FINAL REPORT

Methodology for the dimensioning of the aFRR needs

September 30, 2020

EXECUTIVE SUMMARY

PART 1: INVESTIGATION OF FEASIBLE aFRR DIMENSIONING METHODS AND RECOMMENDATIONS FOR THE PROOF OF CONCEPT[1]

This study investigates **opportunities to replace or improve the current aFRR dimensioning methodology**, in order to maintain sufficient balancing quality while taking into account future system evolutions. In the past years, some opportunities for further improvements were identified for the current method and particular attention will be put on:

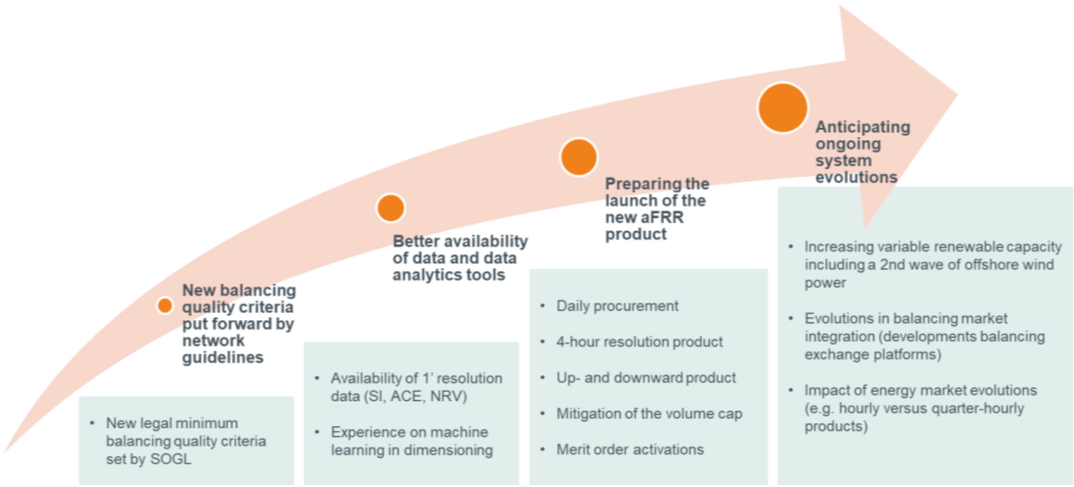
- taking into account intra-15' variations of the LFC block imbalances;
- taking into account the dynamic potential, varying aFRR needs in function of the risks (if any);
- taking into account the evolutions in the FRCE quality in line with Article 157(b) of the SOGL.

As **a new methodology needs to be robust for future evolutions,** an overview is made of most important relevant evolutions in the power system. Not only does the European legislation put forward new minimum criteria concerning FRCE-quality (which is still considered acceptable for Elia's LFC block), digital technologies also brought new tools to analyze system conditions. In addition, a new aFRR product that will be launched in 2020 will be based, at least partially, on a daily procurement with a 4-hour resolution product unlocking dynamic dimensioning possibilities similar to currently implemented for FRR. Finally, the method has to be robust towards increasing renewable generation capacity, challenging balancing quality through variability and limited predictability, and future market evolutions impacting the ability of BRPs to balance their portfolio.

This study aims to propose methodologies to improve the current aFRR dimensioning methodology to be further investigated in the Proof of Concept. These are based on an exhaustive analysis of methodology design options which are (1) implementable from a practical point of view (in terms of transparency and complexity); (2) compliant with European legislation; (3) robust towards future power system evolutions (including installed RES capacity and HVDC interconnections), and (4) meeting minimum technical criteria maintaining reliability of the system and acceptable balancing quality.

Note that the scope of the study is on dimensioning the aFRR needs. Investigations concerning the optimal allocation of this reserve capacity to different means such as balancing capacity, non-contracted balancing energy bids or reserve sharing in line with Article 32 of the EBGL is out of scope of the study.

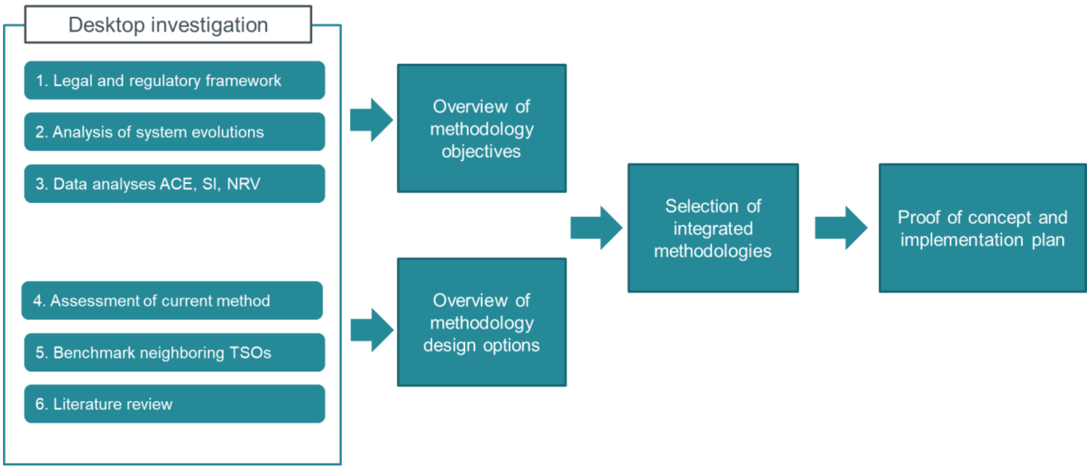
[1] This full report represents the results of the first and second part of the study. The first part was subject to a public consultation on June 2, 2020. Feedback received from stakeholders is taken into account in the second part of this full report. In addition, a consultation report is published with Elia's answers on the remarks and questions received from stakeholders. No substantial modifications or updates were conducted on the first part, representing the information relevant on June 2, 2020.



- **Investigating methodology objectives and methodology design options**

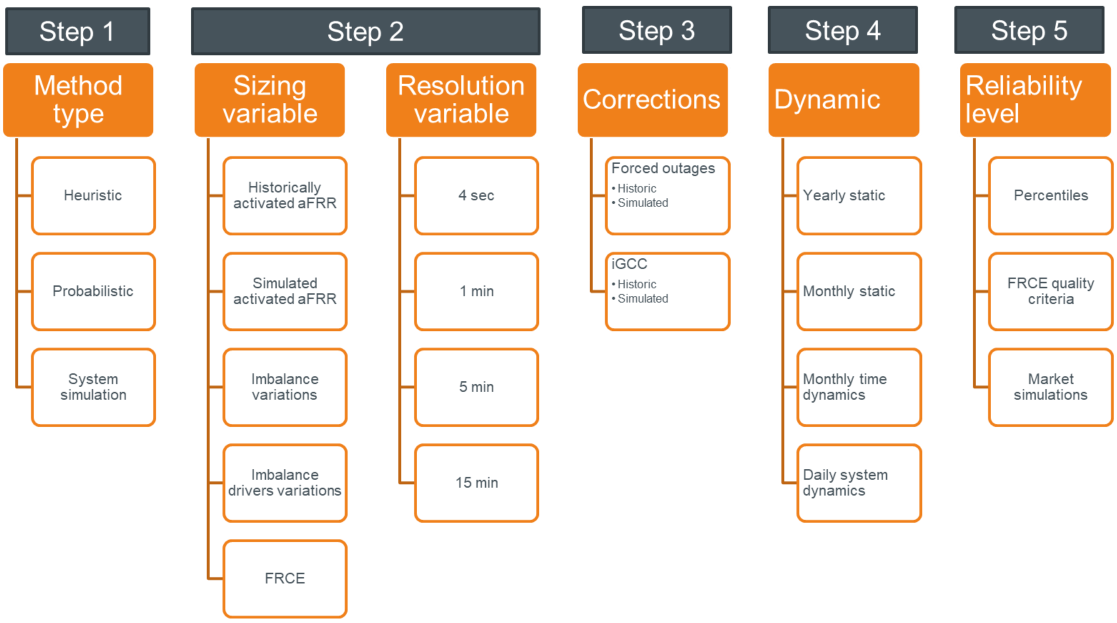
The study is based on an extensive desktop investigation. First, the **legal and regulatory framework** is investigated which is found to provide, in contrast to FRR dimensioning, little guidance on aFRR dimensioning principles. This is besides a few legal criteria on absolute warning limits concerning ACE / FRCE-quality. TSOs will therefore need to find themselves methods which provide a trade-off between meeting such minimum thresholds (and avoid over-procurement in general) and meeting their responsibility to cover their FRCE as good as possible and contribute to the European frequency stability. It is observed that currently:

- Elia attains acceptable results concerning balancing quality compared to other TSOs, as reported in ENTSO-E's reporting. It is found to have an average performance concerning meeting Level 1 and Level 2 criteria;
- Elia currently dimensions relatively little aFRR in comparison with its neighbors compared to the peak load in the LFC block. Although this comparison does not give a full view on specific system complexities, it might give an indication that Elia already attains an acceptable FRCE-quality with minimal procurement.



The **literature analyses and benchmark** of Elia's current method with neighboring TSOs reveals some methodology design options. A trend is observed towards probabilistic approaches where the most advanced approach seems to be found in the German LFC block where a dynamic probabilistic methodology is implemented based on simulated aFRR activations. Also some interesting design options are found in the Dutch system (taking into account activated IGCC, i.e. imbalance netting with other LFC blocks, in the aFRR dimensioning).

Based on these analyses, an exhaustive list is made of all possible different **methodology design options**. These options are categorized in five categories which are walked through in order to make a selection of feasible integrated methods. In **step 1** the method type is selected being deterministic, probabilistic or simulation-based as discussed in the literature. In **step 2**, the sizing variable and its resolution is determined which is the main variable on which the reserves are determined. Different options are found in the benchmark with other TSOs and complemented with Elia's insights analyzing the objectives and the legal framework. In the current method, this would be covering a certain percentage of all LFC block imbalance variations (sizing variable) with a resolution of 15' (resolution).

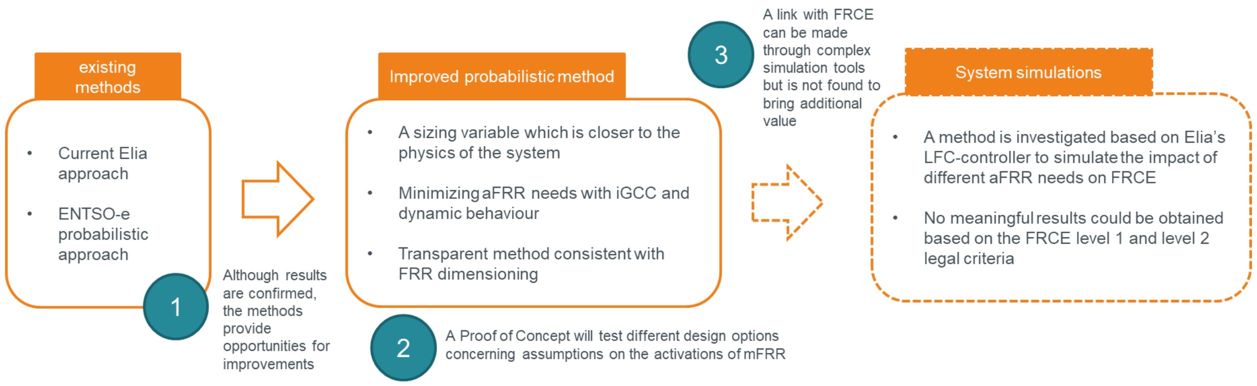


Step 3 considers possible corrections of this variable to explicitly include or exclude the impact of forced outages of large generation units and to take into account IGCC or not reducing the aFRR needs. **Step 4** will then determine if a yearly, monthly or daily dynamic dimensioning will be considered based on the determined potential. Finally, in **Step 5**, the method to determine the reliability level is specified, i.e. the percentage of LFC block imbalance variations to be covered in the current method.

The analysis of the information shows that **existing methods** such as the current Elia approach, or even the recommended methods by ENTSO-E are found to have drawbacks or at least provide opportunities for improvement. Mainly, the robustness towards new aFRR product design and increasing renewable capacity installed is challenging the current methodology.

- The study puts forward that **improving the probabilistic method** seems the best way forward. The probabilistic method is a good trade-off between complexity and transparency, while being consistent with the FRR dimensioning method. Such method has also been recently implemented in Germany. The proposed improvement for Elia's aFRR dimensioning is to better align the sizing variable with the system physics (simulate aFRR activations, take into account IGCC) while implementing a dynamic methodology to reduced average aFRR needs.

- An in depth investigation towards **simulation-based models** shows that simulations with Elia's LFC controller allow to investigate the effect of different minimum aFRR means on the ACE / FRCE. This allows to assess the performance concerning ACE / FRCE-quality objectives. No meaningful results were obtained when assessing the impact on the minimum warning limits, i.e. the Level 1 and Level 2 criteria. It is concluded that the method substantially increases complexity without finding accurate aFRR needs, at least as long no specific reliability targets are specified which can be used for dimensioning.



Therefore, Elia recommended to continue investigating the improved probabilistic method in a Proof of Concept. The Proof of Concept further investigates the implementation of the aFRR simulations, i.e. determining the assumptions on the activations of mFRR, and the participation of IGCC. Also the algorithms for the dynamic method and sizing variable resolution, i.e. 5 minutes or 1 minute are investigated, while projections are made up to 2028. This allows to analyze the robustness of the method towards the increasing renewable penetration, including the 2nd wave of offshore expected to be fully commissioned in 2028.

PART 2: RESULTS OF THE PROOF OF CONCEPT, RECOMMENDATIONS AND PLANNING FOR IMPLEMENTATION

The Proof of Concept investigated a probabilistic methodology designed to **cover 99% of simulated aFRR activations**[2]. These simulations are based on historic LFC block imbalances while taking into account IGCC activations and mFRR activations. The methodology is complemented with an ex post check to ensure that the FRCE target parameters are respected.

The **first objective** of the Proof of Concept is to recommend suitable options and parameters to calculate the simulated aFRR activations. This is based on the analysis of sensitivities on the sizing variable, sizing resolution and the approach to include IGCC in the calculations. Concerning the sizing variable, Elia investigated two possible options to determine the mFRR activations, i.e. a dispatch-based method based on realistic mFRR dispatch operations, and an oracle-based method based on mFRR activations assuming a perfect foresight on future LFC block imbalances. These methods were benchmarked against an improved version of the current methodology taking into account a higher 5' resolution and while correcting the LFC block imbalances with the historic IGCC activations before calculating the difference between two subsequent periods.

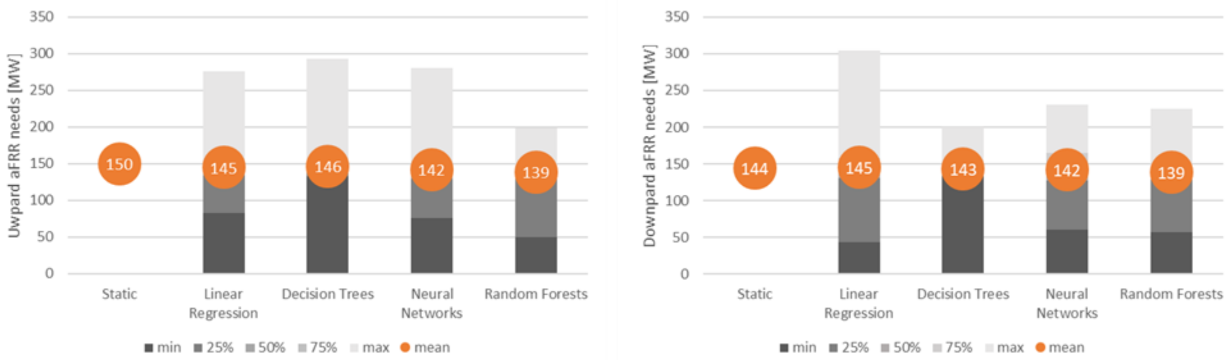
It is found that the oracle-based method can offer a transparent approach with no or limited parameters to calibrate while remaining close to the philosophy of the dispatch of aFRR (by taking into account IGCC and mFRR activations). The perfect world assumption allows to minimize aFRR needs, justified through the use of a high reliability level of 99.0% and a dynamic dimensioning method where the needs are adapted to the risks. This ensures to optimize the procurement costs of aFRR and mFRR for which the latter is substantially cheaper. Analyses have shown that such method is best combined with 5' resolution, aligned with the future 5' full activation time of aFRR, and historic IGCC values, as no additional advantages were found in using simulated IGCC values.

Applying the 'oracle-based aFRR simulation' method will result in '**static' aFRR needs of around 151 MW and 145 MW for respectively up- and downward aFRR needs when analyzed over a period for 2018-19**, not taking into account any extrapolations. Note that these capacities confirm the results of the current aFRR needs implying that the FRCE-quality will remain stable at a level respecting the current FRCE target parameters specified by the guideline on electricity transmission system operation. These FRCE target parameters, are taken into account in the sense that if these targets are not respected, this will require a revision of the aFRR dimensioning methodology.

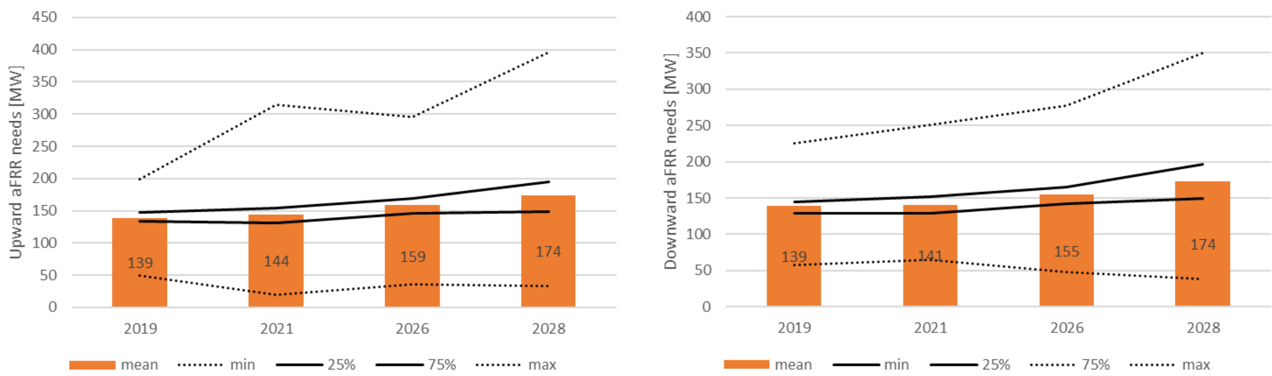
The **second objective** of the Proof of Concept was to investigate whether a possibility exist to vary the aFRR needs in function of the expected system conditions, and adapt the aFRR needs to the risks of the system, or in other words, the risks of using this aFRR capacity. An analysis based on a robust set of features used already for FRR / mFRR dimensioning is used to test four relevant machine learning models including less and more sophisticated methods including artificial neural networks. The model takes into account 19 features to predict the aFRR needs for each period

[2] All calculations in the proof of concept are conducted by N-SIDE, an independent company specialized in innovative decision-aid solutions based on state-of-the-art advanced analytics and optimization methods.

of the next day. Based on an assessment of as well accuracy, but also complexity and interpretability, Elia recommends to use a random forests algorithm for the implementation. It is found in this Proof of Concept, that on average, this method allows to reduce the up- and downward aFRR needs to 139 MW, while the method remains less complex and the results are better interpretable compared to the artificial neural network method. Note that this value is found to be symmetric for both up- as downward aFRR needs despite the separate calculations in both directions. It is to be noted that machine learning methods can be subject for continuous improvement, following system evolutions and new insights and further calibration.



The **third objective** was to assess the robustness towards the increase in renewable installed capacity. In a worst case, where foreseen market performance are assumed not to translate to the LFC block imbalance variations within the 15 minutes, average aFRR needs are estimated to increase towards 178 MW in 2028 for as well up- and downward aFRR needs. However, in a reference case assuming that current market improvements are translated one-to-one to the intra-15' LFC block imbalances, the aFRR needs may even remain stable towards 2028, or even slightly decrease.



Average, min / max and 25% - 75% percentiles of the upward (left) and downward (right) aFRR needs towards 2028 for the worst case

During industrialization, the methodology will be aligned with the aFRR procurement process, as well as with the FRR / mFRR dimensioning process. The aFRR procurement process requires:

- A calculation of the aFRR needs in blocks of 4-hours instead of a 5' resolution ;
- A calculation well before the D-1 procurement gate of 9 AM;
- A calculation of a minimum allocated to the D-2 procurement;
- If required, limits to determine the maximum variability of the aFRR need (and limit the effect of outliers)

This can be aligned with the FRR / mFRR dimensioning process where the calculations are published before 7 AM D-1 in order to simultaneously publish FRR / aFRR / mFRR needs. Note that the aFRR needs are needed to calculate the mFRR needs as the difference between the total FRR needs and the aFRR needs. This methodology is also complemented with a training of the algorithm which can be aligned with the FRR / mFRR dimensioning process. A yearly ex post analysis will assess if the aFRR needs are able to respect at least the FRCE target parameters.

Elia proposes a 'go live' of the proposal elaborated in this study on February 1, 2022, subject to public consultation and regulatory approval of this methodology to be specified in the LFC block operational agreement, and foreseen to be submitted to CREG in Q2 2021. The 'go live' will be preceded with a parallel run of 4 months in order to allow market players to get acquainted to the aFRR needs variations. As from the start of 2021, Elia foresees to start the IT-implementation.

PART 1: INVESTIGATION OF FEASIBLE aFRR DIMENSIONING METHODS AND RECOMMENDATIONS FOR THE PROOF OF CONCEPT

1. Introduction

1.1 Different types of reserve capacity in Elia's LFC block

The diagram in Figure 1 illustrates the main mechanisms of the operation of the current electricity market. **Market players are responsible for balancing injections and off-take in their portfolio.** They must therefore nominate an energy portfolio one day in advance (day-ahead) that guarantees an equilibrium and by moving further closer to real-time resolve any detected imbalance in their portfolio[3]. It is therefore necessary for the market to have sufficient flexibility, both intra-day and in real-time, to compensate for forecast errors on generation and demand, in particular in regards to renewable energy sources and off-take. In addition, the flexibility available in the system must always allow for the loss of power plants and relevant HVDC interconnectors (an unavailability known to occur on day-ahead as well as an unforeseen unavailability after day-ahead).

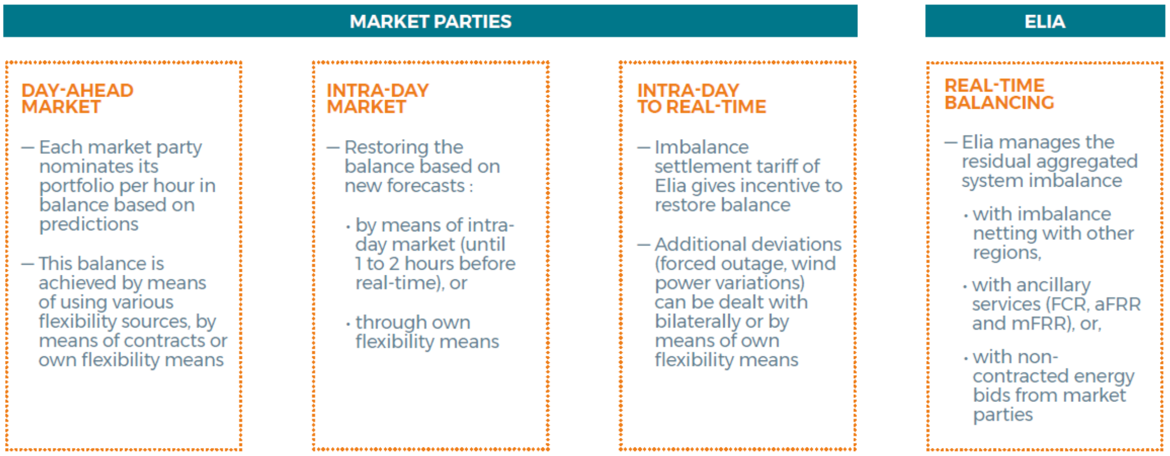


Figure 1: time horizons for flexibility (Elia's adequacy and flexibility study 2019)

The role of the system operator in managing flexibility is complementary to the market because it neutralizes the residual imbalance between injection and offtake that is not covered by market players. By means of the imbalance settlement tariff, it incentivizes the market to cover their balancing responsibility as much as possible. This imbalance tariff is driven by the cost of activating balancing energy to resolve the residual system imbalance, in both an upward (to deal with energy shortage) and downward (to deal with energy surplus) direction. Due to this 'reactive' balancing mechanism, a large part of the required flexibility is delivered by intra-day markets and real-time actions and not by Elia.

[3] In parallel to this study, Elia conducts a study on the advantages and disadvantages of eliminating or relaxing the obligation for BRPs to nominate a balanced portfolio in Day Ahead as provided for in article 23 of the Terms and Conditions BRP. This study is foreseen to be consulted on October 15, 2020.

The TSO uses reserve capacity to cover the residual system imbalance as represented in Figure 2. If an imbalance in the system occurs, this results in an increase or decrease in the system frequency. Because the control zones of the ENTSO-E network - also called the Load Frequency Control (LFC) blocks of which the ELIA LFC block represents the Belgian geographical area - are connected, a frequency disturbance impacts the entire synchronous zone. The Frequency Containment Reserve (FCR) must restore the balance between the power provided and the power supplied. It is used to stabilize the frequency at a level greater or smaller than the initial frequency, rather than balancing the ELIA LFC block. Section 1.2 explains how the required FCR volume is dimensioned by ENTSO-E at European level and allocated to the relevant LFC blocks.

