE approach, the idea is not to create one curve for each 4-hour period, but to create two curves, min and max, which will be used as boundaries for robust modeling of uncertain BC and BE price forming.

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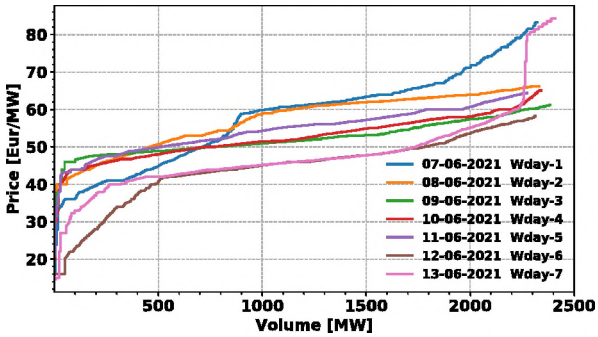
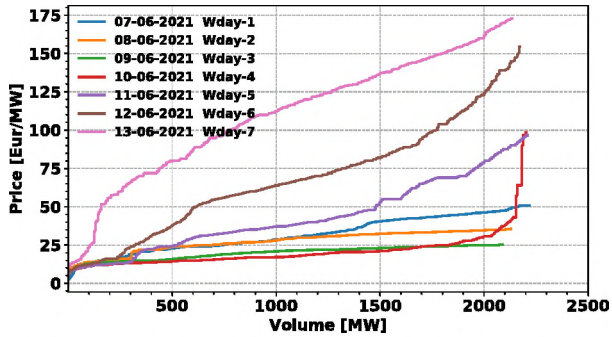
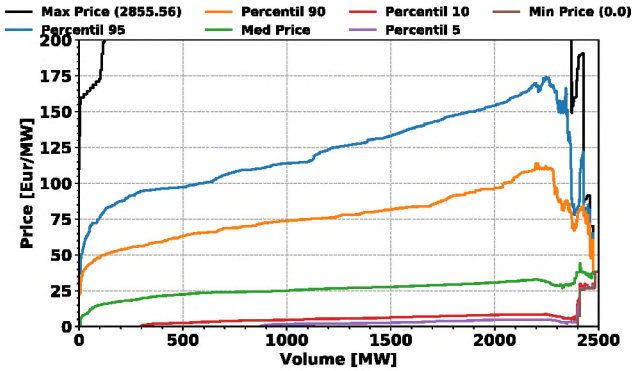


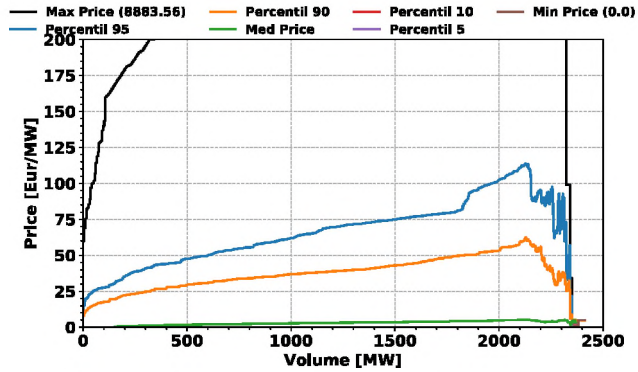
(a) Real aFRR Up BC Curves for One 4-hour Period for 7 Days



