



Explanatory Note on Elia's LFC block operational agreement approved on July 19, 2023.

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2 Introduction

The LFC Block Operational Agreement, hereafter referred to as LFCBOA, applies to the Elia LFC Block and contains the methodologies listed in Article 119 of Commission Regulation (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation, hereafter referred to as SOGL.

3 Whereas

The operation of European Load-Frequency Control (LFC) processes is based on geographical areas, where every area has their individual responsibilities with respect to the LFC structure. The superior structure is the synchronous area in which frequency is the same for the whole area. The synchronous area Continental Europe (CE) consists of several LFC blocks, each LFC block consists of one or more LFC areas. An LFC area itself consists of one or more monitoring areas.

Each of these operational areas has its own obligations. A monitoring area has the obligation to calculate and measure the active power interchange in real-time in that area. A LFC area has the additional obligation to fulfil the frequency restoration quality target parameters by using the frequency restoration process. A LFC block is in addition responsible for the dimensioning of frequency restoration reserve (FRR) and replacement reserves (RR). The synchronous area has the obligation to fulfil the frequency quality target parameters by using the frequency containment process.

The structure of the LFC blocks is determined in a common proposal developed by all TSOs of Synchronous Area “Continental Europe”, regarding the development of a proposal for the determination of LFC blocks in accordance with Article 141(2) of the SOGL. This document, submitted for consultation on 28/11/2017¹, and subject for approval by all NRAs, defines the ELIA LFC block, previously referred to as a control zone, in which there is only one LFC area and monitoring area, and thus only one TSO, i.e. ELIA.

The LFC Block Operational Agreement is defined in Article 3 of the SOGL, as a *“a multi-party agreement between all TSOs of a LFC block if the LFC block is operated by more than one TSO and means a LFC block operational methodology to be adopted unilaterally by the relevant TSO if the LFC block is operated by only one TSO”*. A ‘load-frequency control block’ or ‘LFC block’ is defined by the same Article of the SOGL as *“a part of a synchronous area or an entire synchronous area, physically demarcated by points of measurement at interconnectors to other LFC blocks, consisting of one or more LFC areas, operated by one or more TSOs fulfilling the obligations of load-frequency control.”*

The document needs to be in accordance with the Synchronous Area Operational Agreement (Article 118), hereafter referred to as SAOA, drafted by all TSOs (ENTSO-E) by 12 months after entry into force of the SOGL. When drafting the SAOA for RG CE, the TSOs considered that it was advantageous to extend the minimum content of the SAOA required by the SOGL with additional content based on the previous operational handbook of ENTSO-E, the Network Code on Electricity Emergency and Restoration and EBGL. The extended SAOA, as described above, shall be referred to as the Synchronous Area Framework Agreement (SAFA). The SAFA contains four parts:

¹https://consultations.entsoe.eu/system-operations/lfc-blocks_ce/supporting_documents/171129_LFC%20blocks%20determination%20Proposal%20Final_for%20public%20consultation.pdf

- Part A² includes the content required by SOGL, EBGL and the Network Code on Electricity Emergency and Restoration. It has been submitted to public consultation and NRA approval
- Part B includes the content required by the applicable legislation but is not subject to NRA approval
- Part C includes the content that was introduced by the Parties on a voluntary basis in order to further strengthen the objectives of the RG CE SAFA
- Part D represents the contractually agreed Exemptions and Derogations for individual Parties from the requirements in respect to Part A to C of the respective Policy

Annexe 1 of the SAFA, which is the Policy on Load-Frequency Control and Reserves, determines amongst others the dimensioning rules for Frequency Containment Reserves or 'FCR', and the common operational processes related to controlling the frequency quality in the synchronous area. The Elia LFC block is part of the synchronous area Continental Europe.

A first version of the LFC BOA was approved by CREG on May 27, 2019 after a public consultation and entered into force on August 27, 2019 while the previous version was approved by CREG on July 14, 2022. This version includes all modifications up to this proposal for amendment to the LFC BOA, mainly concerning the dimensioning of the aFRR dimensioning in Article 9 (cf. Section 3.2 of this explanatory note). In addition, some additional updates concern:

- Textual modifications to facilitate the foreseen implementation of a technology-neutral framework for participation of units in exceptional balancing measures in Article 7, Article 12 and Article 13 (cf. Section 5.3, 7.2 and 7.3 of this explanatory note).
- Modification of the Full Activation Time of aFRR from 7.5 to 5 minutes in Article 14 (cf. Section 7.4 of this explanatory note).
- Textual modifications to facilitate the foreseen implementation of a dynamic sharing calculation in Article 10 (cf. Section 6.3 of this explanatory note).
- Modification of the calculation method of the minimum threshold in FRR dimensioning in Article 8 (cf. Section 6.1 of this explanatory note).