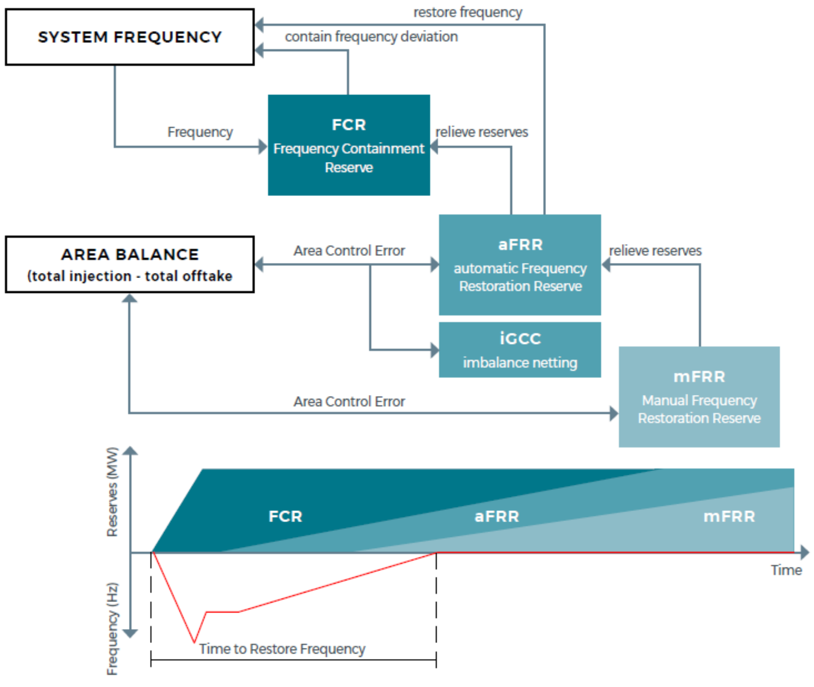


Figure 2: Schematic overview of the activation of operating reserves

The Frequency Restoration Reserve (FRR) must free up the FCR of the synchronous zone and ultimately bring the frequency to its nominal value in order to prevent network instability, or even a failure of the entire electricity system, in the event of additional system imbalances. Each control area is therefore obliged to maintain its balance which is monitored by means of quality criteria assessing the Frequency Restoration Control Error (FRCE) or Area Control Error (ACE), i.e. the real-time deviation between measured and scheduled cross-border exchanges on a quarter-hourly (and even by minute) basis.

Unlike the FCR, the FRR ensures that the frequency in the synchronous zone is restored, and that the control zone is re-balanced. The automatic FRR (aFRR) is mainly used to compensate for short and random imbalances. The manual FRR (mFRR) serves as compensation for long, persistent and/or very extensive imbalances. Once requested by Elia:

- aFRR must be activated automatically by the BSP within 30 seconds and must be fully available within 7.5 minutes;
- mFRR is manually activated by the BSP and must be fully available within 15 minutes.

1.2 Elia's dimensioning methodology for the needs and means for reserve capacity

The required FCR volume is dimensioned by ENTSO-E for the synchronous area of continental Europe. It is currently calculated on the largest contingency, currently the loss of 3000 MW. This volume is allocated to the corresponding LFC blocks according to their weight (in terms of consumption and generation) in the synchronous zone. The methodology is specified in the Synchronous Area Framework Agreement of Continental Europe, hereafter referred to as 'SAFA'[4]. The current FCR capacity in Belgium for 2020 is 78 MW.

The required FRR reserve capacity is dimensioned by Elia for its LFC block. First the needs are determined with a methodology presented in Elia's LFC block operational agreement[5]. As from February 3, 2020, Elia implemented a daily dynamic dimensioning for up- and downward FRR needs. The volumes are thereafter allocated towards the different products for balancing capacity with a methodology presented in the LFC Means[5].

- Dynamic dimensioning methodology for the FRR needs

As required by Article 157(2)b of the Commission Regulation (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation (hereafter referred to as "SOGL"), ELIA determines the positive and negative FRR needs based on a combination of a probabilistic and deterministic methodology (Figure 3). The **probabilistic methodology** is based on estimating the imbalance risks for each quarter-hour of the next day and determining the required reserve capacity on FRR to cover 99.0% of the imbalance risks, i.e. the 99.0% percentile of the probability distribution curve of the positive and negative LFC block imbalances. The probabilistic method is based on machine learning algorithms relating the imbalance risk to day-ahead predicted system features such as renewable generation, demand, weather conditions, as well taking into account the imbalance risks due to forced outages of available power plants and the Nemo Link interconnector.

In parallel, Elia considers the dimensioning incident by means of a **deterministic methodology**. This method has to ensure that the positive and negative FRR needs shall not be less than the positive and negative dimensioning incident of the LFC block, as required by Articles 157(2)e and 157(2)f of the SOGL. The dimensioning incident is defined by Article 3 of the SOGL as the highest expected instantaneously occurring active power imbalance within a LFC block in both positive and negative direction. Finally, Elia applies an additional **minimum threshold** to ensure that the required positive and negative reserve capacity is sufficient to cover at least the positive and negative historic LFC block imbalances for 99.0% of the time in order to be in line with Articles 157(2)h and 157(2)i of the SOGL.

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[4] Annex 1 of the SAFA which is the Policy on Load-Frequency Control and Reserves, determines amongst others the dimensioning rules for FCR, published on : https://transparency.entsoe.eu/system-operations-domain/operational-agreements-of-synchronous-areas/show

[5] Published on https://www.elia.be/en/electricity-market-and-system/system-services/keeping-the-balance

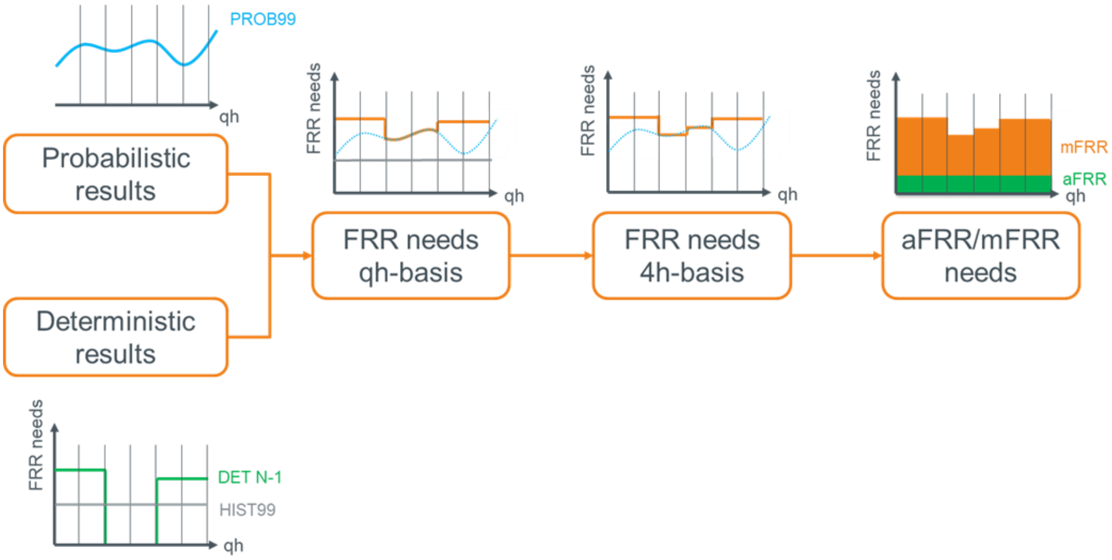

Figure 3: Calculation process of the FRR/aFRR/mFRR needs

Both methodologies are used in parallel to calculate the positive and negative FRR reserve capacity required for every quarter-hour of the next day. The required reserve capacity for each quarter-hour is determined based on the maximum value of the deterministic and probabilistic methodologies. The result is expressed in periods of 4 hours by means of the maximum over all quarter-hours in this period. The calculation is conducted before 7 AM.

Note that the mFRR need is determined by subtracting the FRR needs with the results of a 'static' aFRR dimensioning methodology for which the methodology and results are determined as well in the LFC block operational agreement. This is based on covering a fixed percentile of the expected absolute 15' imbalance variations. As improving this methodology is the scope of this study, it is discussed in more detail in Section 2.2.1.

- Methodology to determine the FRR means to be contracted

In compliance with Article 32 of Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing, hereafter referred to as "EBGL", ELIA conducts an analysis on optimal provision of reserve capacity. This analysis shall take into account the following options for the provision of reserve capacity:

- procurement of balancing capacity within control area and exchange of balancing capacity with neighboring TSOs, when applicable;
- sharing of reserves, when applicable;
- the volume of non-contracted balancing energy bids which are expected to be available both within their control area and within the European platforms taking into account the available cross-zonal capacity.

ELIA currently determines the balancing capacity for aFRR equal to the aFRR needs (taking into account the absence of aFRR sharing and the limited potential of non-contracted energy balancing bids). The aFRR capacity is determined symmetrically meaning that the downward reserve capacity is equal to the upward reserve capacity.

The upward mFRR needs are assumed to be partially covered with the sharing of mFRR but not by non-contracted balancing energy bids after showing the limited potential. In contrast, the downward mFRR needs are assumed to be fully covered with sharing of mFRR and non-contracted balancing energy bids. More information can be found in ELIA's LFC Means.

1.3 Elia's reserve capacity volumes

Table 1 shows the historical global FRR/aFRR needs between 2013 and 2020. Although a decreasing trend in FRR needs is observed between 2013 and 2016, this is mainly due to market design improvements. After a small increase in 2018, the reliability target in the calculations was reduced from 99.9% to 99.0% following SOGL minimum requirements. As from 2020, Elia implemented a dynamic FRR dimensioning process where the FRR needs are dimensioned for the next day.

Table 1: Evolution of the FRR needs

[MW]	Upward FRR Needs*	Symmetric aFRR Needs*
2013	1260	140
2014	1241	140
2015	1240	140
2016	1203	140
2017	1183	144
2018	1190	139
2019	1039	145
2020	Dynamic	145(151)

Based on Elia's volume assessments (Final Decisions CREG)

Table 1 shows that aFRR needs remained fixed at 140 MW until 2017 when the reliability target was fixed at 79% which was observed to provide sufficient ACE / FRCE-quality. **However, as from 2019, aFRR needs started increasing following the increased variability in the LFC block imbalances induced by the integration of variable renewable energy (wind and solar).** This was found to further increase to 151 MW in 2020 but it was decided to freeze the volume to 145 MW while awaiting the assessment of the current methodology towards potential improvements in this study.

Note that the latest long-term projections for aFRR were conducted in 2016 in the framework of the first adequacy and flexibility study (Table 2)[6]. These non-binding indicative volumes are based on the 2016 applicable volume determination methodology, excluding any additional measures and volumes that would be required dealing with exceptional situation (e.g. loss of the offshore wind power generation due to storm events). While the aFRR needs were expected

[6] Published at https://www.elia.be/en/electricity-market-and-system/adequacy/adequacy-studies. Note that these volumes have as sole purpose to give an idea of the future trend with respect to volume needs and do by no means substitute for the legally or regulatory determined volume assessment process in place between Elia and the CREG.

to increase to 175 MW (and even 190 MW in the ‘High RES scenario) following the integration of renewable energy (including offshore wind power).

Table 2: Estimated evolution of the FRR needs in the Base Case and High RES scenario, as published in the adequacy study and assessment of the need for flexibility of 2016

Horizon	aFRR ‘Base Case’	aFRR ‘High RES’
2021	175	175
2023	175	175
2027	175	190

However, in Elia’s later projections, these figures were already revised downwards towards 160 MW between 2021 and 2023, based on return of experience on aFRR dimensioning with increasing shares of renewable generation. Indeed, it is found that the long-term aFRR projections might have been too conservative in terms of the impact of renewable generation prediction errors on the LFC block imbalance variations. Note that accuracy of extrapolations is improved when more data became available on wind and solar generation and forecasts.

1.4 Robustness towards expected system evolutions

Figure 4 provides the main reasons to investigate a new methodology for aFRR dimensioning. First of all, **new balancing quality criteria** are put forward by the SOGL providing new legal minimum balancing quality criteria which are complemented by a set of proposed indicators. Note that since 2018, results are published by ENTSO-e in its balancing reporting, as well as reported by Elia to CREG in its balancing and reserve reporting in line with requirements defined in the LFC BOA.

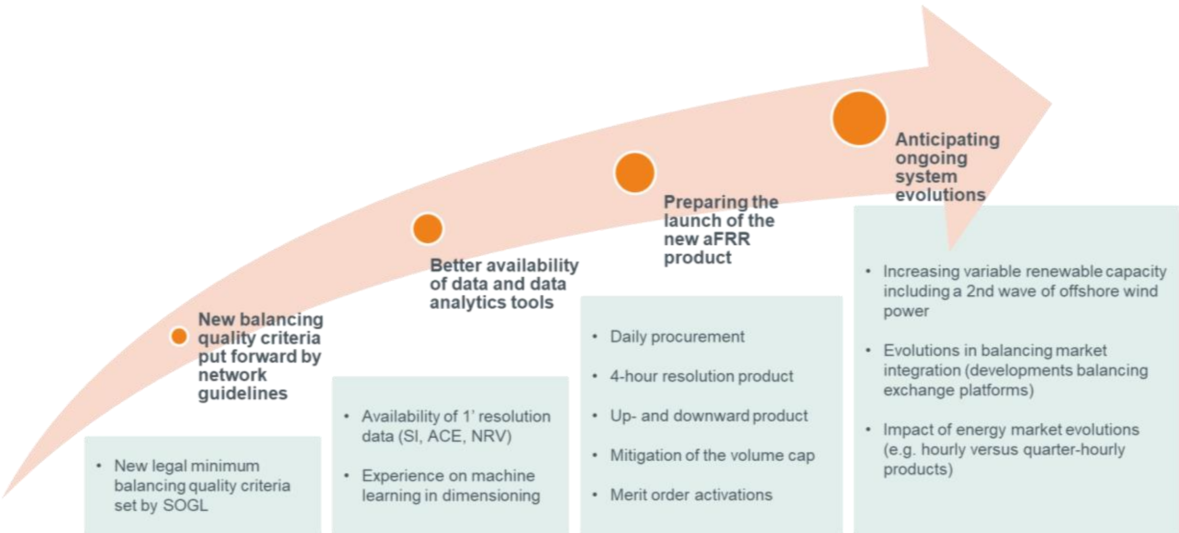

Figure 4: Overview of expected system evolutions

Secondly, **digitalization of the sector** brought new tools for data analytics which can be combined with elaborated data available and published by Elia (e.g. 1’ LFC block imbalance data). In addition, in recent years, Elia gained more experience on data analytics for several applications of which one was the dynamic dimensioning of FRR based on machine learning algorithms.

Thirdly, Elia is currently preparing the implementation of a **new aFRR product design**. This product design might hold some opportunities to conduct the dimensioning closer to real time through daily procurement and 4 hour product resolution as well as the implementation of separate up and downward products. In addition, the impact of allowing the participation of non-contracted balancing energy bids and merit order activations has to be investigated.

Finally, and not at least, there are a few **system evolutions** ahead which may impact aFRR dimensioning. Firstly, there is an increasing variable renewable capacity including a 2^{nd} wave offshore wind power, foreseen. The variability and limited predictability of these resources are a well-known challenge for power system balancing. But also evolutions in the European balancing market integration and the impact of other market evolutions such as quarter-hourly products have to be investigated.

1.5 Objective, scope and structure of the study

This study investigates opportunities to improve or replace the current aFRR dimensioning methodology, in order to maintain balancing quality while taking into account future system evolution. Particular attention will be put on:

- taking into account intra-15' variations of the LFC block imbalances;
- taking into account the dynamic potential, varying aFRR needs in function of the risks (if any);
- taking into account the evolutions in the FRCE quality in line with Article 157(b) of the SOGL.

This study proposes options to improve the current aFRR dimensioning methodology to be further investigated in a Proof of Concept. These are based on an exhaustive analysis of methodology design options which are (1) implementable from a practical point of view (in terms of transparency and complexity); (2) compliant with European legislation; (3) robust towards future power system evolutions (including installed RES capacity and HVDC interconnections), and (4) meeting minimum technical criteria maintaining reliability of the system and acceptable balancing quality.

In a first step, Section 2 investigates different design options found in the literature, benchmark with neighboring TSOs and Elia's expert view and experience with dimensioning of reserve capacity. Thereafter, Section 3 proposes a selection of an integrated method which will be further investigated in a Proof of Concept in the second part of the study. Following the consultation on this document, the Proof of Concept for the chosen methodology will be executed. The results of this proof of concept will be published by Elia in Q4 2020.

2. aFRR dimensioning design options

Figure 5 shows an overview of the investigation method followed to find an improved or new aFRR dimensioning method. The starting point is an extensive desktop investigation. Firstly, an overview is made of the **methodology objectives**. This is based on an analysis of the legal and regulatory framework, listing ongoing system evolutions and an analysis of the current balancing quality. This allows to identify the requirements of an aFRR dimensioning methodology. Secondly, an overview is made of possible **methodology design options** which is based on an assessment of the current methodology, a benchmark of methods applied by other European TSOs and a literature review.

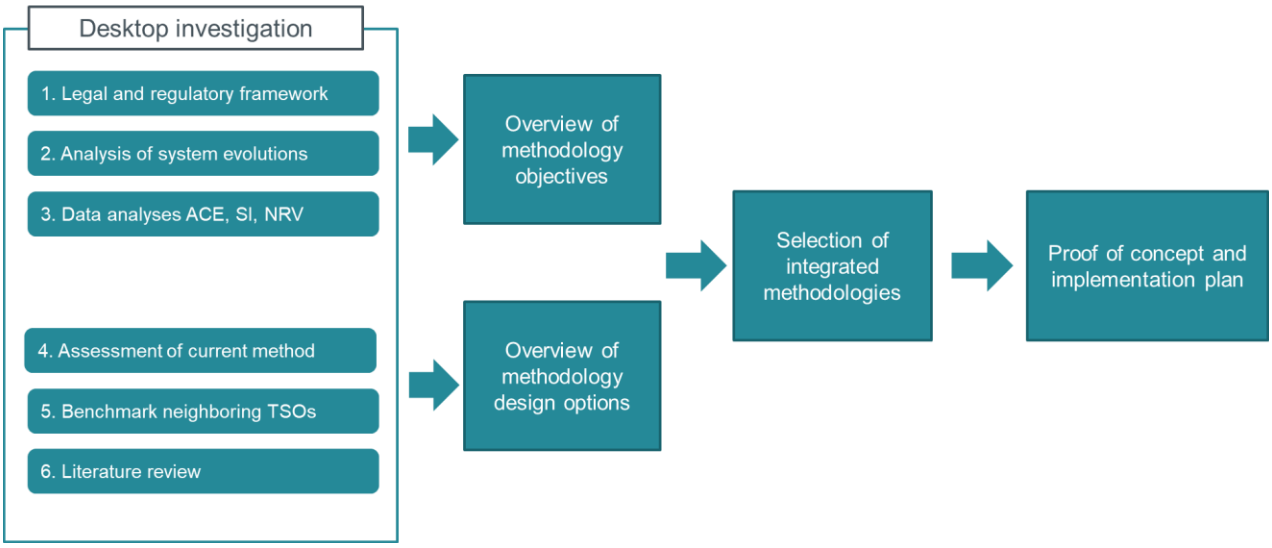

Figure 5: Overview of the approach to find a new or improved aFRR dimensioning method

These analyses allow to make a selection of integrated methodologies. After an assessment of these methods, the most promising method(s) are proposed for further investigation in a Proof of Concept with projections towards 2020 to 2028. Based on the results of the Proof of Concept presented in Section 6 and Section 7, an implementation plan will be proposed in Section 8.

2.1 aFRR dimensioning objectives

2.1.1 Legal and regulatory framework

The legal framework provides only little guidance for aFRR dimensioning. The **Clean Energy Package** or **Federal Grid Code** neither provide specific requirements for aFRR dimensioning within the LFC block. However, the **'SOGL'** specifies some dimensioning rules on FRR which are given in Article 157. Despite that little attention is given to determining the ratio between aFRR and mFRR, three paragraphs in Article 157(2) of the SOGL are relevant:

> *c. all TSOs of a LFC block shall determine the ratio of automatic FRR, manual FRR, the automatic FRR full activation time and manual FRR full activation time in order to comply with the requirement of paragraph (b). For that purpose, the automatic FRR full activation time of a LFC block and the manual FRR full activation time of the LFC block shall not be more than the time to restore frequency;*

b. all TSOs of a LFC block in the CE and Nordic synchronous areas shall determine the reserve capacity on FRR of the LFC block sufficient to respect the current FRCE target parameters in Article 128 for the time period referred to in point (a) based at least on a probabilistic methodology. In using that probabilistic methodology, the TSOs shall take into account the restrictions defined in the agreements for the sharing or exchange of reserves due to possible violations of operational security and the FRR availability requirements. All TSOs of a LFC block shall take into account any expected significant changes to the distribution of LFC block imbalances or take into account other relevant influencing factors relative to the time period considered

a. all TSOs of a LFC block in the CE and Nordic synchronous areas shall determine the required reserve capacity of FRR of the LFC block based on consecutive historical records comprising at least the historical LFC block imbalance values. The sampling of those historical records shall cover at least the time to restore frequency. The time period considered for those records shall be representative and include at least one full year period ending not earlier than 6 months before the calculation date.

It concluded that article (a) and (b) deal again with the dimensioning of FRR in general and are therefore also applicable on aFRR needs being part of the FRR needs. Section B-6-2-2-1-5 of the SAFA,[7] although this part is not approved by NRAs, provides some additional guidance by specifying two approaches to provide a recommendation for a minimum amount of aFRR:

1. *The amount of the aFRR that is needed typically depends on the size of load variations, schedule changes and generating units. In this respect, the recommended minimum amount of aFRR has to ensure:*

   • that the positive aFRR is larger than the 1st percentile of the difference[2] of the 1-minute average ACEol[3] and the 15 minute average ACEol of the LFC Block of the corresponding quarter of hour[4], and

   • that the negative aFRR is larger than the 99th percentile of the difference of the 1-minute average ACEol and the 15 minute average ACEol of the LFC Block of the corresponding quarter of hour.

   This recommended statistical approach is based on historical data with:

   [2] Difference to be calculated on 1-minute resolution

   [3] ACEol means remaining ACE open loop without contribution of mFRR and RR activations.

   [4] To be calculated between minutes 0:00-14:59, 15:00-29:59, 30:00-44:59, 45:00-59:59 of each hour of the day

2. *An alternative approach based on empiric noise management (recommended in the former UCTE) may also be taken into account leading to recommended minimum amount of aFRR given in the following graph [Figure 6] with Lmax being the maximum anticipated consumer load for an LFC Area over the period considered.*

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[7] Annex 1 of the SAFA which is the Policy on Load-Frequency Control and Reserves, specifies amongst others the aFRR minimum amount recommendations (B-6-2-2-1-5), published on : https://transparency.entsoe.eu/system-operations-domain/operational-agreements-of-synchronous-areas/show

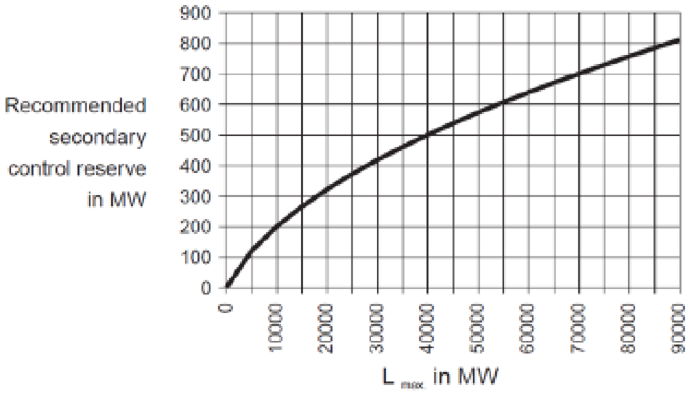


Figure 6: Recommended minimum aFRR reserve in the former UCTE

However, it is specified that that the first method is considered more future proof as it also takes into account other features as only the peak load.

Some additional guidelines can be derived from legal objectives on FRCE-quality. First of all, some indicators are specified in Article 131(1) of the SOGL:

b. for each LFC block of the CE or Nordic synchronous areas during operation in normal state or alert state in accordance with Article 18(1) and (2), on a monthly basis:

(i) for a data-set containing the average values of the FRCE of the LFC block over time intervals equal to the time to restore frequency:

- *the mean value,*
- *the standard deviation,*
- *the 1-,5-,10-, 90-,95- and 99-percentile;*
- *the number of time intervals in which the average value of the FRCE was outside the Level 1 FRCE range, distinguishing between negative and positive FRCE, and*
- *the number of time intervals in which the average value of the FRCE was outside the Level 2 FRCE range, distinguishing between negative and positive FRCE;*

(ii) for a data-set containing the average values of the FRCE of the LFC block over time intervals with a length of one minute: the number of events on a monthly basis for which the FRCE exceeded 60 % of the reserve capacity on FRR and was not returned to 15 % of the reserve capacity on FRR within the time to restore frequency, distinguishing between negative and positive FRCE;

Note the article 128 of the SOGL also attach legal target parameters to the Level 1 and Level 2 indicators:

3. All TSOs of the CE and Nordic synchronous areas shall endeavour to comply with the following FRCE target parameters for each LFC block of the synchronous area:

(a) the number of time intervals per year outside the Level 1 FRCE range within a time interval equal to the time to restore frequency shall be less than 30 % of the time intervals of the year; and

(b) the number of time intervals per year outside the Level 2 FRCE range within a time interval equal to the time to restore frequency shall be less than 5 % of the time intervals of the year.

It is to be noted that the these criteria are never intended to be used as the basis for dimensioning, but rather as an ex post verification if absolute warning limits are not exceeded, as specified in B-1 of the SAFA:

> *The objective behind the level 1 and level 2 parameters is to provide quality targets for the individual ACE quality of each LFC block. Since it is the responsibility of each TSO in its LFC block to keep ACE as low as possible, the level 1 and level 2 parameters must not be exploited in order to reduce reserves or reserves activation. These parameters should rather be interpreted as an absolute warning limit that shows that quality of ACE is below the required standard and that respective countermeasures have been reported and will be implemented urgently.*

In addition, Article 152 of the SOGL also identifies some 'soft' targets which should be endeavored by TSOs, or may act as a trigger for additional measures.

> *9. The TSOs of a LFC block shall endeavour to avoid FRCEs which last longer than the time to restore frequency.*
>
> *12. If the 1-minute average of the FRCE of a LFC block is above the Level 2 FRCE range at least during the time necessary to restore frequency and where the TSOs of a LFC block do not expect that FRCE will be sufficiently reduced by undertaking the actions in paragraph 15, TSOs shall have the right to require changes in the active power production or consumption of power generating modules and demand units within their respective areas to reduce the FRCE as specified in paragraph 16.*
>
> *13. For the CE and Nordic synchronous areas, where the FRCE of a LFC block exceeds 25 % of the reference incident of the synchronous area for more than 30 consecutive minutes and if the TSOs of that LFC block do not expect to reduce sufficiently the FRCE with the actions taken pursuant to paragraph 15, the TSOs shall require changes in the active power production or consumption of power generating modules and demand units within their respective areas to reduce the FRCE as specified in paragraph 16.*

It is concluded that the legal framework does not provide specific aFRR dimensioning rules as it does with FRR. Also the legal criteria on balancing criteria can only give some ex post indications on reserve capacity shortages but cannot be used as sole objective of aFRR dimensioning. The only objective is that of the aFRR product which is activated to restore the FRCE where temporary deviations are netted or resolved by FCR. It has to be taken into account that a perfect FRCE is not possible due to the activation lead time of aFRR (7.5 minutes and expected to evolve towards 5 minutes) and mFRR (15 minutes and expected to evolve towards 12.5 minutes). **Due to the absence of clear legal requirements on aFRR dimensioning, the proposed dimensioning methodology and proposed reliability level shall need to find trade-off between meeting such minimum thresholds (and avoid over-procurement in general) and meeting their responsibility to cover their FRCE as good as possible and contribute to the European frequency stability.**

2.1.2 Ongoing and upcoming system evolutions

The objective of improvements in aFRR dimensioning is to have a method which can correctly take into account ongoing and future system evolutions. An overview is listed for which attention is given in the development of a new method, and testing in the Proof of Concept.