(b) Real aFRR Down BC Curves for One 4-hour Period for 7 Days

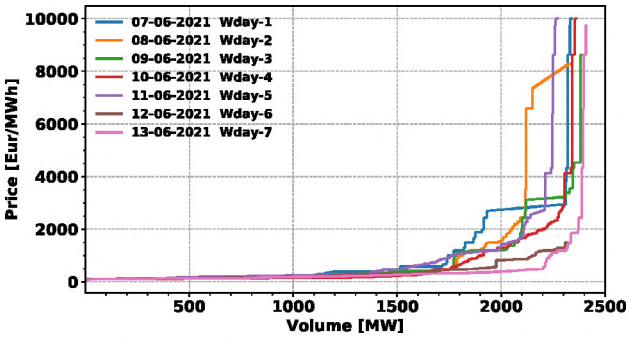


(c) Statistical View on aFRR Up BC Bidding Curves

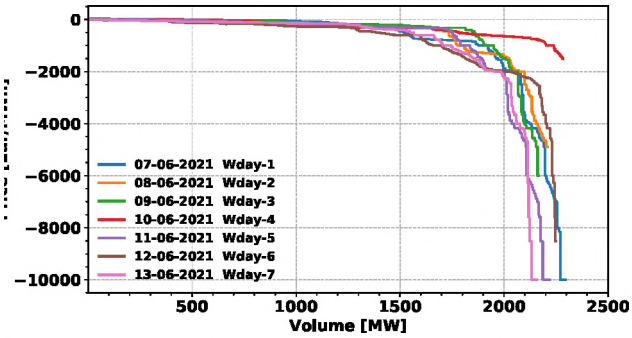


(d) Statistical View on aFRR Down BC Bidding Curves

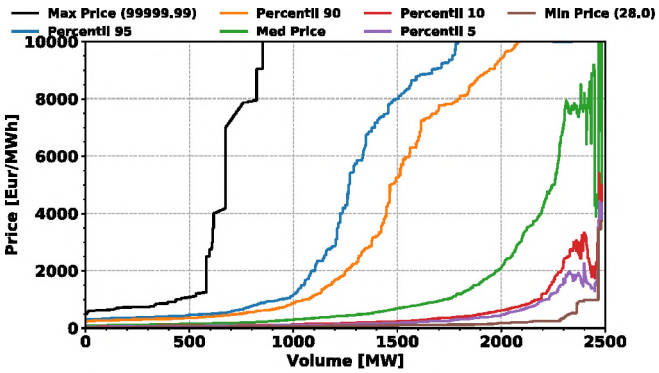
Fig. 3: aFRR BC Bid Plots for: 2020-2021



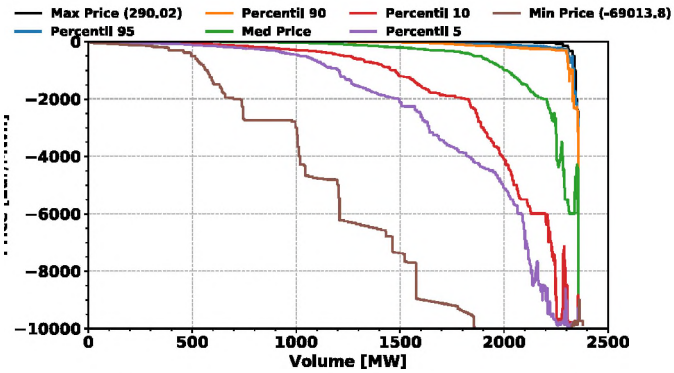
(a) Real aFRR Up BE Curves for One 4-hour Period for 7 Days



(b) Real aFRR Down BE Curves for One 4-hour Period for 7 Days

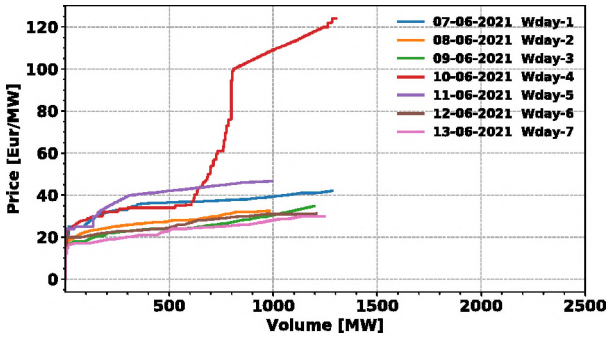


(c) Statistical View on aFRR Up BE Bidding Curves

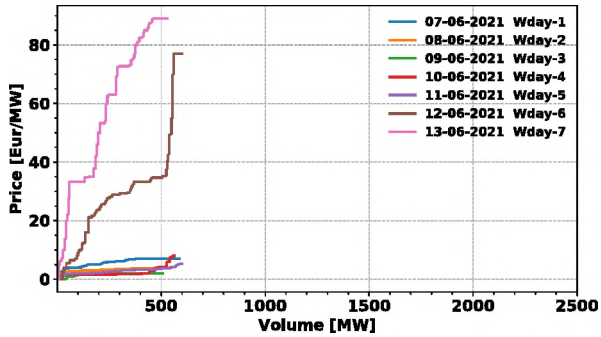


(d) Statistical View on aFRR Down BE Bidding Curves

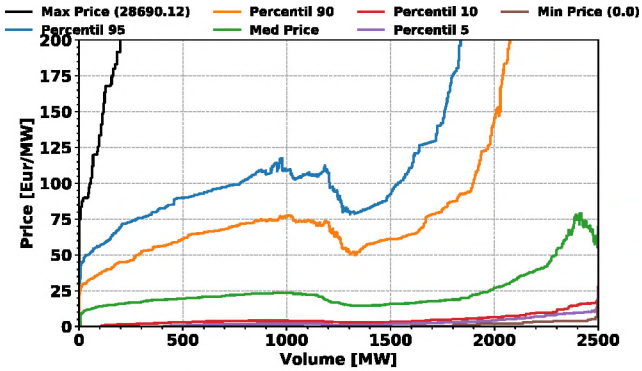
Fig. 4: aFRR BE Bid Plots for: 2020-2021