²<https://transparency.entsoe.eu/system-operations-domain/operational-agreements-of-synchronous-areas/show>

4 General Provisions

4.1 Definitions

For the purposes of this proposal, the terms used have the meaning of the definitions included in Article 3 of the SOGL. When referring to reserves³, following definitions are particularly relevant:

- 'active power reserve' means the balancing reserves available for maintaining the frequency;
- 'reserve capacity' means the amount of FCR, FRR or RR that needs to be available to the TSO;
- 'frequency restoration reserves' or 'FRR' means the active power reserves available to restore system frequency to the nominal frequency and, for a synchronous area consisting of more than one LFC area, to restore power balance to the scheduled value.

Furthermore, a Balancing Service Provider or BSP is defined according to the Article 2(6) of the commission regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing, hereafter referred to as EBGL:

- 'Balancing Service Provider' means a market participant with reserve-providing units or reserve-providing groups able to provide balancing services to TSOs.

4.2 Objective

The main objective of the LFCBOA is to determine the dimensioning rules for Frequency Restoration Reserves or 'FRR', and specify common operational processes to fulfil the "frequency restoration quality target parameters" by using the frequency restoration process as defined in Article 3 of the SOGL, and specified in Article 143 of the SOGL. The FRCE or 'frequency restoration control error' is the control error for the 'Frequency Restoration Process' or 'FRP' which is equal to the area control error 'ACE' of a LFC area or equal to the frequency deviation where the LFC area geographically corresponds to the synchronous area. For the Elia LFC block, this is therefore equal to the ACE, defined in Article 3 of the SOGL.

³Note that when referring to reserve capacity on FRR, ELIA refers to all reserve capacity available to the TSO to cover the needs following the dimensioning rules on FRR defined in the SOGL. However, the commission regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing, hereafter referred to as EBGL, refers to different means to cover these needs for reserve capacity on FRR and ELIA refers to balancing capacity when referring to procured or contracted reserve capacity by means of monthly, weekly, or even daily auctions when relevant. As defined in Article 2 of the EBGL :

- 'balancing capacity' means a volume of reserve capacity that a balancing service provider has agreed to hold and in respect to which the balancing service provider has agreed to submit bids for a corresponding volume of balancing energy to the TSO for the duration of the contract

Note that positive reserve capacity refers to upward capacity to cover production shortages (positive LFC block imbalances), while negative reserve capacity refers to production excesses (negative LFC block imbalances).

The subject matter of the SOGL is to safeguard operational security, frequency quality and the efficient use of the interconnected system and resources as specified in Article 1 of the SOGL, including the rules aiming at the establishment of a Union framework for load-frequency control and reserves. By means of determining the dimensioning rules for FRR and specifying the operational processes to fulfil the load-frequency obligations, the LFCBOA contributes to the objective specified in Article 4 of the SOGL:

- a) determining common operational security requirements and principles;
- b) determining common interconnected system operational planning principles;
- c) ensuring the conditions for maintaining operational security throughout the Union;
- d) ensuring the conditions for maintaining a frequency quality level of all synchronous areas throughout the Union;
- e) promoting the coordination of system operation and operational planning;
- f) ensuring and enhancing the transparency and reliability of information on transmission system operation by means of describing the dimensioning rules;
- g) contributing to the efficient operation and development of the electricity transmission system and electricity sector in the Union.

Article 119(1) of the SOGL lists the requirements of the LFCBOA. Note that with one TSO in the ELIA LFC block, the cooperation of TSOs within the LFC blocks is not relevant, as is therefore part of the elements to be covered on the LFCBOA. Nevertheless, the definition of dimensioning rules and the operational processes related to ensuring acceptable quality of the ACE of FRCE are relevant and described in this document.

Note that this document is in line with Article 211 of the Code of Conduct. This Article requests that the needs for balancing services other than the FCR shall be determined by the transmission system operator for the LFC block in accordance with Article 119.1 of the SOGL. The TSO shall communicate his evaluation method for those needs to the CREG for approval in accordance with Articles 6.3(e) and 119.2 of the SOGL.