- **Modifications related to the new aFRR product design :** some modifications to the aFRR product design were implemented by Elia in the course of this study and can have an impact on the dimensioning:

- the evolution towards a 4-hour product with a daily procurement, at least for a part of the balancing capacity[8], facilitates a daily dynamic dimensioning processes such as with mFRR. A dimensioning closer to real time allows to reduce uncertainty and have a more accurate dimensioning reducing aFRR needs in lower risk periods, while increasing in higher risk periods;
- having separate up- and downward products for the 4-hour product facilitates to separately assess reserve capacity needs and should allow to reduce reserve capacity for one if asymmetry in the needs is identified;
- the merit order activation should have no impact on the ACE / FRCE-quality or aFRR dimensioning as aFRR reserve capacity has a full activation time is 7.5 minutes, independently of the volume requested by Elia to be activated by the BSP;
- the mitigation of the limit on activated capacity, through the activation of additional available non-contracted balancing energy bids, can positively impact the ACE / FRCE-quality by activating more aFRR reserve capacity with a faster activation time than mFRR..

- **Balancing energy platforms:** Elia already participates for several years in an imbalance netting platform (IGCC), netting imbalances between LFC blocks before activating aFRR when netting potential and ATC are available. In addition, as from 2022, Elia will participate in the EU balancing energy exchange platforms (MARI for mFRR and PICASSO for aFRR) that will facilitate the activation of balancing energy outside the LFC block upon availability.
    - the IGCC cooperation has proven to have a significant impact on the aFRR activations and balancing quality and evolutions may therefore impact aFRR dimensioning. Releasing the current profile limits for IGCC (maximum allowed import and export) will further increase FRCE-quality and might therefore have a downward effect on required aFRR needs if this is taken into account in the dimensioning (note that until now, IGCC has never been directly accounted in the dimensioning due to the non-guaranteed capacity). Furthermore, the netting opportunities will increase following the interconnection capacity with Germany trough ALEGrO.
    - PICASSO will allow to activate more volumes than locally available, but this will however never be guaranteed.

  Exchange of aFRR balancing capacity and sharing are at this moment too premature to contribute in the analyses.

[8] Note that part of the aFRR balancing capacity will still be procured with a 24-hour symmetric product on D-2. In D-1 six blocks of 4-hour product are procured, separately for up- and downward capacity.

- **Energy market design :** energy markets determine the ability of BRPs to deal with variations of demand and generation trough day-ahead, intra-day markets and might therefore reduce residual LFC block imbalances to be covered by the TSO with aFRR and mFRR;
    - Shorter market resolutions such as 15' minutes in day-ahead and intra-day may increase the ability of BRPs with limited flexibility in their portfolio to balance their portfolio. It will also result in less hour to hour imbalances due to high ramps of the residual load. As the imbalance settlement period is fixed at 15', the effect is mainly expected for FRR but reduced variability of the LFC block imbalances could also affect the aFRR needs.
    - Imbalance settlement impacts the incentive for BRPs to balance their portfolio. Specific measures are implemented to further fortify this incentive (e.g. alpha reinforcing the LFC block imbalance prices in case of large deviations) or tools allowing BRPs to have better estimations of positions and optimize their portfolio (e.g. a tool to estimate the DSO-infeed of individual BRPs). Elia will continue to investigate ways to incentivize and facilitate BRPs to balance their portfolio. As the imbalance settlement period is fixed at 15', the effect is mainly expected for FRR but reduced or increased variability of the LFC block imbalances should impact the aFRR needs as well.
    - Deterministic Frequency Deviations are a phenomenon which results in frequency deviations during particular change of hours in the day with high physical demand variations. Among the identified causes is the fact that the market rules between generation and consumption are based on the exchange of energy blocks of fixed time periods. A dedicated study is conducted in parallel with this study[9]. However the solutions to mitigate the DFD issue is unlikely to have an impact on aFRR needs (although there might be an indirect impact when the aFRR needs are dynamically dimensioned taking into account the time of the day). In fact, additional aFRR volumes will have limited impact to solve DfDs with high rate of change of frequency (RoCoF), therefore can be considered as less effective comparing to other solutions.

- **Energy transition**
    - Increasing RES, including the second wave of offshore wind energy investigated in parallel in a specific study, challenges the BRP portfolio balance through its inherent variability and limited predictability resulting in more residual imbalances. Variations within 15' can therefore impact the aFRR needs which might be expected if BRPs focus on balancing their portfolio on a 15' basis. Offshore is characterized by a higher variability than onshore and photovoltaics. This is due to the highly concentrated location. In a separate study[10], DTU is investigating the effect of variability and limited

[9] The results of this study are foreseen has been consulted on July 1 to August 31, 2020 on **https://www.elia.be/en/public-consultation**

[10] More information on : **https://www.elia.be/en/public-consultation/20200608_public-consultation-on-the-integration-of-additional-offshore-capacity**

predictability of offshore wind power generation. These inputs are used to investigate the effect of offshore on the new method.

- More and more new flexibility providers enter the system. The adequacy and flexibility study of 2019 shows that sufficient flexibility is expected to be installed in the system to deal with fast variations but that it will not be available when needed. Specific reservation mechanisms for BRPs or TSOs remain necessary. While these will contribute to the BRPs' flexibility to balance their portfolio, these are expected to mainly mitigate the impact on FRR but effect can spill-over through aFRR needs when facing less LFC block imbalance variations.

In conclusion, we can say that the new methodology should be robust to some evolutions, in particular the new aFRR product design provides interesting opportunities for close-to-real-time and asymmetric dimensioning to keep aFRR needs as low as possible. On the other hand, increasing renewables, in particular offshore challenge the balancing quality and the impact will be specifically studied in the Proof of Concept. Finally, it should be investigated how IGCC, for which the availability cannot be guaranteed, can be taken into account to reduce aFRR needs. The methodology should also be robust for other market evolutions such as shorter resolution products or increased system flexibility. Preferably, a self-learning method based on historical LFC block imbalance or FRCE quality can take into account the effects of measures on balancing quality of BRPs.

2.1.3 ACE / SI quality

Figure 7 visualizes the evolution of monthly absolute average and standard deviation of the 15' LFC block imbalances, the 15' FRCE / ACE and the 15' Net Regulation Volume (NRV). Table 3 shows yearly statistics, i.e. average, absolute average, standard deviation, and the 1% / 99% percentile for the 15' LFC block imbalances and variations, and the 15' FRCE and variations.

Despite the growth in variable RES, the absolute average levels of the LFC block imbalances has remained relatively stable since 2016, despite a small increase in 2019. However, the standard deviation, an indicator for the variability, already started increasing slightly since 2017. While the first is mainly relevant for the FRR dimensioning, the second is relevant for the aFRR needs and clarifies the increasing aFRR needs since 2017.

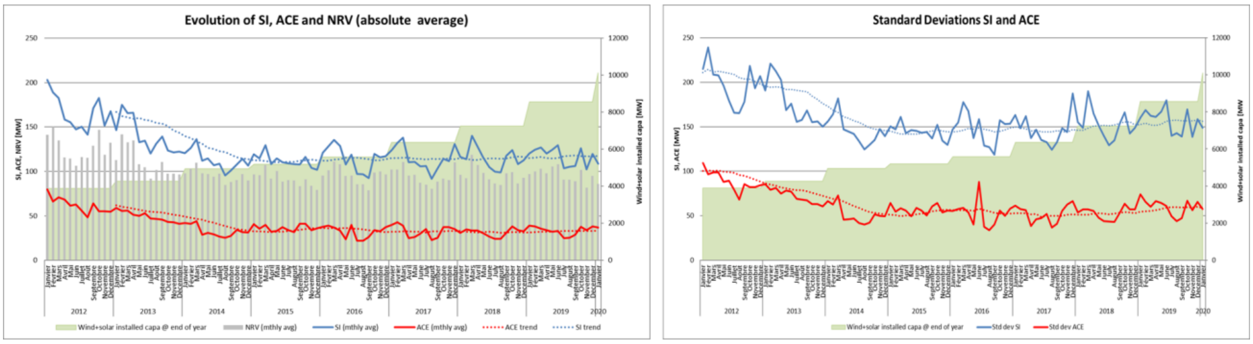


Figure 7: Evolution of the monthly average (left) and standard deviation (right) SI, ACE/FRCE and NRV

Table 3 : Key statistics of the LFC block imbalances and FRCE between 2015 and 2019

[MW]	LFC block imbalances					LFC block imbalance variations				
	2015	**2016**	**2017**	**2018**	**2019**	**2015**	**2016**	**2017**	**2018**	**2019**
AVG	4.0	16.7	23.0	1.5	4.8	0.0	0.0	0.0	0.0	0.0
MAE	112.0	114.8	114.8	115.0	117.4	93.7	91.4	95.2	99.6	100.0
ST.DEV	146.6	151.1	151.4	153.5	158.3	124.7	122.9	127.9	134.6	136.4
P1	-356.2	-384.0	-375.8	-401.6	-404.2	-342.8	-340.9	-347.1	-364.4	-374.2
P99	376.1	391.3	400.1	409.4	414.2	307.8	315.1	327.2	362.8	358.4
[MW]	FRCE					FRCE variations				
	2015	**2016**	**2017**	**2018**	**2019**	**2015**	**2016**	**2017**	**2018**	**2019**
AVG	-2.4	-0.6	0.8	-1.9	0.3	0.0	0.0	0.0	0.0	0.0
MAE	94.9	10.1	211.9	1.0	10.0	41.9	8.0	194.9	1.0	34.0
ST.DEV	53.9	45.0	46.4	47.9	49.8	71.5	56.2	59.5	63.3	63.1
P1	-179.4	-157.8	-152.4	-166.6	-165.7	-203.6	-178.2	-190.5	-195.7	-201.2
P99	150.7	142.5	151.3	150.1	159.1	206.2	174.3	182.5	197.5	194.2

In 2018, Elia started monitoring the FRCE-quality with new indicators specified in Article 131 of the SOGL. As explained in Section 4.1, this monitoring is conducted in dedicated documents. Table 4 shows with FRCE-indicators that the Level 1 and Level 2 target are fulfilled in 2018 and 2019 (note that the target for level 1 and level 2 is to be compared with the sum of the number of times where the FRCE exceeds the positive and negative level 1 and level 2). In terms of the absolute legal limit, Elia is at 24% for level 1 and 35% for level 2 limit. Nevertheless, when comparing this performance with other countries in Continental Europe (Figure 8), we can see that Elia shows an average performance compared to other TSOs.

Table 4 : FRCE-indicators compliant with article 131 of the SOGL for 2018 and 2019

FRCE-indicators	2018	2019
The mean value	-1.9	0.3
The standard deviation	47.9	49.8
1-percentile	-166.6	-165.7
5-percentile	-75.6	-69.9
10-percentile	-40.0	-35.2
90-percentile	32.9	36.4
95-percentile	63.0	67.9
99-percentile	150.1	159.1

FRCE-indicators	2018	2019	Target
Number of time intervals: average FRCE > Level 1 positive	1059	1211	10512
Number of time intervals: average FRCE < Level 1 negative	1417	1250	
Number of time intervals: average FRCE > Level 2 positive	262	300	1752
Number of time intervals: average FRCE < Level 2 negative	352	345	

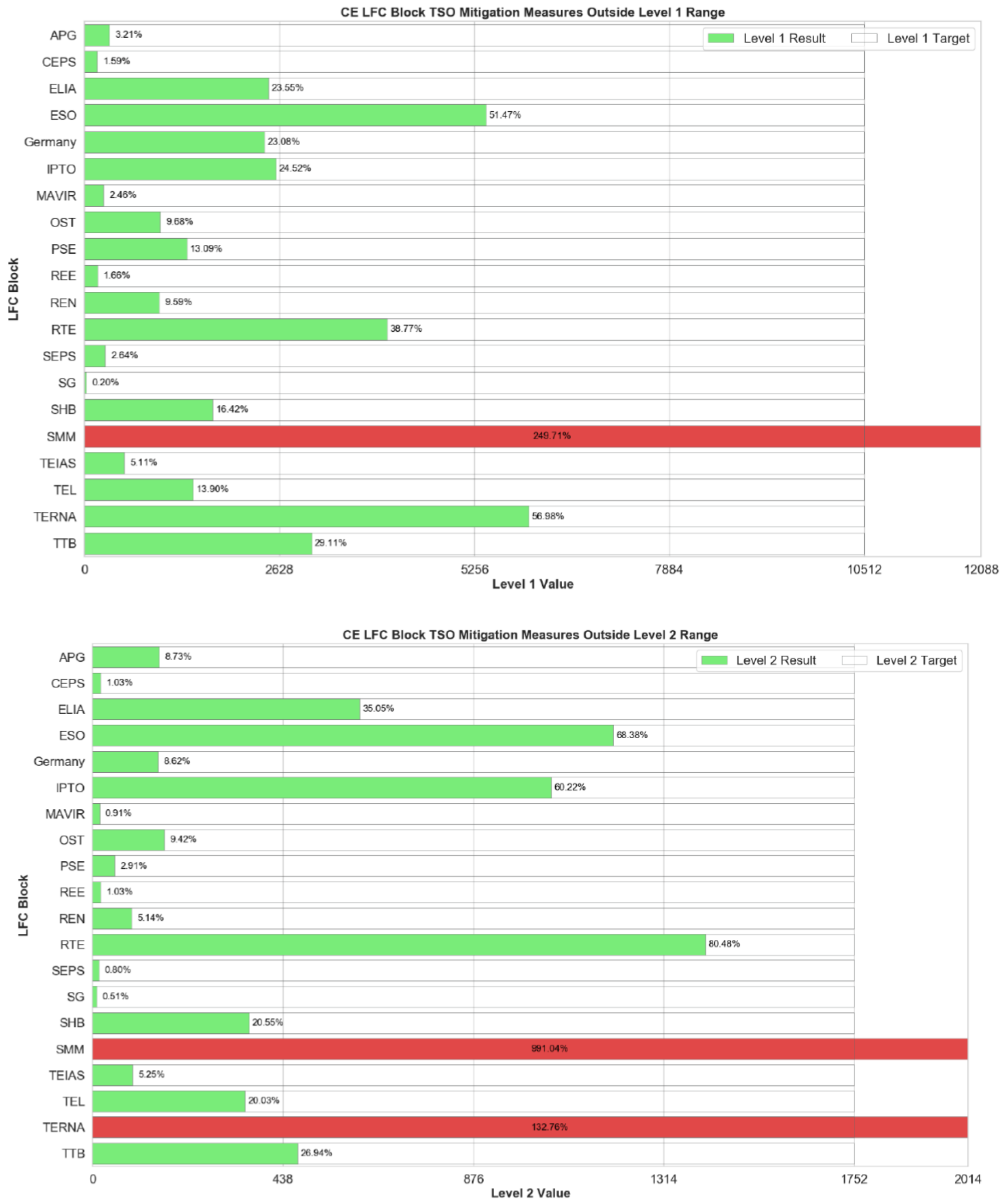


Figure 8: Level 1 and Level 2 performance in 2018 (ENTSO-E LFC block monitor 2018)

Figure 9 shows the aFRR procured in neighboring counties as registered in the ENTSO-E transparency platform for December 2019. Of course, absolute figures are difficult to compare due to the size of the LFC block but the empirical noise method of ENTSOe (Section 2.1) is useful to make such comparison: in this method, the aFRR needs are solely based on the peak load of a LFC block. In can be seen that Elia already procures little aFRR in comparison with its neighbors.

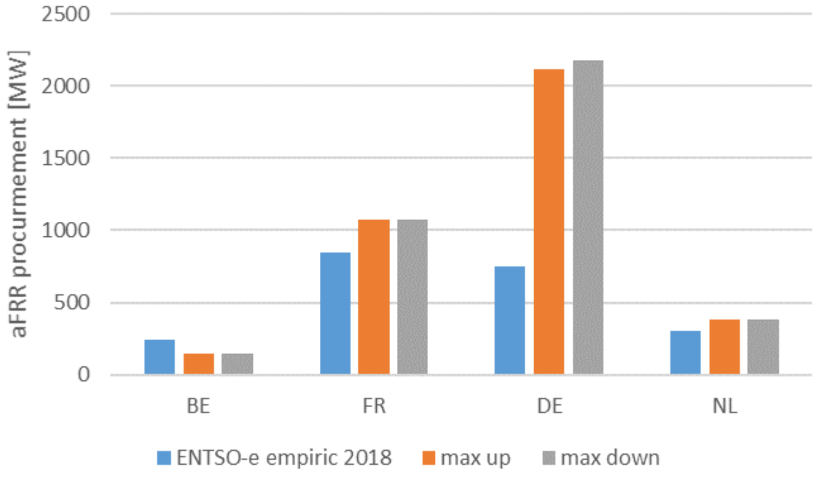


Figure 9 – aFRR procured compared to the aFRR needs in the empirical noise method

In conclusion, Elia has a good FRCE-quality which is shown by its average performance in terms of the legal minimum criteria. This is not only achieved by its available aFRR means, but also the availability of IGCC (although the availability is not guaranteed) and the dispatch procedures. It must however be noted that a small increasing trend is observed since 2017 in the 15' variations which was already translated in increasing aFRR needs under the current method. In addition, Elia procures little aFRR in comparison with its neighboring counties.

Of course, Belgium as a small well-interconnected country, benefits from the availability of IGCC to manage its FRCE. Nevertheless, it has little margin for average aFRR means reductions as the available aFRR means procured are already relatively low compared to other counties and FRCE-management of individual LFC blocks is important to maintain stable frequency in the European synchronous zone.

2.2 Methodology design options

2.2.1 Assessment of the current methodology

Considering the evolutions described in previous chapters, the current dimensioning methodology deserves a review and provides some opportunities for further improvement. In particular:

- **Dimensioning process**

The expected LFC block imbalance variations result from an upscaling of historic imbalances to the expected values in the future. This upscaling is based on the forecast errors of the incremental capacity installed of wind and photovoltaics while forecast tool and LFC block imbalance improvements are taken into account by means of extrapolation factors (which are uncertain). Currently, the dimensioning is conducted on a yearly basis, based on a LFC block imbalance time series of 2-years.

The new aFRR product design allows to consider a closer to real time calculation and might even allow to take into account system features for the next day. This should allow to reduce uncertainty and therefore avoid the use of extrapolation factors.

- **Dimensioning variable**

The system imbalance variations are determined as the absolute power variation between two periods of 15 minutes. The 15' values are covered by FRR, while the 15' variations are assumed to be covered by aFRR. In addition the dimensioning variable does not take into account asymmetry for up- and downward dimensioning.

Foreign examples and literature point out the importance of intra-15' variations, and with the availability of 1' data, it might be useful to investigate if an increased resolution can bring the results closer to the system physics. A separate up- and downward sizing also makes sense when facilitating up- and downward products.

- **Dimensioning accuracy**

The aFRR needs are determined to cover 79% of absolute variations of imbalance. The percentile is determined based on acceptable historic FRCE-quality (based on Elia's experience and ex post analyses). However, with the integration of new balancing criteria in SOGL, this reliability level and approach may be subject for revision.

2.2.2 Benchmark

An analysis is conducted of available information concerning the dimensioning methodology for aFRR of Elia's neighboring TSOs, i.e. The Netherlands, France, Germany and Great-Britain. Also Ireland and Nordics are added following their particular interests concerning the renewable developments in the country, and the development of a regional dimensioning approach. Figure 10 provides a summary overview.

- **The Netherlands**

The volume of FRR is based on historical imbalance values and on the size of a reference incident, or in other words the largest imbalance that can result from an instantaneous change of active power of a single power generation module, single demand facility or single HVDC interconnector, or from a tripping of an AC line within the LFC block.

Until 2019, the subdivision of the dimensioning of FRR into aFRR and mFRR is conducted according to the 'empirical noise method' in ENTSOE SAFA. The policy describes the deterministic method to determine the minimum required volume of aFRR based on the historical peak load of the Netherlands for the same semester of the year. However, TenneT may raise this minimum with an additional volume if required due to low FRCE-quality.

Since 2019 (2^{nd} semester), a new method is implemented based on the probabilistic method described in SAFA where the aFRR is dimensioned on the 1% percentile of the 1-minute average and the 10-minute average of the LFC block imbalances which are increased with the activated FRR and imbalance netting.

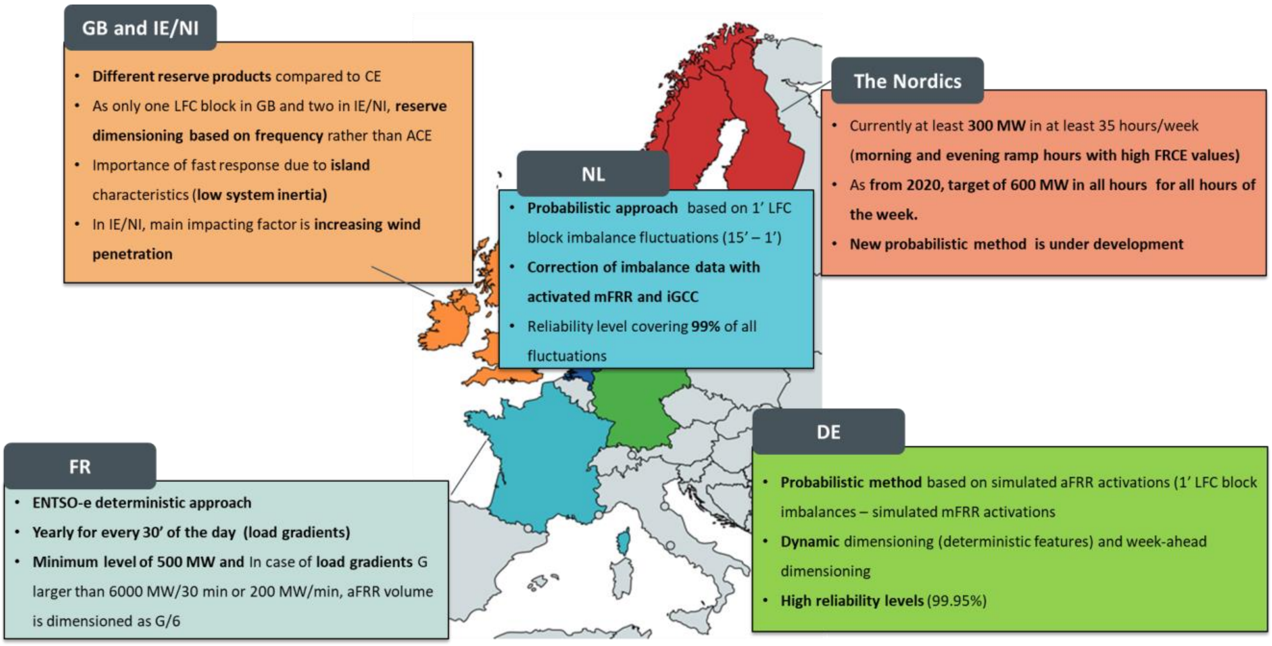


Figure 10- Overview of aFRR dimensioning with other TSOs

- **Germany**

Germany has a common methodology for the four LFC area's for which the general principles are described in the LFC block agreement approved by the NRA. Until 2019, FRR dimensioning was based on a 'static' quarter-yearly dimensioning using 15' LFC block imbalances for representative quarter-hours covering 99.95% of all imbalances. In contrast, the aFRR needs were calculated based on a statistical 'noise', i.e. fluctuations within the 15' and the ramps of planned exchanges with other LFC blocks.

The new methodology is based on a week-ahead dynamic dimensioning taking into account the dimensioning incident and a probabilistic method based on historic 1' LFC block imbalances up to 3 year (filtered from forced outages). Note that in Germany, the probabilistic outcome is always larger as the dimensioning incident. The probabilistic methodology is a dynamic method where reserves are determined week-ahead with projections up to a year. In the current implementation, only deterministic parameters such as time of day and day of week, month and season are therefore taken into account. A machine learning clustering method is used to determine periods with similar LFC block imbalances. The probability distribution curve of these LFC block imbalances are convoluted with the forced outages.

The split between aFRR and mFRR is conducted by developing a new time series of simulated mFRR activation based on the historical 1' LFC block imbalances. With the technical characteristics of the mFRR product with minimum action duration and activation lead times, the remaining demand for aFRR activations can be derived. A probability distribution of these simulated aFRR activations is made for the same cluster (after convolution with the forced outages) and a reliability level is set to cover 99.9% of all simulated aFRR activations.

- **France**

France determines the FRR needs based on a specific model comparing the expected LFC block imbalances with the available capacity in the system. The FRR needs are calculated with a dynamic dimensioning methodology covering 99% of the expected LFC block imbalances. Note that this is a continuous process.

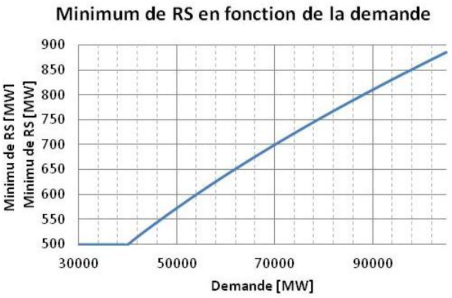
For aFRR, there is a deterministic aFRR calculation where on yearly basis, the aFRR is determined for each period of 30' in a day in function of the demand and the demand gradients. The method is based on the deterministic method specified in Continental Europe Operation Handbook Policy 1. However, during high demand gradients, another formula is used to have more aFRR during these periods and a minimum level of 500 MW is set. Note that there are discussion ongoing on modifications of this methodology.

:

- si G < 6000 MW/1/2h (ou 200 MW/mn alors

  PR = max (500 ; $(\sqrt{10 * D + 22500} - 150)$)

- si G ≥ 6000 MW/1/2h (ou 200 MW/mn), alors **PR = G / 6**



où

- D est la valeur de la demande globale (consommation + échanges) la plus élevée sur la période considérée
- G est le gradient de la demande (exprimé en MW par ½ heure)

Figure 11: aFRR dimensioning methodology (RTE 2020)

- **Nordic**

In the Nordics, a new FRR dimensioning methodology is currently under development and it might therefore be a case for inspiration. This will be based on a common methodology for the four LFC area's (new methodology is currently under development as the existing methodology is not compliant with SOGL).