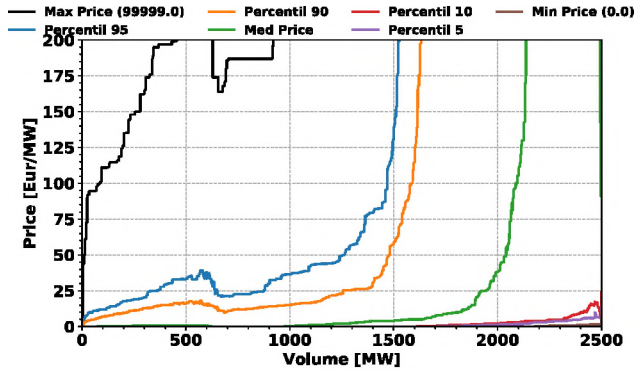
(a) Real mFRR Up BC Curves for One 4-hour Period for 7 Days



(b) Real mFRR Down BC Curves for One 4-hour Period for 7 Days

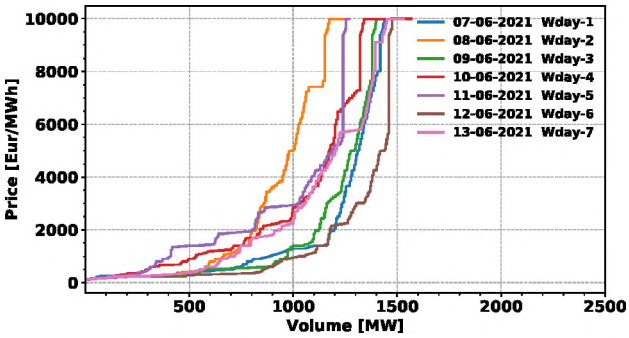


(c) Statistical View on mFRR Up BC Bidding Curves

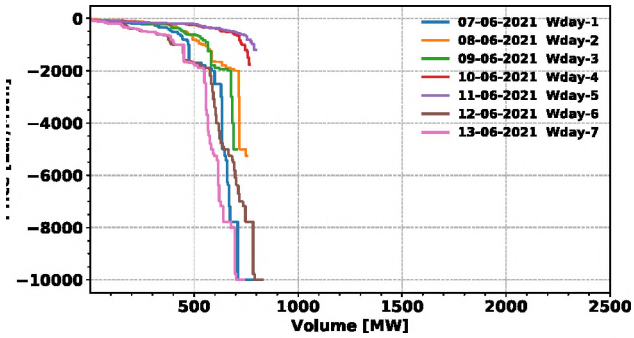


(d) Statistical View on mFRR Down BC Bidding Curves

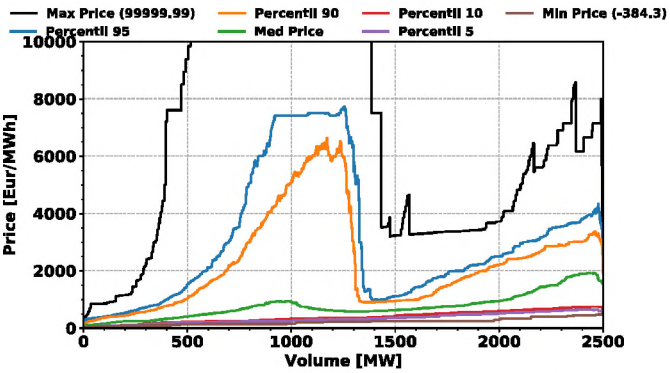
Fig. 5: mFRR BC Bid Plots for: 2020-2021



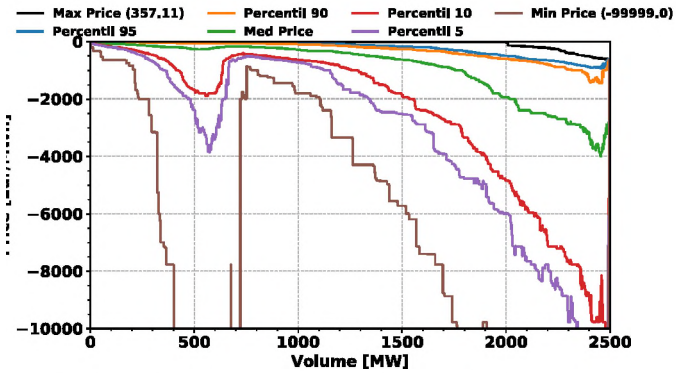
(a) Real mFRR Up BE Curves for One 4-hour Period for 7 Days



(b) Real mFRR Down BE Curves for One 4-hour Period for 7 Days



(c) Statistical View on mFRR Up BE Bidding Curves



(d) Statistical View on mFRR Down BE Bidding Curves

Fig. 6: mFRR BE Bid Plots for: 2020-2021