The supporting document has been developed in recognition of the fact that the LFCBOA, which will become a legally binding document after NRAs' approval, inevitably cannot provide the level of explanation, which some parties may desire. Therefore, this document aims to provide interested parties with greater descriptive information and explanation of the methodology text contained in the LFCBOA.

4.3 Timing for implementation

Article 6(6) of the SOGL requires Elia to define a proposed timescale for implementation. The modifications presented in Section 3.1, 3.2 and 3.3, mainly concerning the aFRR dimensioning method, are planned to enter in to force on October 1, 2024 after the approval by CREG. Note that the modifications will enter into force after the implementation of the aFRR balancing capacity gate closure time at 9 AM D-1 after approval in a next version of the Terms and Conditions for balancing service providers for Frequency Restoration Reserve with automatic activation (aFRR), hereafter referred to as T&C BSP aFRR.

A parallel run for which the results will be published on daily basis, but without effect on the reserve dimensioning and balancing capacity procurement will be foreseen between July 1, 2024 and September 30, 2024. Until October 1, 2024 the aFRR dimensioning method specified in the version of the LFC BOA, approved by CREG on July 14, 2022 will be applied. In practice, this means that the up- and downward aFRR needs will remain fixed at 117 MW.

In accordance with article 3(8)(g) of the implementation framework for the European platform for the exchange of balancing energy from aFRR, the modification of the aFRR full activation time is foreseen before December 18, 2024 and will be coupled with the implementation of the modification of the value in the Terms and Conditions BSP aFRR.

Note that the new modifications concerning the exceptional balancing measures specified in Article 7, Article 12 and Article 13 will enter into force together with the modifications already approved by CREG on February 10, 2022. It was specified that Article 7, Article 12, Article 13, as well as the decrease in full activation time for mFRR in Article 14 of the LFCBOA, approved by the CREG on February 10, 2022, still needed to enter into force. These were foreseen to enter into force together with the entry into force of the next version of the Terms and Conditions for balancing service providers for Frequency Restoration Reserve with manual activation (mFRR), hereafter referred to as T&C BSP mFRR.

This way, implementation of exceptional balancing measures was coupled to the implementation of explicit bidding for mFRR. Part of the exceptional balancing measures are based on the calculation of available balancing means, which is impacted by the implementation of explicit bidding for mFRR. For reason of simplification, and avoiding temporary developments, the implementation of both evolutions is coupled. In addition, also the implementation of the 12.5' mFRR FAT is foreseen to be coupled with explicit bidding, both requiring a modification of the Terms and Conditions BSP mFRR.

4.4 Subject

Article 119(1) of the SOGL provides an exhaustive list of the methodologies and conditions to be developed in the LFC block operational agreement. According to Article 119(1) of the SOGL, the methodologies and conditions according to paragraph a, d e, f, i, j, m and n (Table 1) are without application in the Elia LFC block :

- Elements under a., d., e. and j. are not applicable since Elia is the only TSO in the Elia LFC Block, or due to the fact that the LFC Block consists in only one LFC area.
- The element under f. is not applicable as Elia does not apply additional requirements on technical infrastructure other as defined in the SAOA following Article 151(2) of the SOGL.
- The element under m. is not applicable as Elia does not apply additional limits on the exchange on FCR with other LFC blocks other as the limit specified in Article 163(2) of the SOGL.
- The element under i. is not applicable as RR is currently not applied in the Elia LFC Block.
- The element under n. is not applicable as reserve exchange for FRR or RR is currently not applied in the Elia LFC block.

Table 1 : Overview of non-relevant methodologies and conditions according to Article 119 of the SOGL

a.	where the LFC block consists of more than one LFC area, FRCE target parameters for each LFC area defined in accordance with Article 128(4);
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d.	where the LFC block is operated by more than one TSO, the specific allocation of responsibilities between TSOs within the LFC block in accordance with Article 141(9);
e.	if applicable, appointment of the TSO responsible for the tasks in Article 145(6);
f.	additional requirements for the availability, reliability and redundancy of technical infrastructure defined in accordance with Article 151(3);
i.	the RR dimensioning rules defined in accordance with Article 160(2);
j.	where the LFC block is operated by more than one TSO, the specific allocation of responsibilities defined in accordance with Article 157(3), and, if applicable, the specific allocation of responsibilities defined in accordance Article 160(6);
m.	if applicable, any limits on the exchange of FCR between the LFC areas of the different LFC blocks within the CE synchronous area and the exchange of FRR or RR between the LFC areas of an LFC block of a synchronous area consisting of more than one LFC block defined in accordance with Article 163(2), Article 167 and Article 169(2);
n.	the roles and the responsibilities of the reserve connecting TSO, the reserve receiving TSO and of the affected TSO for the exchange of FRR and/or RR with TSOs of other LFC blocks defined in accordance with Article 165(6);

According to Article 6(3.e) of the SOGL, the methodologies and conditions determined in c., h., q. and r. shall be submitted to the CREG for approval: the methodologies and conditions in c., q. and r. are specified in paragraph 2, while the methodology in h. is specified in paragraph 3.