Until now, each TSO is dimensioning mFRR needs based on dimensioning incident in its area (but allowing reserve capacity sharing). In addition, 300 MW of aFRR needs are contracted during hours in morning and evening hours where the frequency variations are most challenging (i.e. max 35 hours a week). Note that the TSOs expect that future challenges will require more automated balancing. The Nordic TSOs will increase the number of aFRR contracting hours to all hours. After that, the aFRR volume will gradually be increased from today's level of 300 MW to a tentative target volume of 600MW for all hours of the week.

A new methodology for FRR dimensioning is being developed and specific details are not available yet. However, the basis is to have one common dimensioning where normal imbalances are determined based on the needs for each area, while taking into account cross-zonal capacity to optimize reserve requirements over the different LFC areas. aFRR needs are then determined as part of the total FRR needs. In addition each TSO is responsible to determine the reserve capacity requirements to handle their dimensioning incident.

- **Ireland and Great Britain**

Despite the high penetration of RES in more stringent island conditions, it is difficult to draw lessons from Great-Britain and Ireland as product structure is fundamentally different and focusing on frequency management rather than FRCE-management. EirGrid and SONI for instance do not operate an aFRR process, all FRR in the load frequency control block is mFRR. The dimensioning is conducted based on the largest positive and negative dimensioning incident.

Also NGESO does not operate an aFRR process. In Great Britain, frequency response is referred to in terms of Primary, Secondary and some specific products. Primary and secondary response are automatically provided and dimensioned according to the calculation based on a probabilistic and deterministic approach.

The (fast) reserves are manually applied and needs to cover the largest loss. The overall requirement are calculated using a statistical analysis of historic non-wind plant losses and demand forecasting errors and is set with the objective that there is no more than a 1 in 365 chance (or alternatively a 99.7% confidence).

2.2.3 Literature

In general, it is recognized that **deterministic methodologies** became too simplistic to correctly represent the increasing complexity of power systems with increasing variable renewable generation. Most scientific articles propose approaches that are based on **probabilistic methodologies**, where the main differentiating factors are the reliability level (going from 99.0% to 99.9% until 99.995%), the considered historical input data and the quantity (aFRR or mFRR) derived by difference from total FRR. Probabilistic methods are undoubtedly going to be broadly adopted with the entry into force of European Network Codes (SOGL Article 157).

It is generally acknowledged that aFRR is sized based on the distribution of variations inside the settlement period and the imbalance ramps between consecutive settlement periods, whereas mFRR is based on the distribution of the average prediction error over the settlement period. This reasoning is for instance followed in (De Vos, 2012)[11] where a probabilistic approach with a 99% reliability level is developed based on wind power time series.

(Mauer, 2009)[12] presents the Graf-Haubrich approach, which was used until recently in Germany. This method calculates the necessary control reserve considering all important drivers for power imbalances like power plant outages, load variations and forecast error. Each of the selected drivers of the imbalances is modelled separately to estimate the probabilistic behavior of the consequent power imbalance. The probability density function of the total imbalance is then calculated using a convolution of the algorithm on these separate probabilistic imbalance contributions, as illustrated in Figure 12. An important assumption of this approach is that the combined imbalance drivers (load oscillations,

[11] De Vos, K., Morbee, J., Driesen J. and Belmans, R. (2013) "Impact of wind power on sizing and allocation of reserve requirements", IET Renewable Power Generation (7)1

[12] Maurer, C., Krahl, S., Weber, H. (2009) "Dimensioning of secondary and tertiary control reserve by probabilistic methods", European Transactions of Electrical Power, 2009 (19)

load forecast error, plant outage, intermittent generation error) are independent. This is required to make the convolution step sound from a mathematical point of view. Note that 0.1% deficit and overrun probabilities are considered.

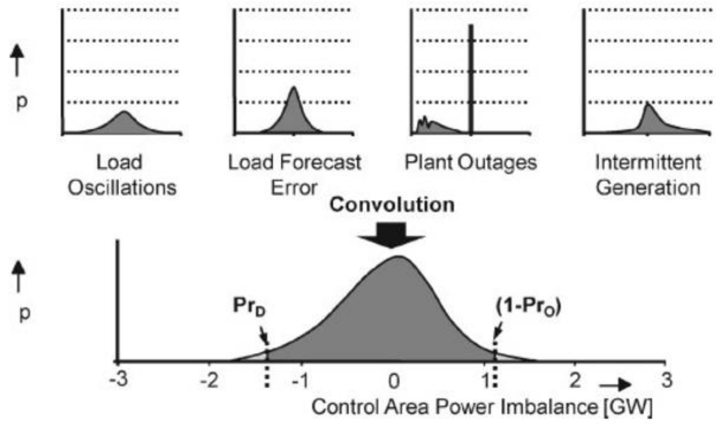


Figure 12: Illustration of the Graf-Haubrich method

The German case is often brought forward to highlight a clear need for dynamic sizing due to the increasing generation of renewable generation. (Jost, 2015a)[13] introduced a dynamic sizing approach based on the method developed by (Mauer, 2009). This dynamic approach allows to size reserves on day-ahead for a product length of 1 hour. Each component of the imbalance is modelled separately using kernel density estimators. An important difference with the Graf-Haubrich method is that the RES forecast error is separated into wind and photovoltaic errors. The total reserve need is estimated by convolving error distributions. The secondary reserve need is computed by convolving these same error distributions scaled by a factor 0.33.

Still in the family of probabilistic methods (Jost 2015b)[14] apply quantile regression techniques with artificial neural networks to forecast the needed reserve capacity required to reach a given reliability level. In this approach, the sizing variable (or target variable) is the 15 minutes LFC block imbalance. In the German context, they identify the following features as relevant for neural network: load (and its gradient), solar and wind generation (and their gradient), residual load (and its gradient), temperature, time of day, day of the week. (Jost 2016)[15] improves on this by (i) correcting the bias of the trained neural network, (ii) tackling the allocation of the total FRR between aFRR and mFRR, and (iii) analyzing the impact of product length, see Figure 13. Such allocation is done by applying the method separately on

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[13] Jost, D., Speckmann, M., Sandau, F, Swinn, R. (2015a) „A new method for day-ahead sizing of control reserve in Germany under a 100% renewable energy source scenario“ Electric Power System Research (119)

[14] Jost, D., Braun, A., Fritz, R. (2015b) Dynamic dimensioning of frequency restoration reserve capacity based on quantile regression, International conference on the European Energy Market, Lisbon

[15] Jost, D., Braun. A., Fritz R, Otterson, S. (2016) Dynamic sizing of automatic and manual Frequency Restoration Reserves for different product lengths, International conference on the European Energy Market, Porto

historical aFRR needs (estimated as aFRR activation corrected with IGCC exchanges) for aFRR dimensioning and on LFC block imbalances for FRR dimensioning

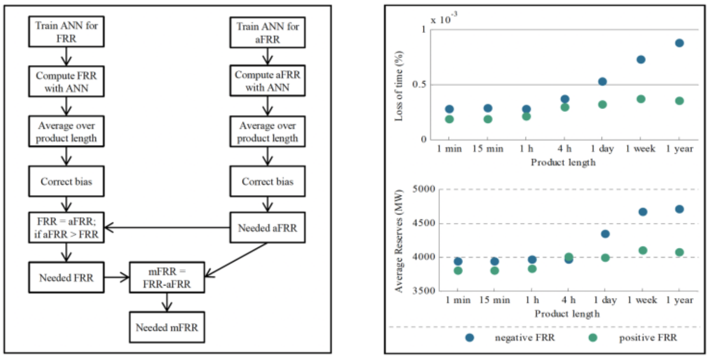

Figure 13- Jost et al. use quantile regression to compute needed aFRR and mFRR volumes.

(Morin, 2019)[16] presents a dimensioning method called OPIUM, based on manual clustering and on specific modelling of each of the imbalance components (i.e. kernel density estimator for wind error, gaussian estimation for other components). Two important conclusions are put forward. First, the risk level (reliability target) chosen by the TSO plays a major role in the aFRR requirement. Secondly, the massive development of RES will lead to a significant rise of aFRR needs.

In (Kippelt, 2013)[17] and (Breuer, 2013)[18], the probabilistic approach is combined with a market simulator tool (i.e. unit commitment) to determine a prognosis of the hourly unit dispatch in order to refine the necessary distributions of the imbalance drivers. Indeed, scientific literature often uses **simulation models** that co-optimizes energy and reserves together. Although this makes sense to represent central dispatch systems, or to investigate the impact of renewables or other aspects on the energy and reserve needs, it is less relevant for developing European dimensioning methods.

2.2.4 Conclusions

Based on the analyses if this section, an exhaustive list is put forward Figure 14 representing all possible different methodology design options found in the literature, benchmark and the regulatory framework complemented with options put forward by Elia. These options are classified in five categories which are walked through in the next section in order to make a selection of feasible integrated methods.

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[16] Morin, J., Prime, G., Wang, Y. (2019) “Probabilistic estimation of the aFRR requirement in the future European power system with high RES penetration” Wind Integration Workshop 2019

[17] Kippelt, S., Schlüter, T., Rehtanz C. (2013) Flexible Dimensioning of Control Reserve for Future Energy Scenarios, IEEE Grenoble Conference

[18] Breuer, C. Engelhardt, C., Moser, A. (2013) “Expectation-based Reserve Capacity Dimensioning in Power Systems with an Increasing Intermittent Feed-in”, International Conference on the European Energy Market, Stockholm

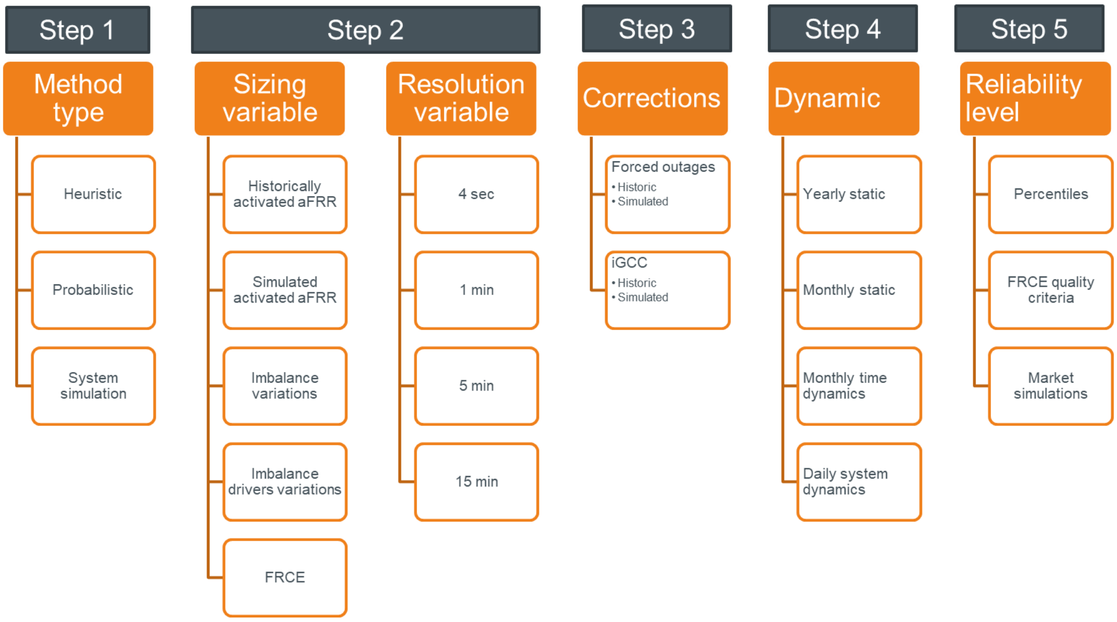


Figure 14: overview of methodology design options

In **step 1** the method type is selected being deterministic, probabilistic or simulation-based as discussed in the literature (Section 2.2.3). In **step 2**, the sizing variable and its resolution are determined which is the main variable on which the reserves are determined as found in the benchmark with other TSOs (Section 2.2.2) and complemented with Elia's insights analyzing the objectives and the legal framework. In the current method, this would be covering a certain percentage of all LFC block imbalance variations (sizing variable) with a resolution of 15' (resolution).

Step 3 considers possible corrections of this variable to explicitly include or exclude the impact of forced outages of large generation units and to take into account IGCC or not reducing the aFRR needs. **Step 4** will then determine if a yearly or monthly to daily dynamic dimensioning will be considered based on the determined potential. Finally, in **Step 5**, the method to determine the reliability level is specified, i.e. the percentage of LFC block imbalance variations to be covered in the current method.

3. Selection of aFRR methodologies

The previous section showed an exhaustive list of all design options found in the literature, best practices of other TSOs and Elia's own analyses. These are categorized in five steps which are walked through to find two feasible integrated methods.

3.1 Selection of aFRR dimensioning methods

3.1.1 Step 1: choosing the methodology type

Three types of methods are put forward in Figure 15. **Heuristic methods** are typically on an iteration based on past performance, or dimensioning aFRR needs as a function of a single system feature (e.g. the peak load of a LFC block). Such methods are still put forward in SAFA as an alternative to the probabilistic method, i.e. the empirical noise method, and is still the basis of aFRR dimensioning in some countries (e.g. France). It is concluded in the literature that these methods cannot grasp the complexity of power system with increasing renewable energy and would for Elia's LFC block even be a step back from the current approaches in use. Also in France and the Netherlands, the methods are currently under revision. For these reasons, heuristic methods are not further investigated in this study.

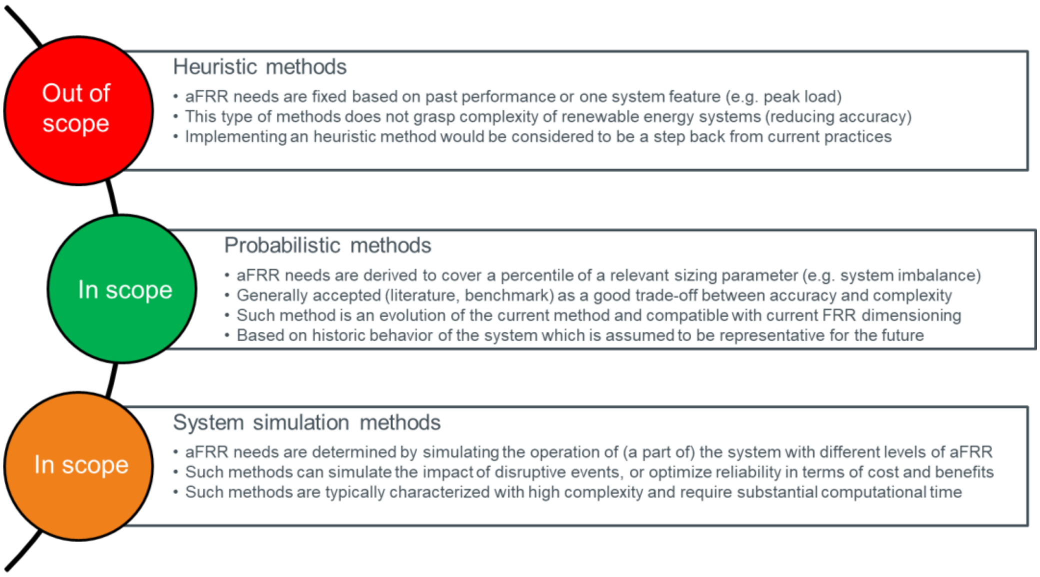


Figure 15: overview of methodology types

Probabilistic methods are considered as a good compromise between accuracy and complexity. In this type of methods, aFRR needs are typically dimensioned to cover a certain percentile of a relevant sizing parameter. Elia's current aFRR dimensioning method is an example of a probabilistic method sizing aFRR needs to cover 79% of historic 15' LFC block imbalance variations. Elia's current FRR dimensioning method is another example. Furthermore, it is also the basis of the recommended approach in SAFA where aFRR is dimensioned based on 1' LFC block imbalance fluctuations. Also in Germany, a probabilistic method is implemented for a while and The Netherlands and Nordics are currently implementing probabilistic methods. These methods will therefore be the main focus of this study. However these methods are based on the assumption that historic data is representative for the future and are therefore less suitable to take into account disruptive events.

Finally **system simulation methods** are considered. In academic literature, some methods are proposed where dimensioning of aFRR needs are integrated in system simulations determining energy and reserve capacity needs together. However, these methods are not suitable with the current European framework where energy and reserve capacity are procured separately. Instead, Elia investigated a particular approach based on its LFC-controller where aFRR needs are determined by simulating the historic activation of aFRR with different aFRR means and assessing the impact on FRCE-quality. Such methods may be useful to simulate the impact of disruptive events or optimize reliability in terms of cost and benefits but are however characterized by high complexity in terms of data requirements and computational efforts and go at the cost of transparency. Although this method exhibits some serious disadvantages, and no examples could be found with other TSOs, such a method is investigated in Section 3.2.

3.1.2 Step 2: determining the sizing variable and resolution

Choosing the sizing variable is the core of a probabilistic method. As shown in Figure 16, this determines the aFRR needs to cover a certain percentage of occurrences, e.g. to cover 79% of historic absolute LFC block imbalance variations in Elia's current methodology.

- **Sizing variable**

First possible approach would be to dimension on the **FRCE,** i.e. to cover for instance a certain percentage of all historic or expected FRCE. In any case, the starting point would be to use historic 15' to 4" data, which might be scaled based to take into account system evolutions. This sizing variable is found to be difficult to use in a probabilistic method as sizing on the result of the aFRR activations will lead to circular calculations where higher FRCE would result in higher aFRR needs that would in its turn result in lower FRCE. These oscillations may not result in a stable aFRR need.

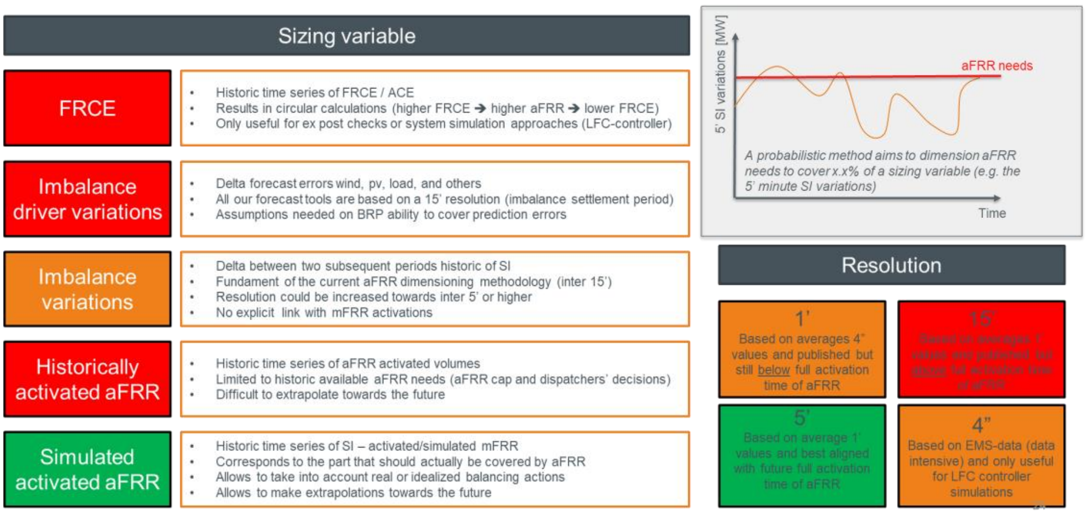


Figure 16: Overview of sizing variables and resolution options

A possibility could be found in simulation methods which can immediately take into account the activation of the dimensioned aFRR. A new method based on emulating Elia's LFC-controller is investigated in Section 3.3 that determines iteratively the effect of different levels of aFRR on FRCE-criteria. Note that no examples could be found where aFRR needs are dimensioned on the FRCE.

Another possibility is considered based on **individual imbalance drivers**, i.e. the variations of wind power, photovoltaic and demand forecast errors. However, it can never be certain that all imbalance drivers are captured. Furthermore, Elia's forecast tools are currently only based on 15' forecasts resolution (in line with BRP forecasts that are based on the imbalance settlement period of 15') which is a serious constraint for the implementation of this method. Finally, additional assumptions would be needed concerning the ability of BRPs to deal with these prediction error variations as Elia should only cover residual LFC block imbalances. Therefore, it is more suitable to dimension directly on these **residual LFC block imbalance variations.** This is the basis of the current methodology (i.e. the absolute difference in power between two periods of 15') and FRR dimensioning. A possible improvement could be to refine the resolution to 5' or 1'. This type of probabilistic method is also proposed by the ENSTOE SAFA, and implemented by The Netherlands, although variations are determined as the difference between the 1' and 15' LFC block imbalances. The main disadvantage is that it makes no explicit relation with the activation characteristics of aFRR and mFRR and assumes that all fast variations can be covered by aFRR.

An improvement could therefore be to take into account these characteristics. An approach on **historically activated aFRR** is abandoned as very dependent on historic conditions, i.e. dispatch behavior and product design, but also on the historically dimensioned aFRR reserve capacity. Another approach implemented in Germany is to use **simulated activated aFRR** where mFRR activations are subtracted from the LFC block imbalances. By means of simulating mFRR activations (considering full activation time and even possibly other product or dispatch characteristics) abstraction can be made from historic product design or dispatch behavior. It allows to estimate aFRR needs based on a perfect mFRR activation strategy.

- **Sizing variable resolution**

Next step consists in choosing the resolution of the sizing variable. The current resolution of **15 minutes** does not match well with the full activation time of aFRR which is currently specified at 7.5 minutes and foreseen to further evolve to 5 minutes. Therefore, a **5 minute** or even a **1 minute** approach would be more adequate to take into account intra-15 minute variations. However, a problem with using 1 minute data is that these fluctuations will never be covered by the aFRR product which can only fully react in 7.5 to 5 minutes.

The highest possible resolution is the 4 second power measurement data which is the output of Elia's EMS. Note that all other data result from averages of this EMS data. This resolution is however discarded for probabilistic approaches as this would be too data intensive without providing additional value considering the full activation time of aFRR. However, this resolution is useful when investigating the simulations of aFRR activations based on Elia's LFC controller in Section 3.3.

3.1.3 Step 3: facilitating the contribution of Forced Outages and IGCC

In this section, it is investigated if corrections should be made to the sizing variable:

- **Forced Outages of power plants or relevant HVDC-interconnectors**

Although aFRR will contribute to restoring the FRCE during forced outage events of large generation units and relevant HVDC interconnectors, in this case Nemo Link, it is concluded that this is not an objective for aFRR dimensioning. Indeed, FCR is dimensioned to deal with regional dimensioning incident in Continental Europe, as well as the FRR dimensioning for which the mFRR will deal with the forced outage. It is observed that the German LFC block takes into account forced outages (statistically with a duration of 15') but in a small country like Belgium, this would result in very high aFRR needs. It is therefore proposed to **remove periods with forced outages from the dataset (as in the current methodology).**

- **IGCC**

It is already explained that IGCC largely reduces the activation volumes of aFRR. On the other hand, it is very difficult to model since it relies on a complex optimization over different LFC blocks and since the interconnection capacity is not guaranteed as it can already have been used for long-term, day-ahead, intra-day and soon the regional balancing platforms and reserve sharing.

Nevertheless, given the large impact of IGCC, it is proposed to subtract (part of) IGCC activated volumes from the LFC block imbalances. In a dynamic probabilistic methodology with sufficient high reliability level, the risk of taking IGCC into account might be acceptable as results will be adapted if IGCC becomes less available. An alternative is to simulate available IGCC based on historic observations.

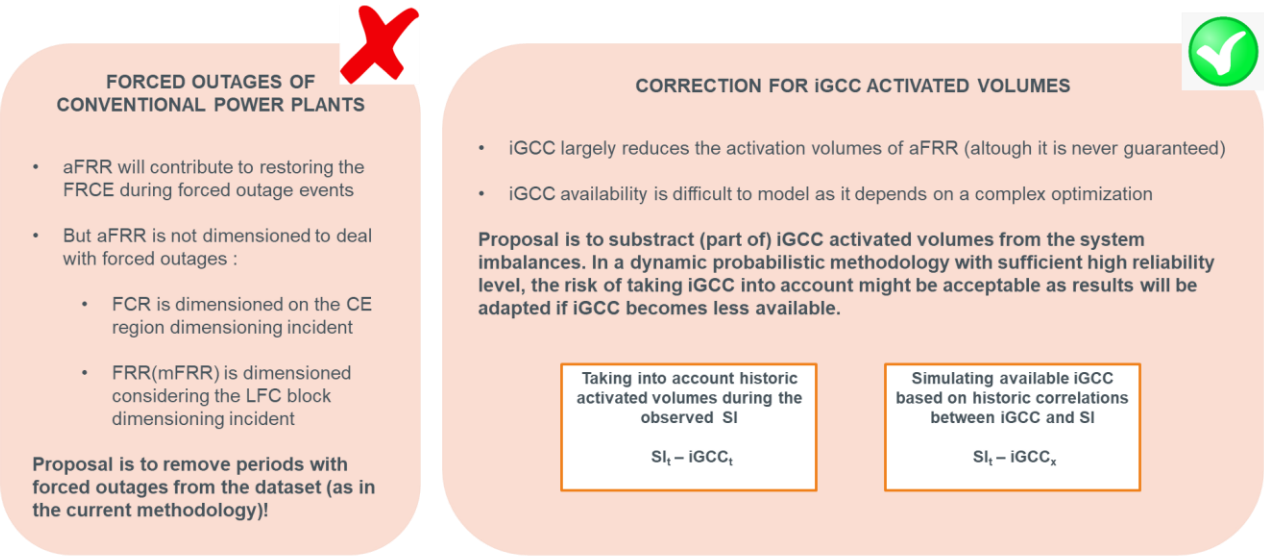


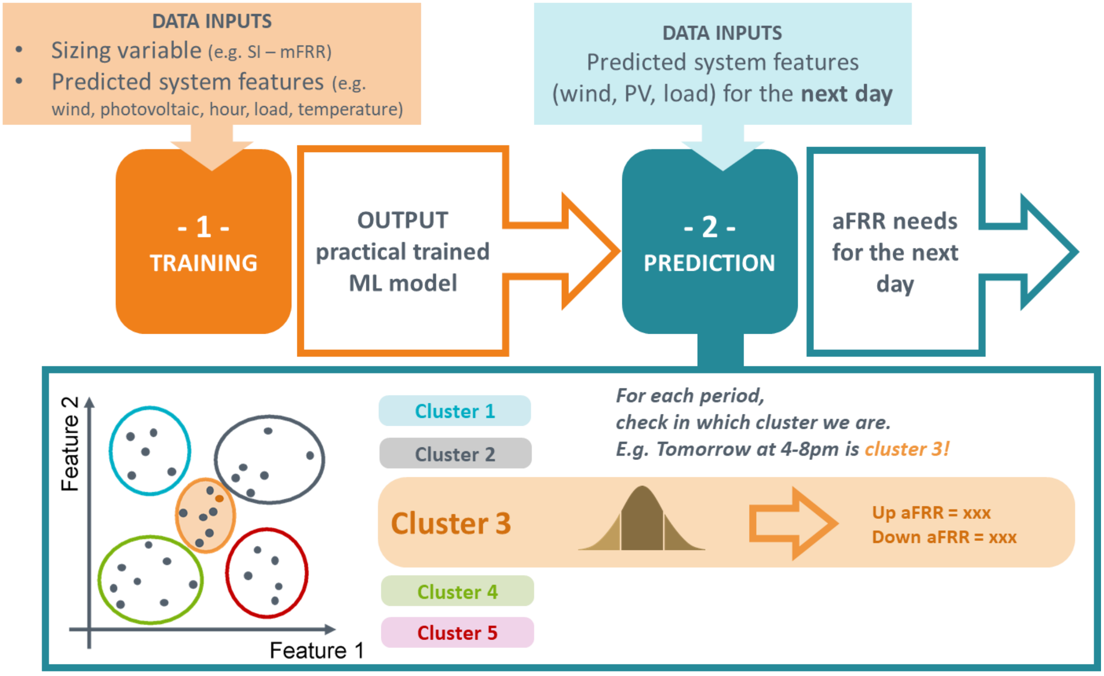
Figure 17: Overview of corrections on the sizing variable

3.1.4 Step 4: capturing dynamic potential

It is already explained that the new aFRR product with a (partial) daily procurement on a 4 hour resolution allows to dimension closer to real time. This would avoid upscaling the sizing variable to take into account incremental renewable capacity or other system evolutions impacting the system imbalance.

This method can be based on the FRR dimensioning methodology where machine algorithms are trained to learn correlations between system features (e.g. predicted renewable production, load and time of day) and the sizing variable, e.g; the simulated aFRR activations. Such model would be trained (e.g. monthly) based on 2 years of historic data and this could for instance rely on a clustering algorithm (as the K-MEANS method) although other methods could also be considered.

In day-ahead, expected system conditions (represented by day-ahead predicted features) could be used to determine clusters of similar historic observations. In each cluster, the distribution of the sizing variable could be derived in order to determine the corresponding aFRR needs. Note that the training step (e.g. monthly performed) could be used to determine a minimum aFRR need to still facilitate a partial procurement in D-2. The remaining (dynamic) part, would then be procured in D-1.



3.1.5 Step 5: selecting the reliability level

Final step is to select a proper reliability level. While it might be justified to cover all observations of the selected sizing variable, i.e. the simulated aFRR activations or the LFC block imbalance variations, this would result is a high impact of very specific events, or even data issues (e.g. outliers). This would translate into oversized aFRR needs and potentially highly volatile results. To avoid this, a reliability level of 99.0 % is proposed, i.e. covering 99.0 percentiles of simulated aFRR activations or LFC block imbalance variations. Such high reliability level aligns best with the objectives of FRR (covering the FRCE in 15 minutes) while specific events may be covered with exceptional FRCE-measures specified in the LFC BOA. Furthermore, this reliability level is consistent with the reliability level used in the FRR dimensioning method, in line with the legal provisions foreseen in the SOGL. Finally, a high percentile is justified in a methodology already taking into account IGCC (which is never guaranteed) and implementing a dynamic dimensioning method (adapting aFRR needs to the expected risk).

Further analysis with the LFC controller simulations did also not result in a solid basis to specify lower reliability levels. Main reason is that no adequate legal criteria can be used. The level 1 and level 2 targets discussed earlier can only be used as absolute warning limits and no other legal targets exist. Other potential targets have been investigated by Elia with the LFC controller simulations but results were inconclusive. Ideally, the reliability level is set as a trade-off between cost and benefits but no representative benefit of ACE quality can currently be identified due to socialization under TSOs.

3.2 Feasible approach 1: an improved probabilistic method

Based on the above mentioned analyses, a **first integrated method** that can be proposed is an improvement of the current probabilistic method. The proposed sizing variable is the simulated aFRR activations (compared to the LFC block imbalance variations in the current method) with an intra-15' minute resolution. The activated IGCC is taken into account to reduce aFRR needs, in contrast to the forced outages which are not supposed to impact the aFRR needs. Note that the method to determine the sizing variable and the impact of IGCC will be calibrated in the Proof of Concept.

A dynamic dimensioning approach is proposed consistent with the FRR dimensioning method. Although some dynamic potential is expected, this has to be confirmed in the proof of concept. Finally, the proposed method aims to achieve a fixed reliability level of 99.0%.

3.2.1 Calibration of sizing variable and resolution

It is explained that the proposed sizing variable is based on simulating the aFRR activations by subtracting simulated mFRR activations and IGCC activations from the historic LFC block imbalances. The activation of mFRR can be simulated in different ways as shown in Figure 18, and two approaches are put forward:

- A first approach could be to simulate an **optimal mFRR activation**, assuming a perfect foresight on the LFC block imbalances for the upcoming 15'. Such approach would, for each period within in a quarter-hour (e.g. 5' period) activate mFRR if there are only positive or only negative LFC block imbalances. The activated mFRR would then for instance be the average LFC block imbalances during that quarter-hour. Further calibration of the assumptions and parameters is possible but essentially, this approach is in line with a philosophy that aFRR needs are to be minimized because their faster activation speed results in a procurement cost which is higher (or at least equal) than mFRR.
- An alternative approach could be to simulate a **dispatch based mFRR activation**, assuming realistic dispatch behavior where dispatch activates mFRR without having foresight on the future LFC block imbalances. Such approach would for each period (e.g. of 5') within a quarter-hour activate mFRR if the LFC block imbalance in the two previous periods is higher than 50 MW (or lower than – 50 MW). The activated mFRR equals for instance the average LFC block imbalances during these previous periods.

Exact parameterization of these methods will be further investigated in the Proof of Concept. Results will be compared to the 1', 5' and 15' LFC block imbalance variations.

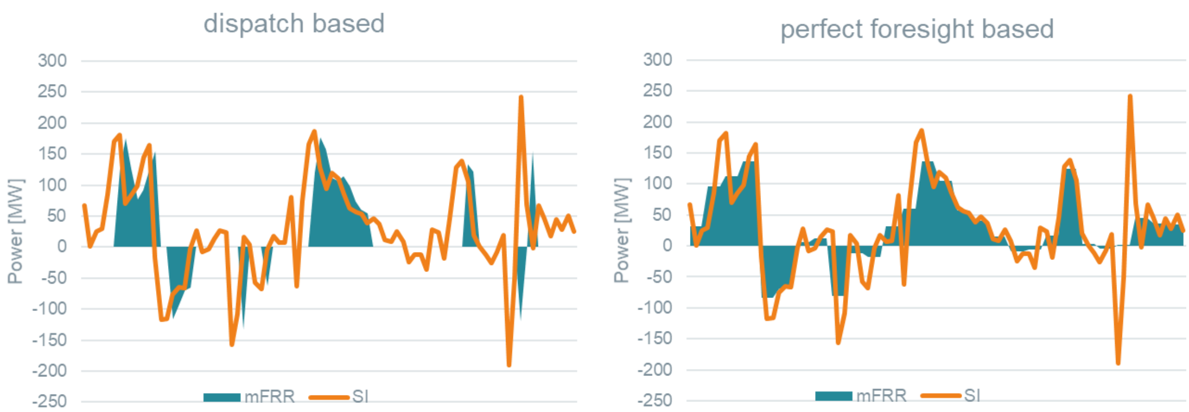
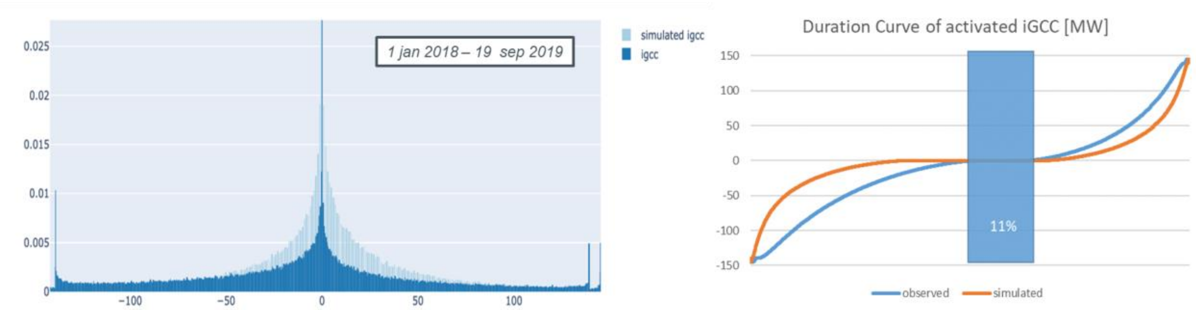


Figure 18: Illustration of simulated mFRR activations in function of the LFC block imbalance

3.2.2 Calibration of IGCC participation

It is explained that the proposed sizing variable can be corrected with IGCC. In a first approach, the sizing variable could be considered to subtract historic activated IGCC from the historic LFC block imbalances before compensating with the impact of mFRR activations. For large enough datasets, historical IGCC activations are sufficiently representative of the full IGCC distribution. Furthermore, this approach would allow to directly capture the correlation between the IGCC activations and the LFC block imbalances. As an alternative, to take into account the non-guaranteed availability of IGCC, or correct for future evolutions, one can consider to use a simulated-based approach.



However, as the available IGCC is difficult to predict, this would be based on a sampling. This considers a random drawing from the distribution of historic IGCC activations taking into account the probability that such volume would be available. Such approach would allow to adapt the distribution to consider limited availability or to take into account future evolutions such as for instance releasing the activated volume caps.

3.2.3 Ball-park figures

To get some feeling with results when selecting methodologies for further investigation, some preliminary calculations are conducted on a limited data set of **January 1, 2018 until September 19, 2019 containing 1' LFC block imbalance data and 1' IGCC activated volumes** as published on the website of Elia. This input data will be updated in the Proof of Concept, while the results will be further investigated towards dynamic potential (machine learning algorithm and calibration), as well as the calculation of the sizing variable (dispatch based or optimal) and resolution (5 minutes or even a higher resolution). The values presented serve only to provide an order of magnitude of different implementation choices of the improved probabilistic method.

The results are shown in Table 5 where for every time series, the 1% and 99% percentile are reported. Results are set of against the current method which would result in capacities of around 360 - 370 MW with those percentiles. These high values compared to the actual aFRR needs are explained by the reliability level which is set much lower in practice, i.e. at 79%. It can be seen that the increasing resolution towards 5' and including IGCC would bring the capacities closer to current aFRR needs (i.e. 145 MW).

Table 5: ballpark figures based on calculations of 1%;99%-percentiles on different sizing variables

Dataset: 1 jan 2018 – 19 sep 2019	Without iGCC		With iGCC	
[MW]	up	down	up	down
5' Simulated activated aFRR (dispatch based)	281	275	239	229
5' Simulated activated aFRR (optimal)	191	204	147	139
5' Imbalance variations	237	231	195	188
15' Imbalance variations	370	360	314	298

Ballpark current volumes
High volumes
Very high volumes

When analyzing the potential results of the proposed sizing variable based on aFRR simulations, it can be seen that the way the mFRR activations are modelled have a large effect on the results. **Dispatch based methods** where mFRR is activated if the LFC block imbalance exceeds a positive (negative) value of 50 MW, and up to a level of the average LFC block imbalance in that quarter-hour, seem to result in relatively high capacities, even when IGCC is taken into account.

For approaches where a **perfect foresight or optimal activation** is assumed, capacities can even be brought back to current levels. In the results of Table 5, mFRR is assumed to be activated if there are only positive (negative) LFC block imbalances in a quarter-hour and up to levels equal to the average LFC block imbalance in that quarter-hour.

3.3 Feasible approach 2: LFC-controller simulations

A potential simulation-based method that is investigated is based on Elia's LFC controller. In reality the LFC controller determines the aFRR requested volumes considering a filtered value of the ACE which is forwarded to a PI controller that determines the requested volumes to be activated for each sampling time period of 4 seconds (t). In order to reproduce the historic scenarios, under different assumptions, the previously activated reserves need to be subtracted and control activation have to be calculated again under new assumptions (e.g. lower activation lead times, different available reserve capacity,...).

The controller automatically determines the required activations based on measuring the ACE open loop (ACEol) of the previous period (t-1). The ACE open loop is the ACE after taking into account the manual mFRR activations. The activated IGCC is also taken into account when determining the required aFRR activations. Note that the objective of the controller is to bring the FRCE back to zero as soon as possible taking into account a resolution of 4". Such simulation-based method considers ramping constraints of aFRR (5min / 7.5min to reach full requested activation) and constraints on the maximum available aFRR means for activation (e.g. 145 MW or higher).

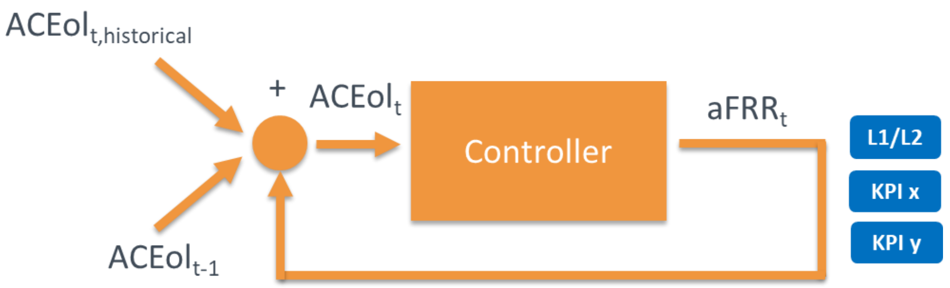


Figure 19: Visual representation of the LFC controller

By means of simulations with this controller, Elia is able to conduct simulations based on historic time series of the ACE, IGCC and the mFRR activations and simulate the resulting ACE after these activations under different scenarios and considering the assumption that market parties' reaction and available IGCC remain equivalent. This allows to assess the impact of different capacities of available aFRR on the final results. This includes the Level 1 and Level 2 FRCE parameters as specified in SOGL, but also potentially other key performance indicators such as maximum FRCE and the duration of a high FRCE.

I has already been noted that this approach is not suitable to simulate large variations of available aFRR capacity from the historic levels as this might neglect the impact of activated mFRR and other market reactions. Also, this approach results in high computational complexity due to intensive data needs and the 'iterative' approach. Though, it might be considered as an additional tool to conduct 'ad hoc' simulations of different available aFRR volumes on the FRCE quality.

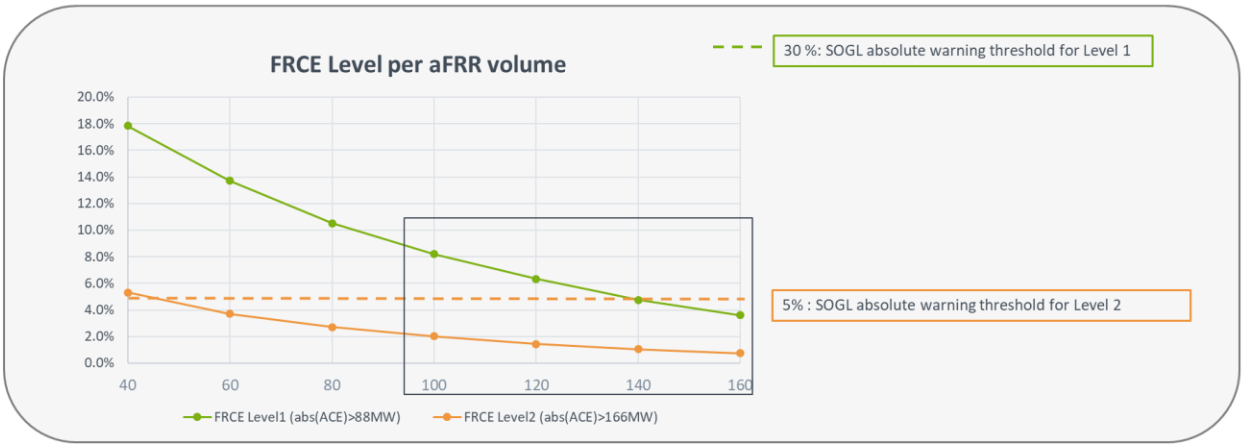


Figure 20: Impact of different aFRR availability on the Level 1 and Level 2 criteria

Unfortunately, this method did not present meaningful results. It is found that almost any level of aFRR needs can be justified when only looking at the legal criteria. Following such a recommendation would be considered as unacceptable by other European TSOs as these Level 1 and Level 2 criteria have to be considered as absolute warning limits and not as sizing targets. An investigation is conducted based on the impact on other indicators such as percentiles (% of the time ACE exceeds a certain threshold) or duration (maximum duration of an ACE above a certain threshold) but these are found to be inconclusive by lack of a legal criteria.

3.4 Proposed approach for the Proof of Concept

Based on the analyses presented in this section, an improved probabilistic method based on simulated aFRR activations with a 5' will be further investigated. LFC block imbalances seems to be a good trade-off between complexity and accuracy, improving the current method in an evolutive way. Furthermore, such method is consistent with the current FRR dimensioning process using similar data and applying similar algorithms.

The method starts from 1' LFC block imbalance data which will be corrected with simulated 'optimal' or 'rule based' mFRR activations. The LFC block imbalances will also exclude periods with forced outages of large generation units or unexpected outages of Nemo Link. Finally, the LFC block imbalances will be corrected to take into account (a part of) the activated IGCC. Indeed, despite that this capacity is not guaranteed, IGCC plays an important role in the FRCE-quality and the activation of aFRR.

It is proposed to maintain a 99% reliability level, aligned with other dimensioning processes. This high reliability level is justified by considering IGCC activations and optimal mFRR activations. A dynamic potential is discovered and needs to be further investigated in the Proof of Concept. The dynamic sizing process can be aligned and integrated in the FRR dimensioning process.

4. Recommendations for the Proof of Concept

4.1 Introduction

The Proof of Concept will further investigate the improved probabilistic method towards the dynamic behavior and robustness towards future system evolutions. Based on the analyses presented in the previous sections, this method is considered as the best candidate for replacing the current methodology:

- it dimensions aFRR reserve capacity in line with the system physics, i.e. on intra-qh simulated aFRR activations, allowing to directly relate required aFRR reserve capacity to the technical characteristics of the activation of the slower mFRR reserve capacity. In addition, one of the main advantages is to consider variations within the quarter-hour, closer to the full activation time of aFRR;
- it minimizes the aFRR needs by considering the activations of IGCC and by being suitable with a dynamic approach, while improving reliability by fixing the reliability level to cover 99.0% of the expected aFRR activations;
- it implements a 'relatively' transparent methodology which improves the current method in an 'evolutive' way and is consistent with the current FRR dimensioning approach.

Figure 21 represents a typical dynamic dimensioning process in three steps. First, the specification of the algorithms and optimal parametrization, as will be specified in the regulatory framework, i.e. LFC BOA. Secondly, a monthly training of algorithms based on historical observations of LFC block imbalances set against predicted system features such as wind and photovoltaic generation, and thirdly the day-ahead prediction of the imbalance risks and the corresponding aFRR needs. Note that this set-up does not exclude the possibility to procure a part of the balancing capacity before day-ahead.

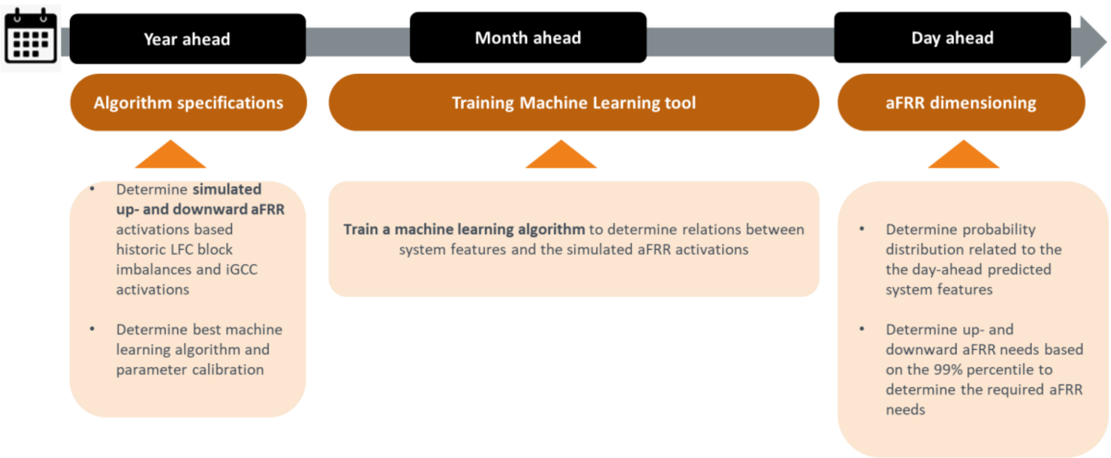


Figure 21: dynamic dimensioning process of aFRR needs

4.2 Determining the sizing variable

The simulated aFRR activations is based on Elia's dataset of 1' historic time series of the historic LFC block imbalances taking into account the historical activated IGCC-volumes. This data is also publicly available on Elia's website. By means of the average, this resolution can be brought to 5’. However, several sensitivities will be conducted on the definition of the sizing variable.

- **Optimal versus dispatch-based methods;**
- **5’ versus 1’ resolution;**
- **Historic activated IGCC or simulation-based activated IGCC.**

Note that specific attention will be put on defining the assumptions on the optimal and dispatch-based methods (e.g. reaction lead times, activated mFRR volumes). The results will be benchmarked with the current method based on LFC block imbalance variations.

In order to allow to train the machine learning models, this first dataset is compared to a second dataset containing the day-ahead predicted features (e.g. wind, photovoltaic generation, demand, time of day, temperature or other). There will be started from the same database used in the dynamic FRR dimensioning but this does not exclude taking into account other system features if this would improve performance of the dynamic dimensioning.

4.3 Determining the dynamic potential

A dynamic approach allows to dimension higher aFRR needs when facing higher risk of large aFRR activations while reducing the average aFRR by means of lowering the aFRR needs during low risk periods. The effect on the average aFRR needs as well as the variations will be quantitatively determined in the Proof of Concept.

Based on the training databases as the FRR dimensioning, and the monthly training process, the dynamic potential will be assessed in a generic and efficient way using a typical clustering algorithm, i.e. similar to the KMEANS algorithm in the FRR dimensioning (cf. LFC BOA). This allows to determine the average aFRR needs as well as the variations for the different sizing variables being investigated. **Based on the results, a subset of sizing variables (features) will be further improved and parameters settings will be fine-tuned. This approach will be compared in a quantitative way with a selection of other categories of algorithms which fit the requirements of the problem, e.g. regression, continuous neighboring, neural networks may be considered to further extract dynamic potential.**

The dynamic aFRR needs will be computed with a resolution of 4 hours aligned with the aFRR procurement granularity. A monthly training and a database going back two years in time will be considered, aligned with the FRR dimensioning method. The static current results will serve as benchmark for estimating the average aFRR volume reduction obtained by the different dynamic methods. Among others, minimum/maximum and average metrics, as well as the duration curves of the aFRR needs will be analyzed. The dynamic aFRR needs will also be compared to the historic simulated aFRR activations (i.e. sizing variable) to compare the observed reliability level with the targeted reliability.

4.4 Determining projections towards 2028

The improved probabilistic methodology will be used to estimate the aFRR needs evolution between 2020 and 2028, with intermediate years 2023 and 2026, for both static and dynamic approaches. Results will be compared to those of the current aFRR methodology.

This assessment will require to project LFC block imbalances and system features towards the future. Projections of LFC block imbalances will rely on projected forecast errors related to projections of incremental wind power and photovoltaics installed capacity. This approach is typically used to extrapolate historic prediction risks towards the future. Projections are taken from Elia's latest adequacy and flexibility study published in 2019. Note that forecast errors are initially projected on 15 minutes granularity. Where available, resolution of the prediction errors is refined to 5' (i.e. for offshore generation) whereas other profiles will be based on interpolations of 15' data.

To test the dynamic potential in the Proof of Concept, the two-year dataset is categorized into two parts, one part will be used to train the algorithm, while another part will be used to test the impact on the daily calculation.

5. Conclusions

Based on desktop research (literature, benchmark, analyses), a list of methodology objectives and possible methodology design options is composed. **Elia proposes to further investigate the improved probabilistic method in a proof of concept (**Figure 22**).**

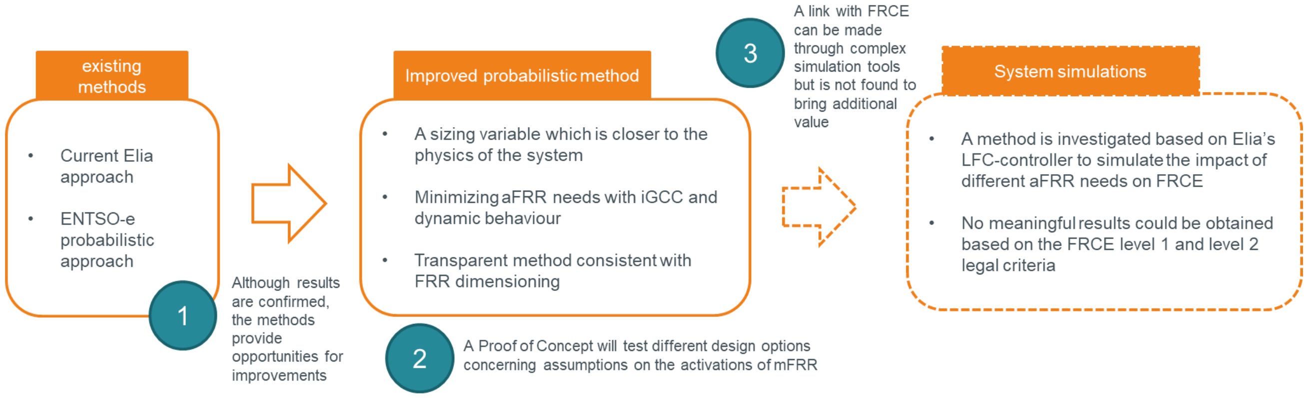


Figure 22: Overview of conclusions of the 1st part of the study

- It is found that **existing methods** such as the current Elia approach, or even the recommended methods by ENTSO-E are found to have drawbacks providing opportunities for improvement. Mainly, the robustness towards new aFRR product design and increasing renewable capacity installed is challenged.
- Analysis of possible design options puts forward that **improving the probabilistic method** seems the best way forward. The probabilistic method is a good tradeoff between complexity and transparency, and is also consistent with the FRR dimensioning method. Such method has also recently been implemented in Germany. Proposed improvements are to bring the sizing variable more in line with the system physics (simulate aFRR activations, take into account IGCC) while implementing a dynamic methodology to reduce average aFRR needs.
- An in depth investigation towards **simulation models** shows that simulations with Elia's LFC controller allows to investigate the effect of different minimum aFRR needs on the FRCE. This allows to assess the performance concerning FRCE-quality objectives. Results show that no meaningful results were obtained when assessing the impact on the minimum criteria, Level 1 and Level 2 criteria. It is concluded that the method presents an increased complexity without providing additional value to the aFRR dimensioning process.