Table 2 : Overview of relevant methodologies and conditions according to Article 119 of the SOGL, specified in Article 6(3.e) of the SOGL

c.	ramping restrictions for active power output in accordance with Article 137(3) and (4);
h.	the FRR dimensioning rules in accordance with Article 157(1);
q.	coordination actions aiming to reduce FRCE as defined in Article 152(14);
r.	measures to reduce FRCE by requiring changes in the active power production or consumption of power generating modules and demand units in accordance with Article 152(16);

According to Article 119 of the SOGL the methodologies and conditions in b., g., k., l., o. and p. are specified in Title 4.

Table 3 : Overview of relevant methodologies and conditions according to Article 119, not specified in Article 6(3.e) of the SOGL

b.	LFC block monitor in accordance with Article 134(1);
g.	operational procedures in case of exhausted FRR or RR in accordance with Article 152(8) of the SOGL;
k.	the escalation procedure defined in accordance with Article 157(4) and, if applicable, the escalation procedure defined in accordance with Article 160(7)
l.	the FRR availability requirements, the requirements on the control quality defined in accordance with Article 158(2), and if applicable, the RR availability requirements and the requirements on the control quality defined in accordance with Article 161(2);
o.	the roles and the responsibilities of the control capability providing TSO, the control capability receiving TSO and of the affected TSO for the sharing of FRR and RR defined in accordance with Article 166(7);
p.	the roles and the responsibilities of the control capability providing TSO, the control capability receiving TSO and of the affected TSO for the sharing of FRR and RR between synchronous areas in accordance with Article 175(2);

Note that g., k., q. of Article 119 concern the exceptional balancing measures. The methodologies and conditions in the SOGL are respectively discussed in Section 2.3, 4.2 and 4.3. **These measures concern balancing situations which are not expected to be resolved with the available FRR following the dimensioning methodology specified in the LFC block operational agreement.** It is to be noted that Elia's reserve dimensioning, in line with the requirements specified in Article 157 of the SOGL and this document, is only designed to cover reasonable risks (being 99.0% if the expected LFC block imbalance risk and the dimensioning incident), and situations can still occur resulting in a high uncovered LFC block imbalance and corresponding impact on the Area Control Error. **However, such events are expected to remain exceptional.**