The Proof of Concept will further investigate the implementation of the aFRR simulations, i.e. determining the assumptions on the activations of mFRR, and the participation of IGCC. Also the algorithms for the dynamic method and sizing variable resolution, i.e. 5 minutes or 1 minute will be investigated.

Projections will be made, and benchmarked with the actual method, towards 2028. This allows to analyze the robustness of the method towards the increasing renewable penetration, including the 2nd wave of offshore. **Stakeholders were invited to provide their suggestions and feedback for the Proof of Concept in a public consultation from June 2, 2020 to July 2, 2020. An implementation planning is drafter in second part of the study, together with the conclusions and recommendations following the Proof of Concept.**

PART 2: RESULTS OF THE PROOF OF CONCEPT, RECOMMENDATIONS AND PLANNING FOR IMPLEMENTATION

This part of the study is conducted after a public consultation on the recommended methodologies for the Proof of Concept. It contains three main sections:

- a **Section 6** investigating the impact of different methodology design options and parameter settings for the proposed methods where aFRR simulations are based on simulated mFRR activations and IGCC. The results are benchmarked against an improved version of the current method based on LFC block imbalance variations. The different options shall be qualitatively and quantitatively assessed in terms of one fixed value, i.e. a 'static' aFRR needs (i.e. not taking into account any relations with the expected system conditions) ;

- a **Section 7** investigating the aFRR needs in a dynamic dimensioning methodology where the 'dynamic' aFRR needs can vary in function of predicted system conditions. A lot of attention is put towards the selection of appropriate machine learning algorithms ;

- a **Section 8** investigating the robustness of the dynamic aFRR needs towards increasing renewable generation. Estimations are conducted towards 2028 taking into account the increase of variable renewable generation, including a 2^{nd} wave of offshore wind power installed.

The analyses in these three sections allow to select and put forward one recommended method for the implementation. These recommendations are discussed in a separate section, together with the implementation planning proposed by Elia (**Section 9**). All calculations in this proof of concept are conducted by N-SIDE, an independent company specialized in innovative decision-aid solutions based on state-of-the-art advanced analytics and optimization methods.

Note that a specific document is published on the website of Elia answering all comments received in the **public consultation** while explaining how the remarks have been taken into account in this part of the study (or why they could not be taken into account). The suggestions did impact the Proof of Concept, but did not require modifications of Part 1 of the study. Section 1 to Section 5 of the report therefore contain no substantial modifications or updates compared to the version published on June 2, 2020.

6. Calibrating the sizing variable

A method has been put forward where the aFRR needs are dimensioned to **cover 99.0% of all simulated aFRR activations**. This section discusses the calibration of the parameters to determine the sizing variable, i.e. the aFRR simulated activations. As shown in the main formula in Figure 23, it is calculated for every period *'t'* by subtracting the relevant IGCC activations and simulated mFRR activations from the LFC block imbalance of the same period.

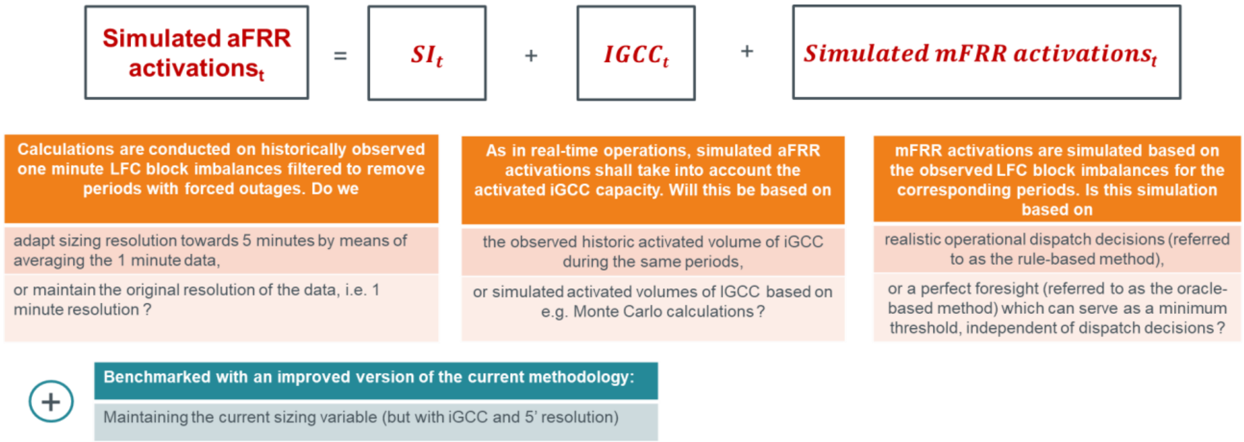


Figure 23: Calculation of the sizing variable "simulated aFRR activations" for every period t and analyzed methodology design options. Note that a positive (negative) LFC block imbalance (SI) refers to an excess (shortage) while a positive (negative) IGCC , simulated mFRR activation and aFRR activation refers to an upward (downward) activation

The simulated mFRR activations are determined on the LFC block imbalances by means of two variations further investigated in Section 6.1, together with analyses of the parameter settings. The approach to take into account IGCC is analyzed in Section 6.2, while the resolution of the sizing variable is discussed in Section 6.3.

6.1 Determining the sizing variable

Two variations are tested to assess the simulated aFRR needs based on a:

- time series of simulated aFRR activations based on historic LFC block imbalances, IGCC and perfect forecast mFRR activations as if the LFC block imbalances were perfectly known in advance ;

- time series of simulated aFRR activations based on historic LFC block imbalances, IGCC and dispatch-based mFRR activations based on previous LFC block imbalances via pre-defined activation rules ;

which are compared with a benchmark method based on an improved version of the current dimensioning methodology where the sizing variable is based on LFC block imbalance variations. The improvements include increasing the resolution from 15' to 5' and correcting the LFC block imbalances with IGCC before determining the variations.

6.1.1 aFRR simulations with dispatch-based mFRR activations

The philosophy of the dispatch-based method is to simulate the mFRR activations based **on realistic dispatch operations**. As shown in the formula in Figure 24 (left), several parameters impact this simulation such as the activation threshold (i.e. the average LFC block imbalance over the periods preceding the period for which the mFRR activations are simulated) and the lead time (i.e. number of 5' periods preceding the period for which the mFRR activations are simulated) over which the level of LFC block imbalances are assessed.

Dispatch-based approach:

If $avg_{t-1;t-r;}(SI) > T$
$mFRR_t = avg_{t-1;t-r}(SI)$
Else 0

T = activation threshold [MW]
r = lead time (number of 5' periods)

		aFRR needs [MW]	
r	T	UP	DOWN
3	100	370	376
1	100	259	240
1	50	252	238
FORECAST		245	227

Figure 24 : Calculation of the aFRR needs covering 99% of the simulated aFRR needs, based on the dispatch-based method and sensitivities (in MW) with historical data for 2019-2020, including the use of an LFC block imbalance prediction (FORECAST)

The results of several sensitivities in Figure 24 (right) show that these parameters have a substantial impact on the results. An initial realistic setting of the activation threshold is set at 100 MW, together with a lead time of 15' (r=3) which means the mFRR is assumed to be activated if the average LFC block imbalances is higher than 100 MW over the previous three periods of 5' and the activate volume is assumed to be equal to the average over the same period. These parameters would be resulting in an up- and downward FRR needs of 370 MW and 376 MW, respectively.

It is found that the aFRR needs decrease with a lower activation threshold and lower lead time. For example, when setting the threshold at 50 MW and the resolution at 5', the aFRR needs are reduced towards 252 MW and 238 MW for respectively up- and downward aFRR needs (while also causing frequent counter-activations between aFRR and mFRR as an activation of mFRR has to be activated for at least 15 minutes). The assessment if such parameters would also be suitable in real-time dispatch operations falls outside the scope of this study and the objective of these sensitivities is only to assess the impact of such on the results of aFRR dimensioning. Other sensitivities using the minimum or maximum values, instead of the average, increase the aFRR needs. Note that the amount of parameters to be calibrated is seen as a disadvantage of the methods as it will result in complex discussions, and can even result in arbitrary choices. In addition, it will be difficult to separate the discussions between dimensioning, and the actual dispatch operations.

It is also observed that the results are substantially higher compared to the aFRR needs which are found with the current methodology, i.e. 151 MW for both up- and downward direction. The main reasons is that in the dispatch-based dimensioning methodology (1) IGCC is not taken into account in the simulations of the mFRR activations (as mFRR activations are currently activated solely on the LFC block imbalance being justified by the uncertainty on its availability on the moment of activation) and (2) because such method results in counter-activations having mFRR activated when the LFC block imbalance is reducing or changing direction. However, as the current aFRR needs already provide satisfying FRCE quality (and are *a fortiori* sufficient to meet the FRCE target parameters specified in Article 128(3) of the SOGL), it is difficult to justify a substantial increase of the aFRR needs.

Additional efforts were conducted to investigate the impact if using forecasted LFC block imbalance instead of historic ones. It is found to further reduce the aFRR needs towards 245 MW and 227 MW for respectively up- and downward aFRR needs. An auto-regressive function is made assuming that the mFRR is activated based on a linear regression of the LFC block imbalance of the three previous 5' periods (a longer horizon did not result in significant correlations anymore):

- mFRR activated = $-1 * (SI)_{t-1} + 0.1 * (SI)_{t-2} - 0.01 * (SI)_{t-3} - 3.5$

6.1.2 aFRR simulations with oracle-based mFRR activations

The oracle-based approach is named based on the assumption of having a **perfect forecast of LFC block imbalances** when simulating the mFRR activations. For this reason, very limited choices are to be made concerning setting the parameters. The method is implemented by means of the simple formula depicted in Figure 25 (left), depicted together with the results in Figure 25 (right). The amount of periods on which the mFRR activations are calculated is fixed at 3, i.e. at 15 minutes, i.e. the minimum activation time of mFRR. The method finds a result of 151 MW and 145 MW for respectively up- and downward aFRR needs.

Oracle-based approach

$mFRR_{t;t+2} = avg_{t;t+2}(SI)$ with t = 1,4,7,…

	aFRR needs [MW]	
	UP	DOWN
SI	151	145

Figure 25: Calculation of the aFRR needs covering 99% of the simulated aFRR needs, based on the oracle-based method and sensitivities (in MW) with historical data for 2019-2020

Note that the aFRR needs obtained with this method confirm the results of the current methodology, and will therefore also attain a similar FRCE quality as today. Being simple and having no parameters to optimize, this method avoids intertwining discussions between dispatch operations and dimensioning, which is considered a disadvantage of the dispatch-based method. It is however a fact that this method is based on an optimistic assumption and therefore sets minimum aFRR needs, with which the dispatcher should then ensure the best FRCE quality possible.

For such method aiming to keep the aFRR needs as low as possible, it is therefore particularly important to monitor the compliancy with Article 157(2)b of the SOGL, i.e. that the method respects at the very least the FRCE target parameters as specified in Article 128 of the SOGL. The FRCE target parameters in Elia's LFC block will be evaluated yearly and any breach thereof will trigger a revision of dimensioning methodology (or the real-time dispatch of Elia's balancing reserves if this is more relevant).

This method allows Elia to minimize the aFRR needs on an assumption of perfect information. Despite that forecast tools are expected to obtain better and better performance, this will probably never be reality. Nevertheless, taking into account the actual cost of aFRR and mFRR capacity, it is justified to minimize the aFRR / mFRR ratio in the FRR dimensioning (and thus procurement), at least as long as acceptable FRCE quality can be attained. As this is currently achieved with similar aFRR capacity, and the objective of this study is not to question the adequacy of the current FRCE quality, the resulting aFRR needs are considered acceptable. Also note that the methodology is combined with an elevated reliability level, as well as a dynamic dimensioning adapting the needs to the risks of the system, which both aim at avoiding an over-procurement of aFRR reserves. **For these reasons, this method will be put forward by Elia as recommended design option.**

6.1.3 Benchmark method : LFC block imbalance variations

Finally, a benchmark method is put forward based on an improved version of the methodology currently in place. This method, as explained in the first part of the study is based on LFC block imbalance variations over two subsequent periods. In this improved version, the resolution is increased from 15' to 5' and also IGCC is taken into account before calculating the variations. The method is implemented by means of the simple formula depicted in Figure 26 (left), depicted together with the results (Figure 26, right). The advantage of this formula is, similar to the previous section, that there are no parameters to calibrate. Calculations result in an aFRR needs of 235 MW and 226 MW for respectively up- and downward aFRR needs. As with the dispatch-based methods (see section 6.1.1), the aFRR needs are elevated compared to current levels which already allow to obtain acceptable FRCE quality. The results are therefore difficult to justify.

SI variations

$$varSI_{t;t-1} = (SI\text{-}iGCC)_t - (SI\text{-}iGCC)_{t-1}$$

	aFRR needs [MW]	
	UP	DOWN
SI variations	235	226

Figure 26: Calculation of the aFRR needs covering 99% of the remaining LFC block imbalance variations after IGCC activations (in MW) with historical data for 2019-2020

In addition, despite that this method is simple and looks intuitive, the LFC Block imbalances corrected with IGCC do not relate well with the real dispatch of aFRR. The reason for this is illustrated with two examples in Figure 28 where the aFRR activations (for which the sign is inversed for graphical purposes) are plotted together with the LFC block imbalances and the LFC block imbalance variations (for this example with an available capacity of 145 MW and a full activation time of 7.5 minutes and no observed mFRR activations) is not activated in the same direction as the LFC block imbalance variations sizing variable. Indeed, the dimensioning method would assume that a positive (i.e. excess energy) but declining LFC block imbalance would already result in an upward activation, while in practice, there can still be an elevated LFC block imbalance to be covered with downward aFRR activations (Figure 28 right). In contrast to the simulated aFRR methods, which explicitly take into account the mFRR activations, LFC block variations are more difficult to relate to dispatch operations.

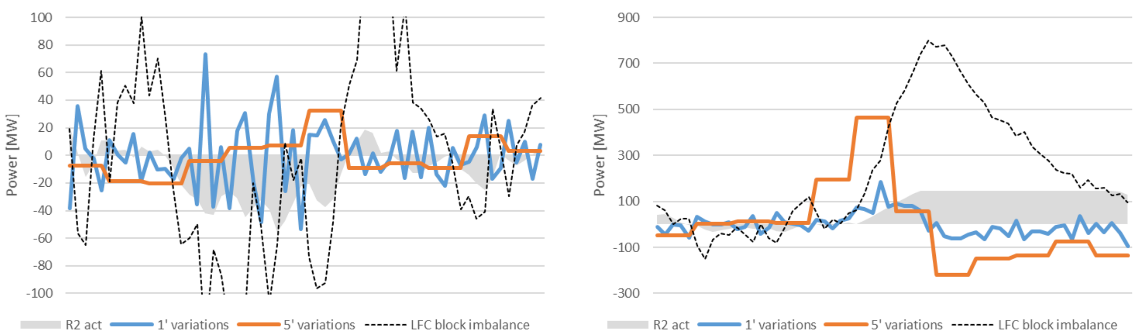


Figure 27: historic observations of aFRR activations (R2 act, positive values represent downward activations), and the LFC block imbalance, as well as the 1' and 5' variations of the remaining LFC block imbalances after IGCC activations (positive values represent excess energy) for a day with usual imbalances (May 17 2020) and high imbalances (May 14 2020).

6.2 Determining the contribution of IGCC

It was already concluded in the first part of the study that aFRR is activated after the IGCC activation and that the availability of this netting has a substantial impact on the activated volumes of aFRR in terms of energy, as well as a positive effect on the quality of the FRCE. Despite the uncertain availability and non-guaranteed nature of the imbalance netting, it was proposed in the first part of the study that this should be captured in the aFRR dimensioning.

The most straightforward approach is to take into account historical IGCC values as we are using a statistical relevant dataset of two years. This means that the sizing variable is for every period t determined by $SI_t - IGCC_t$ rather than simulating the IGCC via a synthetic distribution based on extrapolated characteristics of observed and future expected IGCC behavior. Note that every method will, as also the case in reality, avoid any counter-activations following the activation of mFRR. In other words, if the historically activated IGCC is larger than the $SI_t - mFRR_t$, the simulated aFRR activation is capped at zero.

Simulating the expected IGCC was already concluded to be very difficult or even impossible (Section 3.1.3), and that using a simulated approach could only make sense when the observed distribution is to be modified for instance to cap or boost the contribution in order to reflect certain expected system evolutions, or to take certain margins following the uncertain nature of IGCC. As no reasons were found to justify this, in particular because the dynamic dimensioning takes into account observed trends in IGCC, this option is not further pursued in this study.

It is to be noted that while IGCC is taken into account to compensate the LFC block imbalances, together with the mFRR activations, the simulated mFRR activations do not, as also in real-time operations, take into account IGCC when determining the mFRR activation. Due to the uncertainty on its availability, the dispatcher can only rely on the LFC block imbalance to decide upon the activation of mFRR.

6.3 Determining the sizing resolution

Table 6 shows the results when a sensitivity is conducted on increasing the sizing resolution from 5' to 1'. For this, the 'static' aFRR needs are again determined on historic observations of 2019 and 2020 according to the selected sizing variable and parameters as discussed in the previous sections. In the simulated aFRR methods, it is shown that using a higher sizing resolution will result in higher aFRR needs. In contrast, using a lower resolution is found to reduce the aFRR needs.

Table 6: 'Static' aFRR needs (in MW) following the investigated methodologies with a reliability level of 99%

	1 minute		5 minutes	
	UP	**DOWN**	**UP**	**DOWN**
Rule-based mFRR	284	270	252	238
Oracle mFRR on SI	189	192	151	145
SI variations	128	132	235	226

This effect is illustrated in Figure 28 comparing the real aFRR activations with the 1' and 5' (SI-IGCC) for two specific events. For the sake of simplicity, we assume SI-IGCC as representative for the simulated aFRR activations, making abstraction of the simulated mFRR activations, while the real aFRR activations are still activated with a 7.5' full activation time. For a day with usual imbalances (Figure 28, left), it can be seen the 1' (SI-IGCC) values are rather volatile compared to the averaged 5' values. Dimensioning on 1' values would in this example result in volatile aFRR simulations and higher aFRR needs, which cannot be used as such due to aFRR's slower activation time. The same figure illustrates that the historic activation of aFRR match better with the 5' (SI-IGCC). Also in extreme situations (Figure 28, right), the aFRR needs in a 5' resolution will be lower than 1' values and the same reasoning holds.

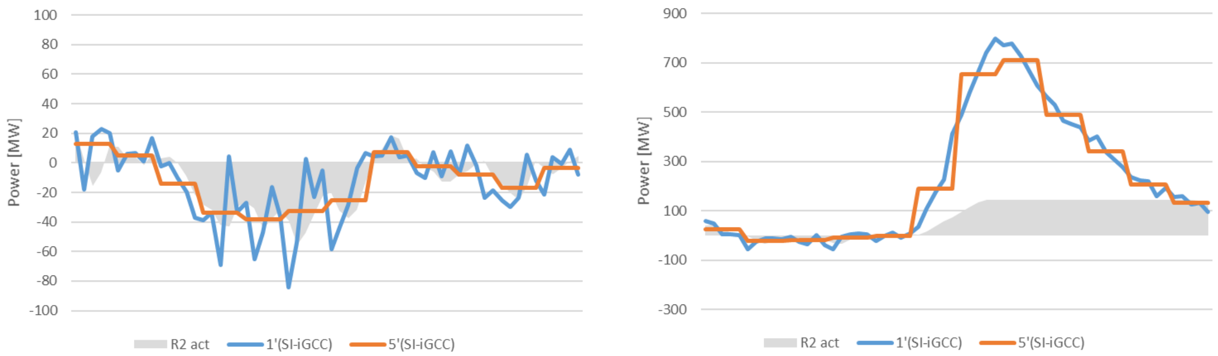


Figure 28: historic observations of aFRR activations (R2 act), and LFC block imbalances corrected with IGCC activations (SI-IGCC) with a resolution of 1' and 5' minutes for a day with usual imbalances (May 17 2020) and high imbalances (May 14 2020). Negative values represent a shortage or upward aFRR activation

It is therefore concluded in this section that the sizing variable resolution should be aligned with the full activation time of the aFRR product, which is foreseen to be set at 5' in the future. A higher resolution results in higher aFRR needs which can be, based on the full activation time of the product, be considered as over-dimensioning. Of course, higher aFRR needs would contribute to better FRCE quality but this is not an objective of the new aFRR dimensioning methodology.

It is noted in Table 6 that for the benchmark method, the opposite is true as a higher sizing resolution would effectively reduce the required aFRR needs. This can be explained as this sizing variable is determined on the ramps of the LFC block imbalances (after taking into account IGCC activations) and variability of large LFC block imbalances decreases with less time between two observations. Nevertheless, where this method would result in aFRR needs covering the 1' ramps, it would not ensure covering higher variations over periods of 5 minutes, which is the objective of the aFRR product.

6.4 Recommendation on the sizing variable

In the first part of its study, Elia has already recommended a methodology designed to cover 99% of simulated aFRR activations, based on historic LFC block imbalances while taking into account IGCC and mFRR activations. In the Proof of Concept, the first objective was to recommend suitable design options based on quantitative analyses, i.e. sensitivities. Elia investigated two possible design options to simulate the mFRR activations, i.e. a dispatch-based method closer to realistic mFRR dispatch operations, and an oracle-based method based on mFRR activations assuming perfect foresight. These methods are benchmarked against an improved version of the current dimensioning methodology. Furthermore, different analyses were conducted on the sizing variable resolution and the way IGCC is taken into account in the methodology. Based on this, Elia recommends to use:

- **oracle-based mFRR activations** providing a simple approach with little parameters for fine-tuning, while separating dimensioning from the dispatch operations. The method allows to find the minimum aFRR needs under perfect foresight assumptions;
- **a 5' resolution of the sizing variable**, aligned with the (future) full activation time of aFRR as any sizing variable resolution higher than this activation lead time will result in an over-dimensioning;
- **historic IGCC activations**, adapted to avoid over-activations following the simulated mFRR activations, while future evolutions of the availability of imbalance netting are expected to be taken into account by the daily dynamic dimensioning.

Such approach is found to result in a fixed or 'static' need of 151 MW and 145 MW for respectively up- and downward aFRR needs, based on a back-casting for 2018 and 2019. Note that such aFRR needs are around the aFRR needs of today, already providing an acceptable FRCE quality. As the objective of studying a new method is not to increase or decrease the FRCE quality, the deviation from the current aFRR needs is, together with other criteria, used as one criteria to assess different design options and parameters. In any case, the method is complemented with an ex post check to ensure the FRCE quality respects the FRCE target parameters specified by Article 128(3) of the SOGL. This will be periodically assessed to trigger methodologic modifications should the performance fall under the targets. Note that part 1 of the study already demonstrated that a direct dimensioning on the FRCE target parameters is not desirable, and even technically not possible in the absence of robust target criteria.

7. Determining the dynamic dimensioning potential

The main objective of this section is to investigate if there is a potential to implement a daily dynamic dimensioning process for aFRR, i.e. investigate if the aFRR needs for the next day can be determined in function of the expected system conditions. This would allow to vary the aFRR needs based on the risk for using this aFRR capacity. This methodology is inspired on Elia's current daily dynamic FRR / mFRR dimensioning where this capacity is determined by means of applying machine learning techniques on a data set of observed predicted system conditions and time features.

In a first step, a model is constructed capturing the relations between specific system conditions, such as typically the expected renewable generation and demand, and the sizing variable, i.e. the simulated aFRR activations. Similar to FRR dimensioning, an algorithm is trained on a periodical basis, e.g. monthly, to capture new evolutions in the data (e.g. increasing renewable capacity, better forecasts of renewable generation, increasing ability of BRPs to balance their portfolio). Because the aFRR needs are, similar to the FRR / mFRR dimensioning, to be dimensioned before the day-ahead market closure, the features must represent data which is available at that time. Note that the current FRR dimensioning is conducted before 7 AM.

In the second step, the trained algorithm is used on a daily basis, i.e. before the day-ahead market closure, to predict the aFRR needs. Corresponding to the **'oracle-based aFRR simulations'** method recommended in the Section 6, these aFRR needs are determined to cover 99.0% of all simulated aFRR activations corresponding with historic LFC block imbalances, IGCC activations and expected mFRR activations during similar predicted system conditions. The results will represent the up- and downward aFRR needs separately for every period of 5' for the next day. This resolution will thereafter be aligned with the product length, in this case 4 hours.

An overview of the steps followed to select and assess a machine learning algorithm is represented in Figure 29, and further specified step-by-step in the next sections. As **the objective is to investigate if there is a dynamic dimensioning potential**, and finally justifying if a dynamic dimensioning process should be incorporated in the aFRR dimensioning methodology or not, several machine learning algorithms are assessed and compared. A lot attention is therefore put in studying suitable algorithms and corresponding parameters to find an acceptable dynamic dimensioning. Nevertheless, the focus of this section remains on identifying the potential for a dynamic dimensioning method for aFRR, rather than the final calibration of the machine learning methods, which can be further refined during implementation of the aFRR dimensioning method.

7.1 Determination of the learning environment

7.1.1 Data collection, cleaning and transformation

A time series of the sizing variable is determined based on two-years (2018-19) of 5' average LFC block imbalances and activated IGCC volumes. This data is published on the website of Elia by means of the 1' LFC block imbalances and activated IGCC volumes. No missing values were observed.

1. Data collection, cleaning, transformation

- Collect largest possible set of relevant features in view of the outcome
- Interpolate missing data (if any)

2. Set up learning environment

- Based on a random split in training data (75%) and test data (25%)
- Based on 10-fold cross validation

3. Correlation study

- Matrix of correlations between features and the outcome
- Matrix of correlations between the features mutually

4. Model selection

- Pre-selection of relevant categories in view of the problem type
- 2 simple methods are selected for quantitative analyses to find a minimum performance level
- 2 more complex models are selected for quantitative analyses to increase performance level

5. Performance indicators

- Justify performance indicators in view of the problem type (regression – clustering / classification)

Figure 29: Overview of the different steps to build and select a suitable machine learning method

Figure 30 provides a list of features used by the machine learning methods for FRR dimensioning. The data has a resolution of 15’ and the data is transformed into a 5’ resolution by means of linear interpolation. There are no missing values, except in the offshore prediction data provided by DTU where periods with very elevated wind speeds are considered as storms and removed from the dataset. This missing data is now completed by means of linear interpolation[19]. Note that following the methodology’s design, all periods with forced outage events of large units are removed.

It is important to realize that a requirement for the method is that all features should be available at the moment on which the reserves are to be sized, i.e. before day-ahead market closure. This may exclude some obvious features such as the day-ahead electricity prices and the offered or activated reserve capacity for the concerned day as the day-ahead market and reserve procurement are closed after the dimensioning of the aFRR reserve capacity.

[19] Note that 5’ resolution data for offshore wind power prediction and generation in 2020, 2026 and 2028 are provided by DTU in the framework of a study on the integration of a second wave of additional offshore capacity in Belgium. This data was particularly relevant to conduct projections towards 2028, but are less relevant for the actual dimensioning for which historic forecasts and observations with a 15’ resolution, available at Elia can be used.

Features

The machine learning methodologies rely on the following features :	
5' Renewable generation and load forecasts	The day-ahead forecast (in MW) of onshore / offshore wind power, solar and total load (where needed interpolated from 15' resolution data)
5' Renewable generation and load forecast variations	The gradients (in MW) of solar, onshore / offshore wind power, and total load calculated as the difference between two quarter-hour day-ahead predictions
5' Scheduled leaps	The difference (in MW) between the hourly averaged predicted residual load (total load minus renewable generation) and the 15' values. Also the absolute value of the scheduled leaps is included as separate feature
15' Weather predictions	The day-ahead predicted temperature (in °C) and solar irradiation
Time features	Month of year, day of week and hour of day (in h)

Dependent variable

To predict one sizing variable representing the aFRR needs :	
5' aFRR simulations	Based on averaging 1' LFC block imbalances and iGCC activations

Figure 30: Overview of features (independent variables) and outcome (dependent variable) used by the machine learning algorithms

Note that the list in Figure 30 also some transformations on the original data, e.g. the scheduled leaps or demand and renewable gradients, as they are expected to show a relation to the sizing variable. It results in a **total amount of 19 features, including transformations**. This list is probably not exhaustive, and probably never will, and can be elaborated during or after implementation based on new insights or new available data. Note however that adding features with weak relations, or complex transformations, can increase complexity and reduce interpretability of the method. The set that is currently proposed captures the most obvious features for which the data is available at the moment of sizing.

7.1.2 Set-up of the learning environment

Figure 31 illustrates the allocation of available data over 2019 and 2019 over the training and test set. As recommended by good machine learning practices, we split the data randomly into a training set (75% of the data) and a test set (25% of the data). This test will only be used for the final evaluation of the method. However, to ensure that for every day, a part of the hours are used as training set and another part as test set, a technique called **stratified random sampling** is used, preserving the ratio of features in training and test set, e.g. ensuring that for each day, a proportion of the hours is allocated to the test and training set.

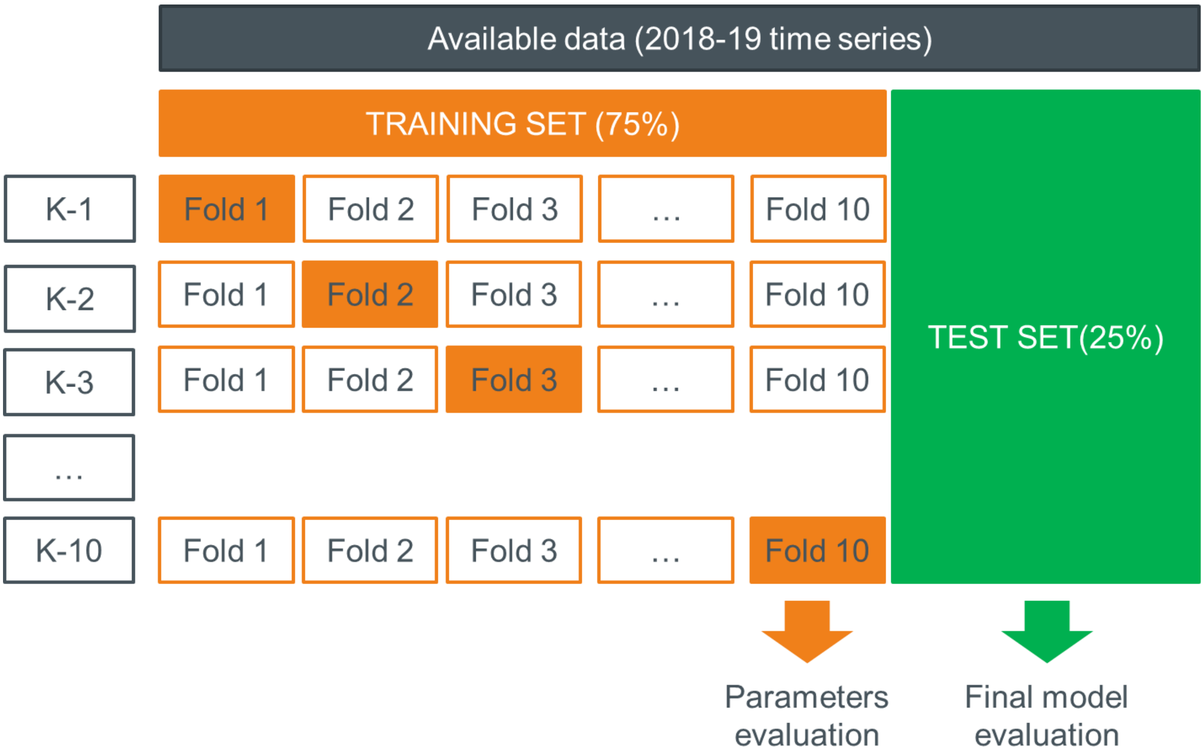


Figure 31: Illustration of a 10 fold cross-validation

With training set, a 10-fold cross validation is conducted to test and find the parameter settings. This means the data is with the same **stratified random sampling** divided in 10 folds or bins, of which one fold is used to assess the performance of the model. This exercise is then repeated 10 times, with different folds, allowing to obtain each time a slightly different performance. Such approach allows to ensure the results are sufficiently robust helping to select the best parameter for the method.

7.1.3 Correlation matrices

Figure 32 represents the correlation between the sizing variable and the 19 different features. It is observed that the correlation between the outcome and features is low or even close to zero. However, the correlation matrix only depicts linear correlations which does not mean there are no relations between the features.

Feature	Correlation
wind_capacity_offshore_in_mw	0.04
wind_capacity_onshore_in_mw	0.03
wind_offshore_dm1_in_mw	0.02
wind_onshore_dm1_in_mw	0.01
temperature_dm2_in_deg_celsius	0.00
wind_speed_dm2_in_m_per_s	0.00
radiation_dm2_in_w_per_m2	0.00
load_dm1_in_mw	0.01
solar_capacity_in_mw	0.03
solar_dm1_in_mw	0.00
time_hour_cos	0.00
time_hour_sin	-0.01
time_day	0.00
solar_dm1_in_mw_grad	0.00
wind_dm1_in_mw_grad	0.00
load_dm1_in_mw_grad	0.00
scheduled_leaps	0.02
scheduled_leaps_abs	0.01
month	0.01

Figure 32: Correlation matrix between different features and outcome

Figure 33 represents the correlations between the 19 features studied. The correlations are represented by colors depending on their value (i.e. red if the correlation is low and green if high). As explained in the previous paragraph, a low correlation does not necessarily imply that there is no relation. For instance we know there is a strong link between the predicted solar generation and hours, but this is not linear (as the time is expressed by means of a co-sinus or sinus function[20]). In applications with a large amount of features, features with large correlations with other features are generally excluded. As the amount of features used is not very large, all features are kept for the training.

[20] If the numerical hour would be directly used by the algorithm, then the distance between hours before midnight and after midnight would be large. For instance the distance between 23:00 and 01:00 would be 22 hours while in reality it is only 2 hours. To avoid this undesirable effect inherent to cyclic features such as the hour of the day, a tranformation to cosinus and sinus features is common. They are define as follows : $hour^{cos} = cosinus(2\pi * hour/24)$ and $hour^{sin} = sinus(2\pi * hour/24)$. The distance between 23 :00 and 01 :00 with these 2 features is small.

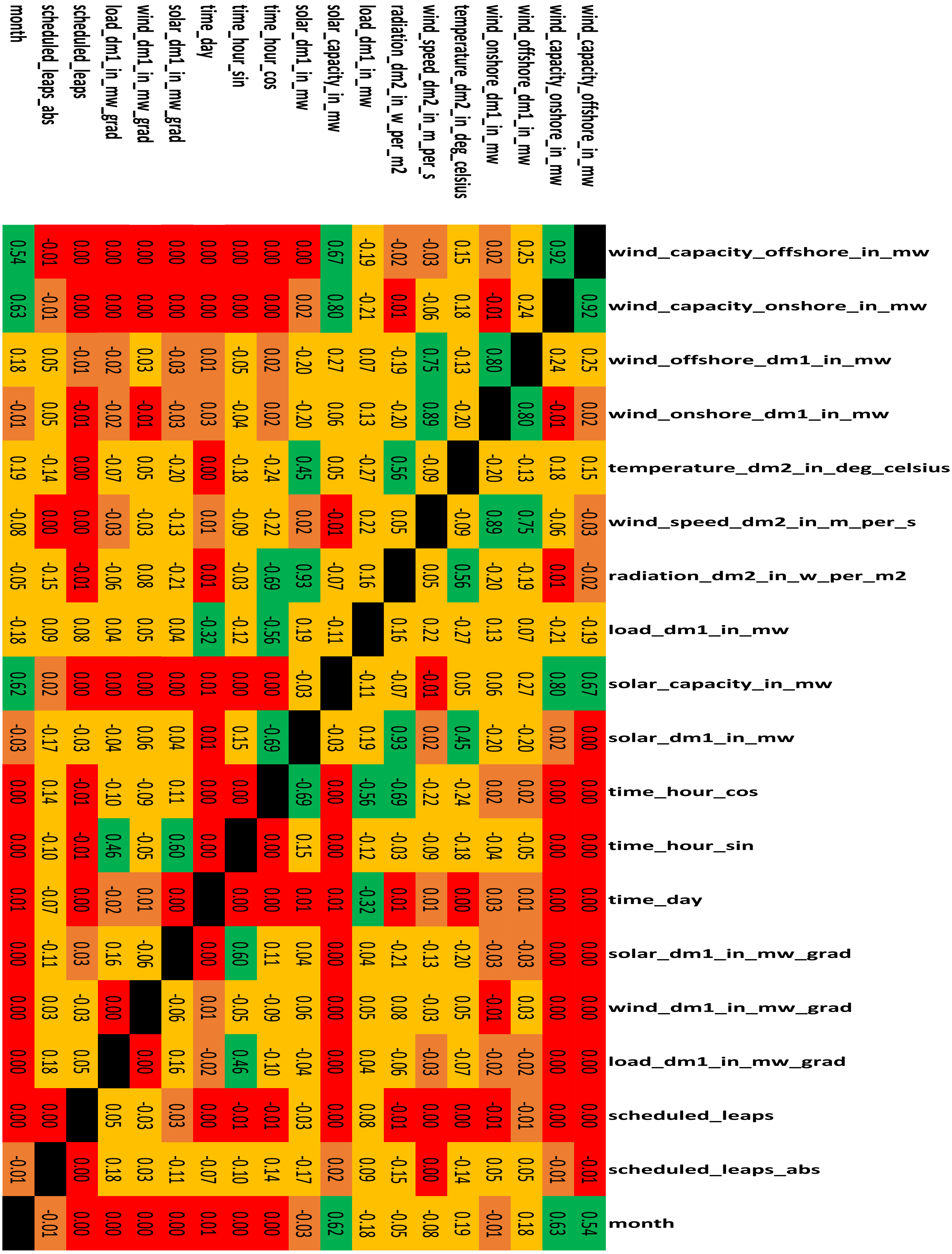


Figure 33: Correlations between the different features

7.2 Model selection and calibration

Figure 35 provides an overview of the different categories of machine learning methods. Focus in this study is on **supervised learning methods** which are typically used when dataset variables are labelled as features or outcome and which is the case in this application. **Unsupervised learning methods** are generally used when this information is not provided. However, this does not mean they cannot be used for a supervised learning problem as well. For instance, the k-means clustering is successfully implemented (in combination with a Nearest Neighbor algorithm) in Elia's FRR dimensioning, where the outcome and features are also well defined. **Reinforcement learning methods** are used when an algorithm is trained based on a dynamic environment (typically used in robotics and gaming) and is out of scope of this study.

In supervised learning, a distinction is made between regression and classification. Focus in this study is on **regression** where the objective is to predict a numerical or continuous variables, in this case the simulated aFRR activation. **Classification** is generally used when predicting discrete variables although several algorithms can also be used for continuous variables.

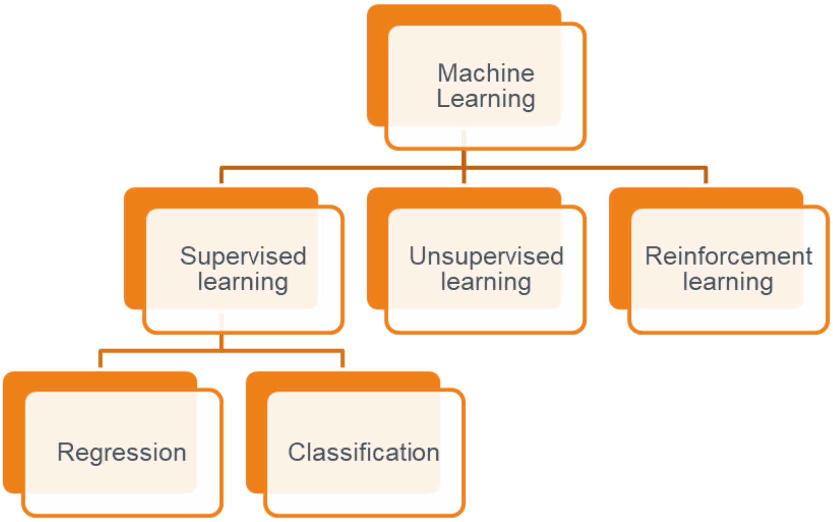


Figure 34: Overview of machine learning categories

Figure 35 provides an overview of the most well-known algorithms used in industry. Most are supervised learning methods, but also a non-supervised learning method is used (K-Means). Although some of the methods are typically used for classification (Naive-Bayes, Decision Trees), all these methods can be used to solve regression problems. Note that an educative explanation of each algorithm type is beyond the scope of this study. The necessary information can be found in specialized literature.

Analyzing the performance of all different methods in a quantitative way is time consuming. Indeed, it requires building the model, and finding the right parameters, which is particularly demanding for the sophisticated methods such as support vector machines and artificial neural networks. Therefore, a pre-selection is made based on a qualitative selection of these algorithms based on accuracy, interpretability and complexity. While the first is preferably kept as high as possible, the interpretability and complexity is preferably kept as low as possible. Note that in FRR dimensioning, a certain level of interpretability is required to justify ex post the dimensioning and procurement of the aFRR needs, as the reservation costs impacts the TSO's costs for ancillary services, and the transmission tariffs.

The pre-selection puts forward a **linear regression** and a **decision tree method** as two less sophisticated methods. These are two very different methods, which allow to identify a dynamic potential, if there is any, and this with simple and intuitive methods. These two methods are complemented with a **random forests** and **artificial neural networks** method which are two more sophisticated models to further increase accuracy. Note that these two methods are selected above the support vector machines. Despite that these support vector machines are typically characterized by achieving high accuracy, they are also characterized by a complex parametrization and require a lot of computational time for training when working with large data sets as is currently the case. As for this problem, the artificial neural networks are expected to also provide a high accuracy as well, but with a less complexity in the parametrization, while random forests is also characterized with a higher interpretability of the results, this justifies the choice for these two methods.

Figure 35: Overview of the qualitative pre-selection of methods for the Proof of Concept

7.2.1 Linear regression

A linear regression in one of the simplest machine learning methods (Figure 36, upper left), yet also one of the most used methods. The idea behind a simple linear regression is to find the line that fit the best on a cloud of points. From an algebraic point of view, a linear function (so two parameters a and b in the equation Y = a.X+b) is searched for that minimizes the sum of the distances of every observation from this linear function, typically be means of an ordinary least squares method.

To apply this method on aFRR dimensioning, a multiple instead of a simple linear regression is used, which extends the simple linear regression with several explanatory variables ($X_1,\ldots X_t$) instead of just one, as in the previous example. In addition, a quantile loss function, instead of the ordinary least square method, is used here to forecast a quantile, i.e. percentile, value. This way, if the forecast aims to predict a value that has to be higher as 99% of all observation, the quantile in the quantile loss function is set at 99%. In the case of the simple linear regression, instead of being “in the middle” of the cloud of points, the produced line will now be more or less above 99% of the points. This is referred to in the literature as quantile regression[21].

Along with its simplicity, the advantages of the linear regression is that there is no parameter configuration (i.e. besides finding the coefficients in the linear function). For these reasons, this type of method is frequently used as a benchmarking method. One of the main advantages is that it also depicts the strength of the correlations which is useful to interpret the results. In general, this type of problems is less suitable when the features and outcome show non-linear relations which is also found to be the case here. It is therefore expected that this benchmark method will be outperformed by the other methods.

7.2.2 Decision trees

Decision tree algorithms (Figure 36, lower left) are built on “if-else statements” that can be used to predict a result based on data. Although these types of methods are typically used for classification problems (the models are then called classification trees), these are also widely used for regression problems, and hence referred to as regression trees. Here, because the aFRR needs dimensioning deals with continuous variables, it concerns a regression tree.

Decision trees are simple, effective while having a fast training phase. One of the main advantages is that these are very interpretable as they are based on the human decision process. Indeed, decision trees are widely known and understood in business economics. The disadvantage, however, is that these models are prone to overfitting which happens when the learning algorithm continues to develop hypotheses that reduce training set error at the cost of an increased test set error. In other words, overfitting results in a model that performs poorly on new data and should thus be avoided. The same issue also implies that decision trees are generally sensitive to modifications in the training set[22].

The most important parameter in the design of a decision tree is its height (i.e. the number of “questions” before obtaining a prediction). After conducting several sensitivities (up to 40), the height in this his problem is fixed at 20. Further increasing the height is found to result in overfitting. Another parameter to be determined in decision trees during the training process is how the split in each decision node is made. As already explained in the linear regression, the aFRR

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[21] Koenker, R. (2005). Quantile Regression. Cambridge University Press. pp. 146–7.

[22] Breiman, L.; Friedman, J. H.; Olshen, R. A.; Stone, C. J. (1984). Classification and regression trees. Monterey.

needs dimensioning has to predict a quantile or percentile instead of providing a point forecast. For this reason, a quantile regression tree is used. That means the uses a quantile prediction in the leaves of the tree instead of the classical mean prediction[23]. So in practice after the training phase, when the tree with a new data (a set of values for the different features) is used, it will reach a leaf on which a (quantile) prediction is attached. This prediction has been computed (with the quantile loss function) to be (for instance) greater than the real value with 99% probability.

The decision tree is built by using the *Decision Tree Regressor* algorithm from the *sklearn* library with its default parameters. A classical mean squared error with improvement score by Friedman is used.

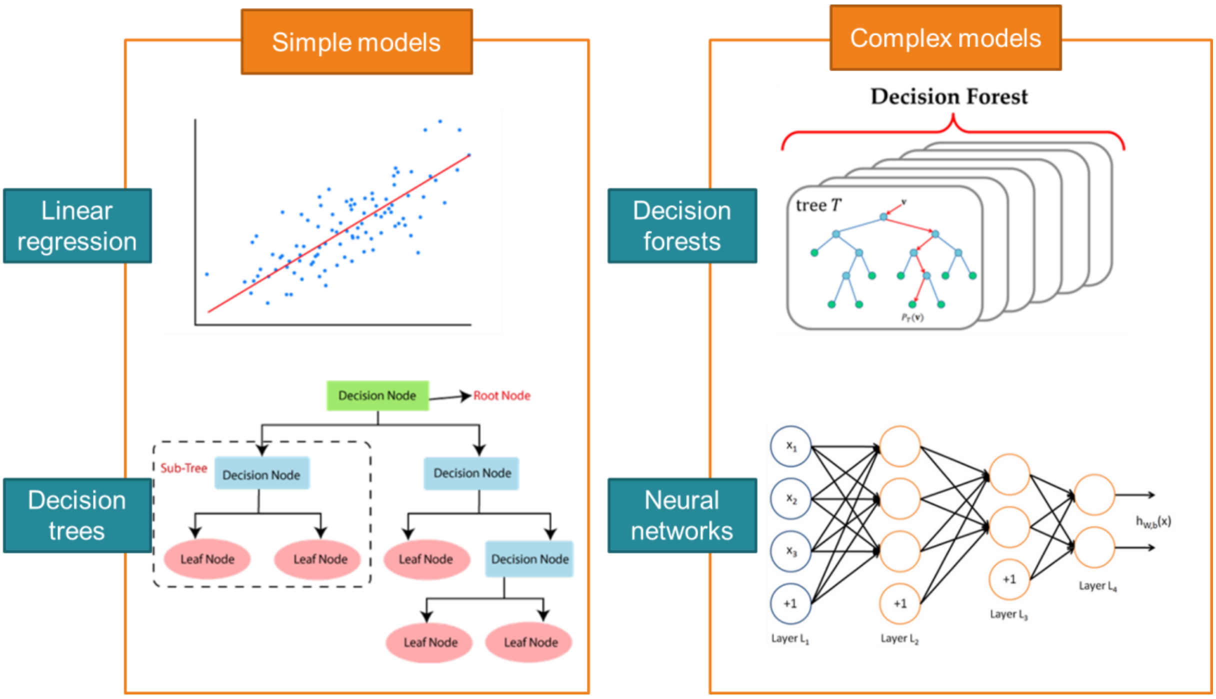

Figure 36: Graphical illustration of a linear regression (upper left), a decision tree (lower left), a random forest (upper right) and neural networks (down right).

7.2.3 Random forests

Random forest (Figure 36, upper right) are based on building a large number of individual decision trees that operate as an ensemble. Ensemble methods are techniques that create multiple models and then combine them to produce improved results. In the present case: a random forest is an “ensemble method” since it creates multiple models (decision trees) and combine them (forest) to improve results.

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[23] Meinshausen, N. "Quantile regression forests." Journal of Machine Learning Research 7.Jun (2006): pp. 983-999.

Each individual tree in the random forest produces a prediction, then a global prediction is reached (for instance by taking the average of all the prediction in the case of a continuous variable). These types of models generally provide a high performance while being versatile, and robust against different problems. Of course, complexity is larger as with the individual decision trees and this method also coming at a cost of less interpretability compared to the decision trees.

Similarly to the case of a single decision tree, a forest of quantile regression trees is used. Again, the nodes are split based on a classical mean squared error with improvement score by Friedman. After sensitivity analyses up to an amount of trees of 500 and the height up to 8, the number of trees in is specified at 400, while the height of each tree is specified at 4. A large number of small trees is a good way to avoid overfitting problems. A gradient boosting algorithm[24] is used which builds the trees iteratively, and take into account the weaknesses of trees already built in each new tree. After sensitivity analyses up to 0.2, the learning rate is fixed at 0.1 (which is a parameter linked to the weight attributed to each tree for computed the final forest prediction).

7.2.4 Artificial neural networks

Artificial neural networks model the relationship between a set of input and output signals (Figure 36, lower right). The concept is that each artificial neuron has inputs and produce a single output which can be sent to multiple other neurons. The neurons are stacked into different layers to produce the global network. After a training phase, a new input (a set of values for the different features) can be feed to the neurons on the first layer, those will produce an output that will be sent to the second layer of neurons, which can be send to the third layer, … This process continues until it reaches the final layer that will output the final result, i.e. the prediction of the simulated aFRR activations.

To produce an output, a single neuron first takes as inputs some values computed on the previous layers, those inputs are combined into a weighted sum (the weight depends on the links that connect different neurons). Then the neuron adds a bias term to this weighted sum and passed the result through a (usually non-linear) activation function to produce its output[25]. To goal of the learning process is to determine those weight and bias in order to minimize the observed errors when using the network. After the learning process, a specific value can be given to in first layer of the network (i.e. values for each feature) and the output of the last neuron is the forecasted outcome.

Artificial neural networks are versatile learning algorithms which can be applied in nearly any learning task. They are often applied to problems where the input data and output data are well defined, yet the process that relates the input to the output is complex and hard to interpret. These types of models are therefore computationally intensive, slow to train and due to their difficult interpretability, for that reason sometimes referred to as a 'black box' methods.

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[24] Hastie, T.; Tibshirani, R.; Friedman, J. H. (2009). "10. Boosting and Additive Trees". The Elements of Statistical Learning (2nd ed.). New York: Springer. pp. 337–384.

[25] Artificial intelligence (3rd ed.). Addison-Wesley Pub. Co. 1992.

The neural network for this study is built on six sequential complete layers so every node of the layer number N is linked to every node of the next layer number N+1. The first layer has 19 neurons (the number of features) use a well-known “relu” activation function (also known as “rectified linear unit”). The layers 2, 3, 4 and 5 have 10 neurons, also using the relu activation function. The last layer has one neurons and uses a linear activation function. The ‘relu’ function is wildly used which allows to not activate all neurons at the same time which results in computationally more efficient[26]. Several sensitivities are conducted to determine the amount of layers (up to 8) and the amount of neurons per layer (up to 10).

Before the training of the network, A Gaussian kernel initializer is used which is a method to set up the initial weight randomly in the network, otherwise the learning process can suffer from unwanted and avoidable bias (for instance if we set up manually the weight of the network to zero). When training a neural network (i.e. adjust the weights in the network), an iterative method is used called the stochastic gradient descent[27]. Here, a stochastic gradient descent is applied which is based on adaptive learning rate per dimension (Adadelta)[28] that have shown good results in practice[29]. Again, as the interest lays in quantile prediction rather than average point forecasts, a quantile loss function is used in the learning process.