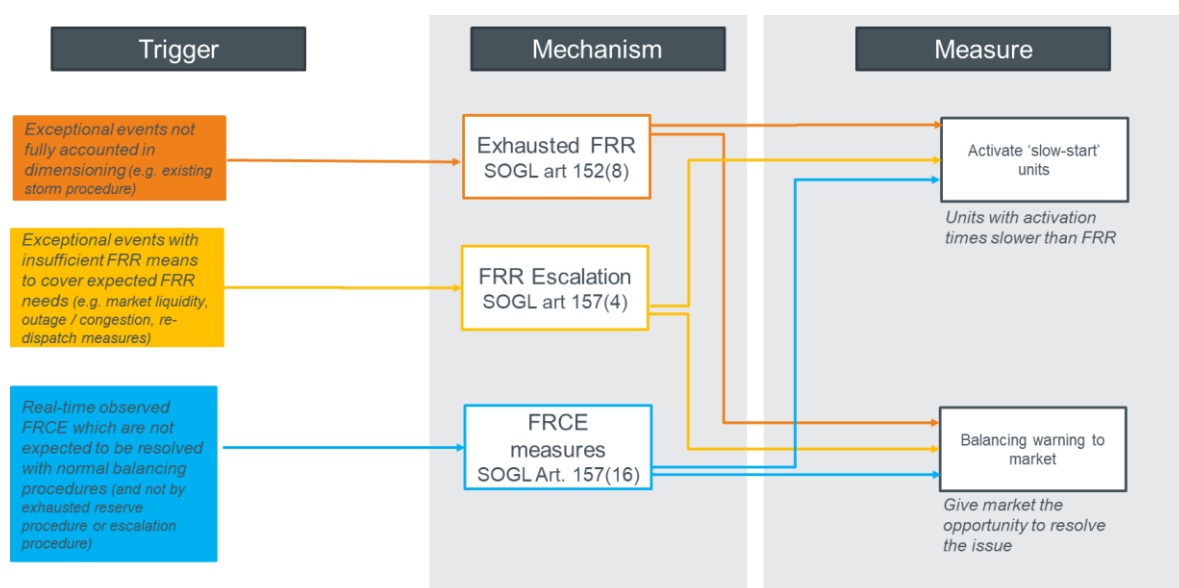


Figure 1. overview of exceptional balancing measures

The timing and high level goal of each measure is shown in Figure 1 and specified as:

- operational procedures for exhausted FRR specified in Article 152(8) of the SOGL which aims to access additional reserves when (risk of) depleting reserves following events not fully accounted in the FRR needs. This procedure can be used between the day-ahead until close to real-time ;
- escalation procedure for FRR specified in Article 157(4) which aims to access additional reserve capacity when (risk of) not adequately covering the dimensioned FRR needs. This procedure can be used between the day-ahead until close to real-time ;
- measures to reduce FCRE specified in Article 152(16) which aims to procedure when facing high FRCE values. This procedure can only be used in real-time.

These measures may result in the activation of units that cannot be activated in compliance with the FRR processes. Note that the application of these measures is currently focused on units that provide MW Schedules subject to the Terms and Conditions Scheduling Agent but that cannot be activated via the FRR processes. Following a study on establishing a framework enabling all types of assets to participate to the exceptional balancing measures⁴, Elia has foreseen in the LFCBOA the option to also activate units that do not provide MW Schedules in the context of the Terms and Conditions Scheduling Agent (e.g., demand facilities), that cannot be activated via the FRR processes and that would offer their available active power on a voluntary basis. Additional actions are needed to enable the actual use of these assets as part of the exceptional balancing measures (e.g. amending the Balancing Rules, developing a new contractual framework for offering this flexibility to Elia and

⁴ The study is available on <https://www.elia.be/en/public-consultation/20210820-public-consultation-of-the-study-on-a-technology-neutral-framework>.

performing the necessary implementations), but with the changes currently proposed no further amendment of the LFCBOA should be necessary.

Measures related to emergency conditions are defined in the methodologies compliant with Commission Regulation (EU) 2017/2196 of 24 November 2017 establishing a network code on electricity emergency and restoration are not in the scope of the LFCBOA. Measures related to the normal activation procedures of reserve capacity are compliant with the reserve process activation structure specified in Article 140 of the SOGL and are not in the scope of this LFCBOA. Measures related to the procedures for exhausted FCR are specified in the synchronous area operational agreement in line with Article 157(7) of the SOGL.

5 Methodologies in accordance with Article 6

5.1 Ramping restrictions for active power output in accordance with Article 137(3) and (4) of the SOGL.

In order to manage the frequency in a synchronous area, there is a need to limit the variation of power injection or withdrawal of the HVDC interconnectors connected towards another synchronous area. Indeed HVDC interconnections are able to deal with nearly infinite ramping rate, which would not be suitable to maintain a constant frequency. Such infinite variations would solicit the FCR on each side, and therefore would weaken the system as less FCR would be available to face a possible outage at the same time. This is not the purpose of FCR and it is preferable to mitigate the impact on the FCR by applying a ramping restriction.

This ramping restriction is also a way to better match the actual physical change in injections or withdrawals by power generating modules or demand, which are also not infinite (even though the commercial trade schedules assume infinite behavior). By this, the impact caused by the variation of power injections or withdrawals on the balance of the LFC block where the HVDC is connected to is limited. While the need for such ramping restriction is present for all synchronous areas, it is especially relevant for smaller synchronous areas such as Great Britain (GB).

Common practice for all interconnectors linking the synchronous area of Continental Europe (CE) and GB is to limit the ramping rate to 100 MW/min. This value is explicitly specified in the LFCBOA of the Elia LFC block for all interconnectors between Elia LFC block and the LFC block of Great-Britain under normal operating conditions. This value is therefore reflected into the agreements for each interconnector between the Elia LFC block and the LFC block of Great-Britain. While the term LFC Block is defined in Article 3 of the SOGL, this terminology is also used to refer to the control zone of Great Britain in case of a Brexit.

Note that each TSO committed to a non-discriminatory treatment of all interconnectors linking the same two synchronous area. The enforced value will also be published on each TSO's website. Any future modification of the ramping rate for the interconnectors between Elia LFC block and LFC block of Great-Britain will require a modification of the Elia LFC block operational agreement.

In order to deal with exceptional situations (such as massive simultaneous flow changes on all interconnectors between GB and CE) in the small GB synchronous area, National Grid requested Elia to have the exceptional measure to further restrict the ramping rate. In this case, Elia, will accept to restrict equitably the ramp rates of all interconnectors between Elia LFC block and the LFC block of Great-Britain. Equitable refers to an equal restriction in terms of ramp rate between all interconnectors between Elia LFC block and the LFC block of Great-Britain. This would be done only when the absence of further limitation of the ramping rate would lead National Grid to emergency

state or if National Grid is already in emergency. In these conditions, there is an obligation for mutual assistance between TSOs (as described in NC Emergency & Restoration), unless it would lead Elia itself into emergency. Elia does not define a similar requirement upon Elia's request in the Elia LFCBOA because it does not foresee to use these additional restrictions. When this measure is applied, a report will be issued in accordance with Article 14 paragraph 4 of NC Emergency & Restoration.

In the future, it is expected that a more elaborated methodology will be established in order to coordinate the ramping of different cables between two synchronous areas by defining a combined ramping rate restrictions in the SAOA (pursuant to Art. 137(1)). This would be the ideal situation to mitigate the impact on the frequency. We note however that this methodology is not ready yet and the current practice of fixed ramping rate is seen as sufficient at synchronous area level for both CE and GB.

Elia currently does not implement technological restrictions of power generating modules and demand units to support the fulfilment of the FRCE target parameters of the LFC block and to alleviate deterministic frequency deviations as specified in Article 137(4) of the SOGL. If such measures would be needed at a certain moment in time, the LFC block operational agreement shall be updated after completion of the relevant approval process.

5.2 Coordinated actions aiming to reduce the FRCE as defined in Article 152(14)

Article 152(14) of the SOGL requires the LFC block monitor, in this case Elia (paragraph 3.1), to inform other TSOs of the LFC block when identifying any violation of the FRCE limits identified in Article 152(12 and 13) of the SOGL, and to implement coordinated actions with other TSOs of the LFC block to reduce the FRCE.

Obviously, being the sole TSO in the LFC block, this article is not applicable for the Elia LFCBOA. Elia can however apply FRCE measures on an individual basis as specified in paragraph 2.3.

5.3 Measures to reduce the FRCE by requiring changes in the active power production or consumption of power generating modules and demand units in accordance with Article 152(16)

Article 152(16) of the SOGL requires Elia to specify, in the LFC block operational agreement, measures to reduce the FRCE by means of changes in the active power production or consumption of power generating modules and demand units within their area.

On the one hand, these concern measures which are taken before the measures specified following the emergency states are defined in COMMISSION REGULATION (EU) 2017/2196 of 24 November 2017 establishing a network code on electricity emergency and restoration (hereafter: NC E&R). The link with procedures defined in the NC E&R is only indirect: only when too high ACE / FRCE gives rise to frequency deviations this relates to the activation criteria of Article 18 NC E&R "frequency deviation management procedure". If there are overloaded (border) lines, Article 19 "power flow management procedure" may be applied.

On the other hand, as the FRCE (ACE) is the result of the activation of FRR following LFC block imbalances, these measure concern measures which are taken after the activation of FRR (aFRR and mFRR) following the processes described in the SOGL for which the reserve process activation structure is defined in Article 140 of the SOGL.

In exceptional circumstances, and on top of the measures and procedures specified in the paragraphs above, Elia reserves the right to activate units which cannot be activated under the specifications of FRR defined in the SOGL. This in order to reduce an elevated FRCE which is not expected to be controlled by the frequency restoration process as defined in Article 143 of the SOGL, nor by means of the mitigation measures as part of the operational procedures for exhausted FRR (cf. Article 12, cf. Section 7.2) and/or of the escalation procedure for FRR (cf. Article 13, Section 7.3). The measures to reduce the FRCE are activated if Elia observes:

- as specified in Article 152(12), the 1-minute average of the FRCE of a LFC block going above the Level 2 FRCE range at least during the time necessary to restore frequency and where the TSOs of the LFC block does not expect that FRCE will be sufficiently reduced by undertaking the actions as specified in Section B-9-1 of the synchronous area operational agreement in accordance Article 152(15) of the SOGL ;
- as specified in Article 152(13), the FRCE of a LFC block exceeding 25 % of the reference incident of the synchronous area for more than 30 consecutive minutes and where the TSO of that LFC block does not expect to reduce sufficiently the FRCE with the actions taken pursuant to Article 152(15) of the SOGL and specified in Section B-9-1 of the synchronous area operational agreement.