From a practical point of view, Keras is used to design the network which is a user-friendly framework for neural networks built on top of TensorFlow 2.0, an open source software library.

7.3 Performance evaluation

The performance of the algorithms are assessed over the separate test set, i.e. data which is only used to assess the performance of the model, and not to train the algorithms, or calibrate the parameters. The first criteria which is investigated is the ability of the algorithm to determine the aFRR needs to cover exactly 99.0% of the sizing variable (i.e. the LFC block imbalances after taking into account IGCC and mFRR activations). If the test set shows that the reliability is below 98.9%, i.e. that the aFRR needs cover less than 98.9% of the sizing variable, the algorithm (or its parametrization) is discarded.

For all algorithms matching the above mentioned criteria, the mean absolute error over the test set is used for further assessment. Due to the nature of the problem (assessing a risk rather than predicting a value), this mean absolute

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[26] LeCun Y., Bottou L., Genevieve B. O. and Müller K.-R. (1998). "Efficient BackProp". In G. Orr; K. Müller (eds.). Neural Networks: Tricks of the Trade. Springer.

[27] Bottou, L. (1998). "Online Algorithms and Stochastic Approximations". Online Learning and Neural Networks. Cambridge University Press.

[28] Rumelhart, David E.; Hinton, Geoffrey E.; Williams, Ronald J. (8 October 1986). "Learning representations by back-propagating errors". Nature. 323 (6088): 533–536.

[29] Zeiler, Matthew D. (2012). "ADADELTA: An adaptive learning rate method".

value us calculated based on a quantile loss function. This quantile loss function[30] compares the real-time observed value with the predicted 99% percentile values. If the value falls outside this [0%; 99%] confidence bandwidth, it will have a lager impact on the mean absolute error than if it falls within the interval. If it is found that another model on the same family (i.e. with a different parametrization) has already achieved a better result, the model is discarded. This process is conducted iteratively until the results converge to a certain mean absolute error which becomes difficult to further improve. Note that this allows finding the dynamic potential with a certain algorithm, if any exists, and a parametrization which achieve reasonable results. Further investigation, particularly for the sophisticated methods may still result in incremental improvements.

Table 7 represents the final results for the four methods which are quantitatively analyzed. It is shown that under the best settings, the sophisticated models can cover the risks with lower aFRR needs, and in particular the random forests in which the aFRR needs can be reduced to 139 MW for both up- and downward aFRR needs (a reduction of almost 6% on average). As it can be seen, the difference between a neural network and random forests is not very large, but as the random forests are less complex and more interpretable, these are put forward as the best solution for the implementation for aFRR dimensioning.

Table 7: mean aFRR needs, reliability level and mean absolute error of the best performing model for each category

aFRR needs	Static		Linear regression		Decision trees		Neural networks		Random forests	
	UP	DOWN	UP	DOWN	UP	DOWN	UP	DOWN	UP	DOWN
Mean value	-150	144	-145	145	-146	143	-142	142	-139	139
Reliability	1.00%	99.00%	1.00%	99.00%	1.10%	99.00%	1.00%	98.90%	1.10%	98.90%
Mean error	1.61	1.58	1.56	1.62	1.6	1.54	1.6	1.57	1.53	1.48

Figure 37 provides a summary of the distribution with the average value and different percentiles for the different methods investigated. One can observe a large spread between the minimum and maximum values of around 150 MW for the random forests method, and even higher for the other machine learning methods, particularly in the less sophisticated methods indicating that these are more sensitive to outliers. This spread is however largely reduced when looking at the 25% and 75% percentiles, i.e. up to a difference of around 15 MW between both 25% / 75% percentiles in a random forest method, and up to 20 MW in the less sophisticated methods.

[30] $L_q(pred, obs) = max[q(obs - pred),\ (q-1)(\ obs\ -\ pred\_val)]$ comparing the delta between the predicted value (pred) and observed value (obs)

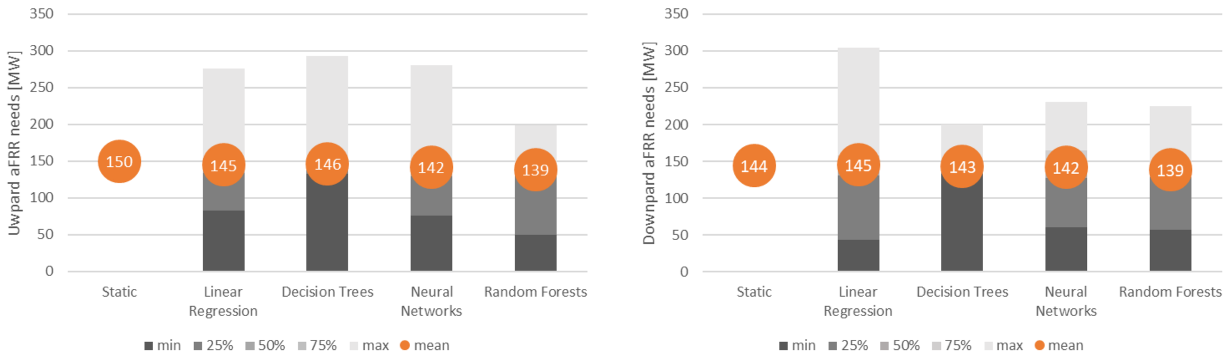

Figure 37: mean, min, max and 25, 50, 75% percentile for the upward (left) and downward (right) aFRR needs for the different algorithms investigated

Further analysis of the distribution (Figure 38) of the random forests method shows that in the majority of the aFRR needs are between 110 MW and 180 MW for both upward as downward aFRR needs. The outliers will be further investigated during the implementation, as well on how they should impact the final aFRR needs.

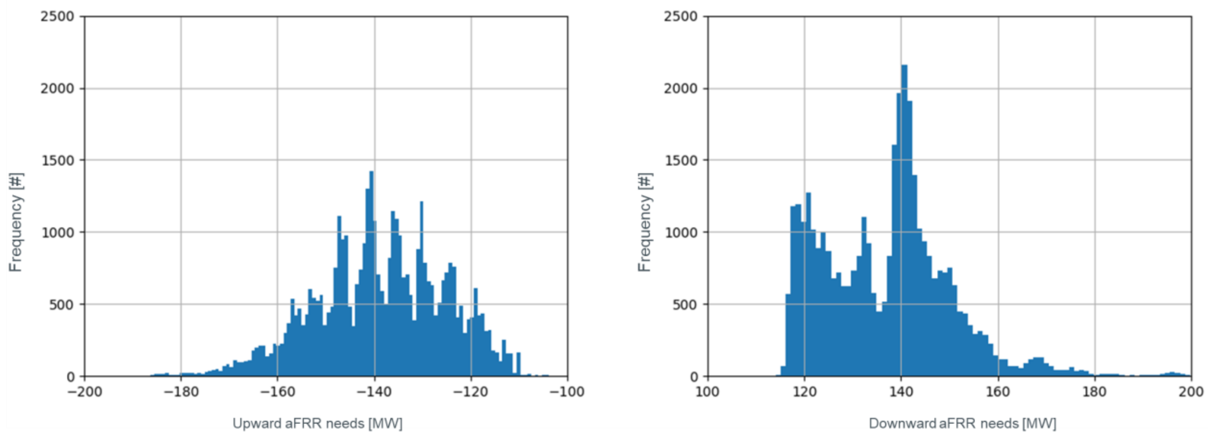

Figure 38: Distribution of the upward (left) and downward (right) aFRR needs over the test set

7.4 Implementation in a dynamic process

Based on the above-mentioned results, Elia recommends to implement a dynamic daily dimensioning similar to the current FRR dimensioning. Such method is found to achieve a reduction in the average aFRR needs while attaining a better reliability management by adapting available aFRR capacity to the risks in the system, and ensuring a more stable system reliability, even during challenging system conditions.

The recommended method is based on a 'random forests' algorithm. This method is found to provide better results than the less sophisticated methods such as 'linear regression' or 'decision trees', while being slightly less complex and more transparent than the artificial neural networks. Despite that the latter are known for their high performance, no evidence of a substantial better performance was yet found. Note that the objective of this study is to find a dynamic potential, if any, rather than the optimization / calibration of the algorithms' parameters. It is therefore possible that further calibration of machine learning methods may result in incremental improvements, while also future system evolutions may also trigger a re-parametrization or even re-selection of the methodology.

Note that an additional sensitivity (Table 8) applying only time features (hour of day, day of week, month of year) reduces the reduction of the average dynamic aFRR needs compared to the static aFRR needs from 5.5% to 2.7 %, when expressed as the average up- and downward aFRR needs reduction compared to the average up- and downward.

Table 8: mean aFRR needs, reliability level and mean absolute error for a random forest method with all features (A) and only time features (B)

aFRR needs	Static		Random forests A		Random forests B	
	UP	DOWN	UP	DOWN	UP	DOWN
Mean value	-150	144	-139	139	-144	142
Reliability	1.00%	99.00%	1.10%	98.90%	01.1 %	98.9%
Mean error	1.61	1.58	1.53	1.48	1.59	1.57

Implementation can be based on a monthly training phase (similar to FRR dimensioning, a more frequent training is not expected to bring much advantages as) and a daily prediction phase (with a publication before 7 AM D-1, together with the FRR / mFRR dynamic dimensioning). This means that the market will know the aFRR needs before the D-1 procurement at least a few hours before procurement. In the final implementation, the 5' results will be aligned with the 4 hour product resolution.

8. Analyzing robustness towards future evolutions

Calculations have all been conducted by means of a back-casting on 2018-19, based on historical time series of observed LFC block imbalances observed in the same period, not taking into account evolutions such as the increasing share of renewable capacity, or other foreseen system evolutions which may impact the aFRR needs following their variable nature.

In order to assess the impact of renewable capacity, a specific method to make projections on FRR / mFRR needs was presented in the framework of the study on the integration of additional offshore capacity[31]. This methodology is based on an extrapolation of the LFC block imbalances, taking into account the prediction errors of incremental renewable capacity. The same methodology is used in this study to estimate the future aFRR needs when implementing the recommended methodology discussed in the previous sections. The investigated time horizon is aligned with the on-going offshore integration study on 2021, 2026 and 2028.

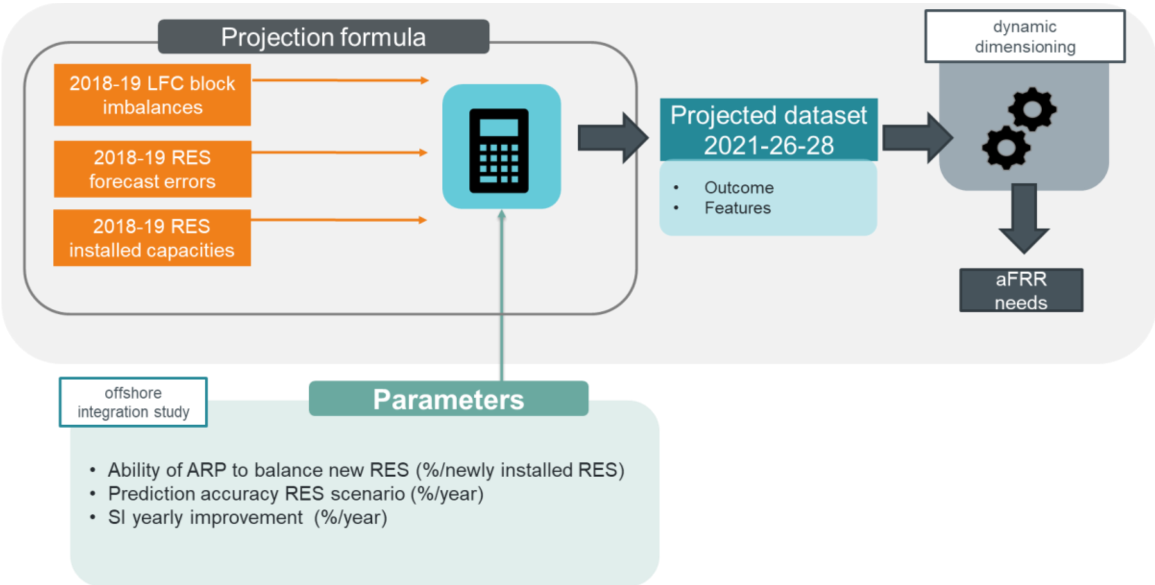

Figure 39: Overview of the methodology for making projections of the aFRR needs towards 2028

8.1 Methodology to make projections towards 2028

The methodology to determine the aFRR needs (Figure 39) is based on an upscaling of the LFC block imbalances as applied in the 'old' static FRR dimensioning, as well as in previous 'long-term' studies such as the offshore integration study. The historic LFC block imbalances of 2018 and 2019 are up-scaled towards 2021, 2026 and 2028. The historic

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[31] More information on : https://www.elia.be/en/public-consultation/20200608_public-consultation-on-the-integration-of-additional-offshore-capacity

time series is extrapolated by taking into account expected system evolutions between the period representing historical records and the period for which the FRR needs are to be determined.

For every 5' time period t, the LFC block imbalances (SI_t) are increased or decreased with the expected forecast errors ($FE_{t,i}$) resulting from the incremental capacity of each variable renewable generation technology *"i"*, i.e. onshore / offshore wind power and photovoltaic power. Correlations between system imbalances and forecast errors are taken into account by always using the same period "*t*" for every parameter. For every 5' time period "*t*", the expected LFC block imbalance in a certain year ($Baseline_t$) is calculated as:

$$Baseline_t = (SI_t + \sum_i IC_{t,i} * FE_{t,i} * A_i * B_i * C_i), \;\; for\ i = wind\ onshore, wind\ offshore, pv$$

- ***$FE_{t,i} = (DA_{t,i} - RT_{t,i}) / MC_{t,i}$***
  - *$DA_{t,i}$: day-ahead forecast [MW]*
  - *$RT_{t,i}$: real-time estimation [MW]*
  - *$MC_{t,i}$: monitored capacity [MW]*

  Onshore wind and solar power historic time series are obtained from Elia's forecast tools as published on the website of Elia. A linear interpolation transforms the data from 15' to 5' data, which is by lack of higher resolution data a fair assumption taking into account the geographically distributed nature of these technologies. For offshore wind power, the 5' time series for the 4.4 GW, 4.0 GW, 3.0 GW and 2.3 GW offshore generation park are obtained from DTU in the framework of the offshore integration study.

- ***$IC_{t,i}$* :** for every technology "i", the difference between the installed capacity between the year corresponding to the period "t" in the historic time series of LFC block imbalances, i.e. 2018-19, and 2021, 2026 and 2028. These values are already specified in Table 9 based on the CENTRAL scenario used and justified in the offshore integration study. These figures are based on the relevant figures of the adequacy and flexibility study 2019, where offshore installed capacity has been revised to the H-RES scenario following the offshore development currently foreseen.

Table 9: Generation capacity at the end of the year [MW]

						Generation capacity at the end of the year [MW]									
CENTRAL SCENARIO	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Wind CENTRAL	**2,371**	**2,774**	**3,305**	**4,123**	**5,046**	**5,210**	**5,374**	**5,537**	**5,701**	**5,865**	**6,765**	7,536	**8,507**	8,679	8,850
Wind onshore	1,658	1,915	2,254	2,513	2,775	2,939	3,103	3,266	3,430	3,594	3,765	3,936	4,107	4,279	4,450
Wind offshore	713	859	1,051	1,610	2,271	2,271	2,271	2,271	2,271	2,271	3,000	3,600	4,400	4,400	4,400
Photovoltaics CENTRAL	**3,200**	**3,587**	**3,932**	**4,433**	**5,070**	**5,600**	**6,262**	**6,925**	**7,587**	**8,249**	**8,800**	**9,351**	**9,903**	**10,454**	**11,005**

- **$A_i = 1 - X_i{*}Y_i$** : improvement factor representing the forecast accuracy improvements following intra-day predictions (X_i) and the ability of the BRP to adjust its portfolio following this information (Y_i).
- **B_i : $(1-Z_i)$** : improvement factor representing the improvement (Z_i) in LFC block imbalance quality following Elia's continuous efforts to incentivize and help BRPs balancing their portfolio.
- **C_i : $(1-W_i)$** : improvement factor representing the improvement (W_i) of the day-ahead forecast error following the improvement in renewable generation forecast tools

It is already shown in the offshore integration study that these parameters have quite a large impact on the FRR needs. In the offshore integration study, three cases are tested starting from a **reference case** assuming that the current observations of the share of renewable capacity will also be valid for incremental offshore capacity installed. This scenario assumed an ability of the BRP to balance 50% of the prediction offshore incremental capacity (while this remains 35% for onshore and photovoltaics). In addition, this case assumes a yearly LFC block imbalance improvement of 1% and a yearly forecast accuracy improvement of 1%.

Main reservation for copying these assumptions towards this study is that at this point, little information is available on the variability of renewables within the 15' and on the ability and the willingness of BRPs to balance their portfolio within the imbalance settlement period. In contrast to the FRR dimensioning, based on the 15' imbalances, no obligations or financial incentives are given for portfolio balancing within the imbalance settlement period and limit future aFRR needs growth. For this reason, the reference case is complemented with an **absolute worst case** where no improvements whatsoever have been assumed.

8.2 Results

Figure 40 represents the absolute worst case where no market performance improvements are observed within the 15', an increasing trend of the up- and downward average aFRR needs is observed towards 159 MW (2026) and 174 MW (2028 and 155 MW (2026) and 174 MW (2028), respectively. Note that the up- and downward aFRR needs are estimated to evolve symmetrically, despite that they are calculated separately. The average represents the average aFRR needs over time, i.e. over the test set analyzed. Note that the 25%-75% percentile, as well as the minimum and maximum aFRR needs indicate an increasing spread of the dynamic results towards 2028.

In contrast, a situation where the market performance fully translates to the intra-hourly time frame (Figure 41), shows that the aFRR needs can be kept stable, or even slightly decreasing average aFRR needs towards 2028. However, it is to be noted that no particular mechanisms oblige or incentivize BRPs to maintain the balance within the 15' imbalance settlement periods.

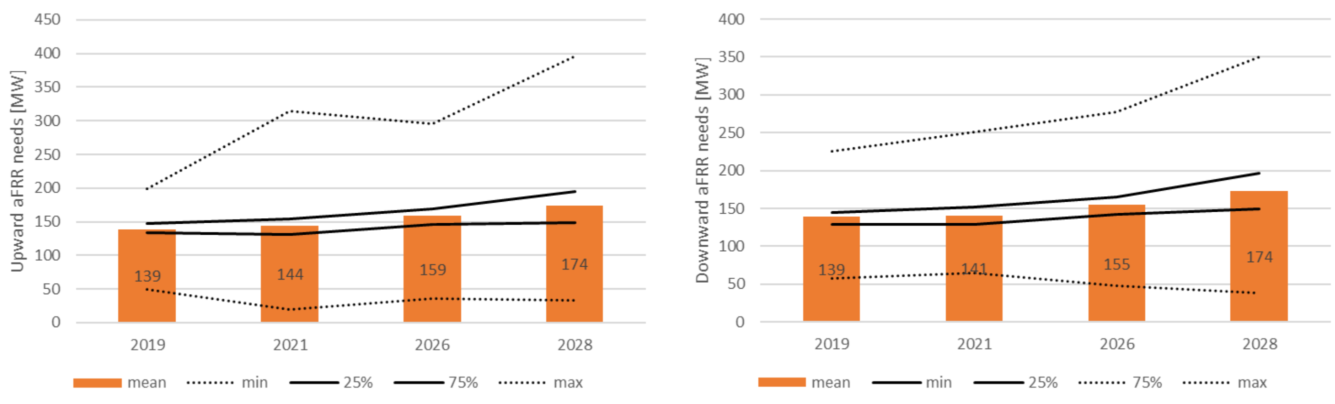
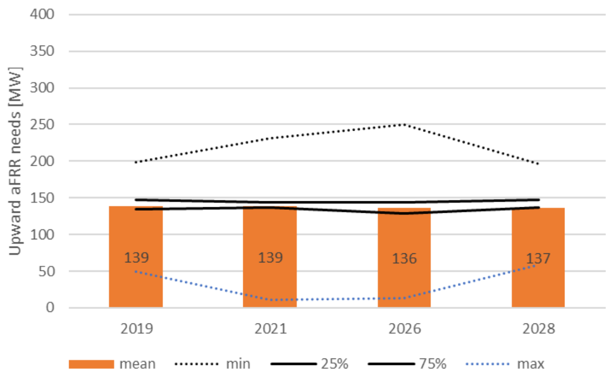


Figure 40: average, min / max and 25% - 75% percentile of the upward (left) and downward (right) aFRR needs towards 2028 for the worst case



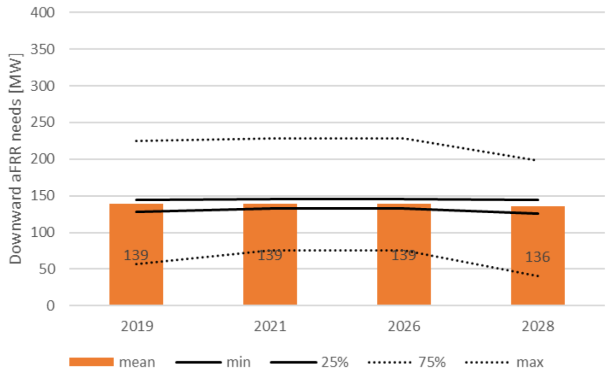


Figure 41: average, min / max and 25% - 75% percentile of the upward (left) and downward (right) aFRR needs towards 2028 for the reference case

9. Final recommendations and planning for implementation

9.1 Recommendations

In the first part of its study, Elia has recommended a methodology designed to cover 99% of simulated aFRR activations, based on historic LFC block imbalances while taking into account IGCC and simulated mFRR activations. This method is complemented with an ex post check to ensure the FRCE quality meets the FRCE target parameters specified by Article 128(3) of the SOGL.

In the Proof of Concept, the first objective was to recommend suitable design options based on quantitative analyses, i.e. sensitivities. Elia investigated two possible design options to simulate the mFRR activations, i.e. a dispatch-based method closer to realistic mFRR dispatch operations, and an oracle-based method based on mFRR activations assuming perfect foresight of the LFC block imbalances. These design options for the 'simulated aFRR method' are benchmarked against an improved version of the current methodology. Furthermore, different analyses were conducted on the sizing variable resolution and the way IGCC is taken into account. Based on this, Elia recommends to use:

- **oracle-based mFRR activations** providing a simple approach with little parameters for fine-tuning, while separating dimensioning from the dispatch operations. The method allows to find the minimum aFRR needs under perfect foresight assumptions;
- **a 5' resolution of the sizing variable**, aligned with the (future) Full Activation Time of aFRR as any sizing variable resolution higher as this FAT will result in an over-dimensioning;
- **historic IGCC activations**, capped to avoid over-activations following the simulated mFRR activations.

Such approach would result in a fixed or 'static' need of 151 MW and 145 MW for respectively up- and downward aFRR needs, based on a back-casting for 2018 and 2019. Note that such values are around the aFRR needs of today, currently providing an acceptable FRCE quality. As the objective of the method is not to increase or decrease the FRCE quality, the deviations from the current aFRR needs is used as a criteria to assess different design options and parameters. The FRCE target parameters in Elia's LFC block will be evaluated yearly and any breach thereof will trigger a revision of dimensioning methodology.

In the Proof of Concept, the second objective was to find a dynamic potential, if existing. An analysis based on a robust set of features, of which most are already used for FRR dimensioning, is used to test four representative machine learning methods including less (linear regression, regression trees) and more sophisticated methods (random forests, artificial neural networks). Based on an assessment of accuracy, but also complexity and interpretability of the method, Elia recommends the random forests method as the best approach for implementation. It is found that on average, a dynamic dimensioning method based on a random forest algorithm reduces the average aFRR needs compared to a static approach with around 6%, while the method is less complex and the results are better interpretable compared to the artificial neural networks. Further calibration of parameters (or method) remains possible before, during and after the implementation.

In the Proof of Concept, the third objective, was to assess the impact of incremental renewable capacity towards 2028. The most important evolution found is the increase in renewable installed capacity. In a worst case, where foreseen market performance improvements do not translate entirely to the LFC block imbalance variations within the imbalance settlement period of 15 minutes, average aFRR needs of around 139 MW in 2019 increase gradually to 174 MW towards 2028. However, a scenario where the expected market improvements do translate one-to-one to the intra-15' LFC block imbalances, the aFRR needs can even remain stable towards 2028.

9.2 Planning for implementation

Figure 42 provides the proposed timeline for implementation of the proposal elaborated in this study. After the publication of the consultation report and the full study on September 30, 2020, Elia will pursue with the industrialization of the methodology. After finalizing further discussions with CREG and analyses on the calibration of the algorithms by the end of 2020, Elia foresees an implementation track of 9 months in order to be ready by September 30, 2021. The next phase is to conduct a parallel run of 4 months to allow the market parties to prepare for the aFRR needs variations corresponding to the dynamic dimensioning. As from the start of the parallel run, the results will be published on a daily basis on Elia's website. The 'go live' is therefore planned after this period, i.e. on February 1, 2022.

Elia will describe the methodology in the LFC block operational agreement, planned to be submitted for consultation by June 30, 2021. In order to ensure that the methodology can be described in sufficient detail (including all parameters), Elia will submit its proposal at the end of the IT implementation, i.e. on September 30, 2021. Of course, the go live date is subject to the approval of the LFC block operational agreement.

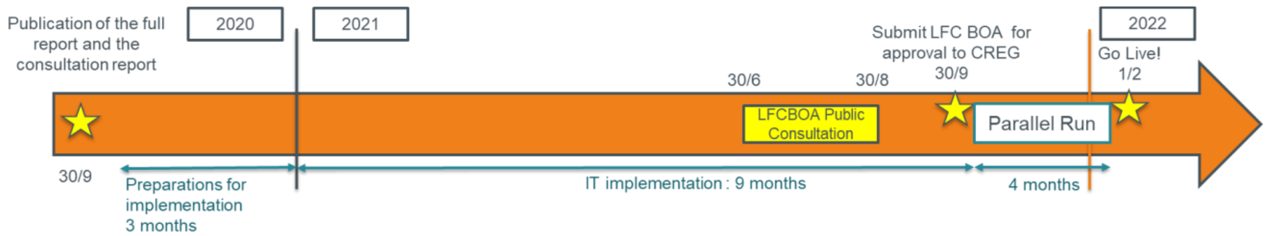


Figure 42: Proposed timeline for implementation of the new aFRR dimensioning methodology

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