Following the nature of the triggers, this measure is only applicable in the close-to-real-time frame as it based on the real-time observation and evolution of the FRCE. In case triggered, Elia can make use of 5 measures:

- A. publish a balancing warning communication asking all BSPs to submit additional FRR non-contracted balancing energy bids and informing all BRPs such that they can adapt injections and off-take in their portfolio accordingly;
- B. activate remaining energy on FRR balancing energy bids which is available but which could no longer be selected for activation on the balancing energy exchange platforms. This can concern the following cases:
 - the volume on an mFRR energy bid that is partially selected for activation (i.e., the marginal bid in a selection). The entire bid and not only the already activated part of the volume is excluded from the merit order in case there would follow other TSO demands (for direct activation) in the concerned direction in the same quarter-hour;
 - the same applies for unselected mFRR energy bids that are associated to a selected bid via a parent-child-relation. All bids in the parent-child-relation are excluded from the merit order used for direction activations following in the same quarter-hour.
- C. activate units subject to the Terms and Conditions Scheduling Agent, in line with Article 130 of the Code of Conduct, and that cannot be activated via the FRR processes;
- D. activate units that do not provide MW schedules in the context of the Terms and Conditions Scheduling Agent, that cannot be activated via the FRR processes and that offer their available active power on a voluntary basis;
- E. request other additional changes in the active power production or consumption of power generating modules and demand units within their area.

For taking the measures specified in point C. and D., ELIA will strive towards techno-economic efficiency by taking into account the maximum and minimum output, start-up time, start-up costs and other technical constraints if relevant.

The flexibility activated by ELIA via this procedure is limited to the capacity needed to bring the large FRCE back to an acceptable level (i.e. below the conditions specified in Article 152(12) and 152(13) of the SOGL). Elia expects that reverting to this measure should only happen in very exceptional circumstances (and occurrence is expected to remain rare) because adequate imbalance prices should give the Balancing Responsible Parties the right incentives to avoid that their portfolio imbalances are triggering such events.

Elia will prepare, at least on annual basis, an overview with a list of events following the triggers specified above, as well as a short motivation on the use of one or more of the above-mentioned measures.

At the latest 15 working days after the use of one of the measures B., C., D. and E. specified above, ELIA shall prepare a report containing a description and justification for this action and submit it to the relevant regulatory authority. The report shall at least contain:

- A description of the exceptional event;
- The result of the evaluations carried out in accordance with the triggers discussed above, including the values of the parameters mentioned and the timing of those evaluations;
- The energy activated per unit and per balancing energy market time unit and the attained techno-economic efficiency, including a justification for deviating from the techno-economic optimum, if applicable;
- The lessons learned from the exceptional event and, if relevant;
- concrete recommendations that could ease the management of the encountered exceptional events;
- actions Elia intends to take, or is taking, in order to verify or enforce the compliance of market parties with their contractual obligations towards Elia.

6 FRR dimensioning methodology in accordance with Article 157 and Article 6

With this new version of the LFCBOA, foreseen to enter into force in 2020⁵, Elia will implement an advanced 'dynamic' dimensioning methodology for sizing the positive and negative FRR needs. This method is based on a daily calculation of the FRR reserve capacity for 6 blocks of 4 hours for the next day. This dimensioning methodology for positive and negative reserve capacity is specified in the LFCBOA in accordance with Article 211 of the Code of Conduct. Article 211 specifies that the FRR reserve capacity needs are determined by Elia in the LFCBOA, pursuant to Article 119(1) of the SOGL

⁵ Until 2019 included, the method for the dimensioning of positive reserve capacity was based on a 'static' dimensioning method conducting a calculation of the required positive reserve capacity on a yearly basis. The method for the dimensioning of negative reserve capacity was based on a simplified 'dynamic' dimensioning method conducting a calculation of the required negative reserve capacity on a daily basis.

and the dimensioning methodology is submitted to CREG for approval according to Article 6(3) and 119(2) of the SOGL.

Article 211 of the Code of Conduct also specifies that ELIA shall submit, after a public consultation, at the same time with its proposal for the above-mentioned methodology for dimensioning the FRR needs, the methodology for determining the FRR means, i.e. for each of the balancing services, the balancing capacity which shall be procured from balancing service providers within the LFC block. This methodology shall be in accordance with Article 32(1) of the EBGL. This proposal shall be subject to a separate document referred to as the “LFC Means”.

In accordance with European and Belgian legal requirements, ELIA makes a distinction between FRR needs, and the required FRR means (Figure 2):

- **FRR needs** are determined as the required reserve capacity on FRR, as well as the ratio on aFRR and mFRR, for covering the expected LFC block imbalances. This calculation is based on prediction error risks and forced outage risks, within the ELIA LFC block. The dimensioning rules for the FRR needs are based on the principles described in Article 157 of the SOGL. ELIA (being the sole TSO in its LFC block) is required to have sufficient reserve capacity on FRR at any time in accordance with the dimensioning rules. The dimensioning rules for the FRR needs also determine the maximum sharing capacity which can be accounted in the dimensioning.
- **FRR means** refer to the volumes of the different types of reserve capacity, i.e. aFRR and mFRR, covering the FRR needs following the FRR dimensioning rules. Article 32 of the EBGL defines that the reserve capacity requirements can be ensured by the procurement of balancing capacity, the sharing of reserves and non-contracted balancing energy bids. The procurement of balancing capacity (to be contracted by ELIA) depends therefore on the estimated availability of FRR reserve sharing capabilities and non-contracted FRR balancing energy bids, also referred to as “free bids”.

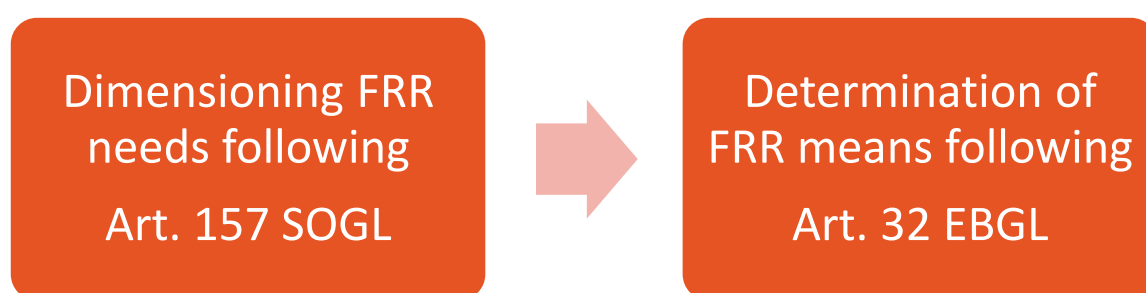


Figure 2 : Distinction between the FRR needs and the FRR means

Consequently, when translating FRR needs to the required FRR means, ELIA takes into account the **FRR sharing agreements**. The maximum FRR sharing capacity which can be taken into account in the dimensioning of the FRR reserve capacity is determined in the dimensioning rules compliant with

Article 157(2) of the SOGL. The reserve capacity to be contracted is determined in accordance with Article 32(2) and Article 18 of the EBGL.

6.1 Dimensioning rules for the FRR reserve capacity needs

As required by Article 157(2)b of the SOGL, ELIA determines the positive and negative FRR needs based on a **probabilistic methodology**. The 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.

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 Article 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. In this respect, the CREG requested an amendment to consider imbalance netting in this minimum threshold, justifying this request in its Decision 2435: *“Since imbalance netting covers the imbalances of Elia’s LFC Block as an alternative to the reserve capacity in the form of FRR, CREG is of the opinion that the reserve capacity in the form of FRR is sufficient if it covers the imbalances of the LFC Block, i.e. after taking into account imbalance netting”*. Although Elia does not share the interpretation that the dimensioning rules in the SOGL effectively aim to take into account IGCC, it agrees to include the requested adaptation in the minimum thresholds specified in this paragraph as it expects no effects in practice in the short term (as dimensioning is currently determined by the result of the deterministic and the probabilistic methodology). In addition, Elia stresses that this adaptation should in no way suggest that the inclusion of imbalance netting in the probabilistic methodology would be acceptable.

Both methodologies are used in parallel to calculate the positive and negative FRR reserve capacity required for every quarter-hour of the next day (Figure 3). The calculation is conducted before 7 AM. The required reserve capacity for each quarter-hour is determined based on the maximum value of the deterministic and probabilistic methodology.

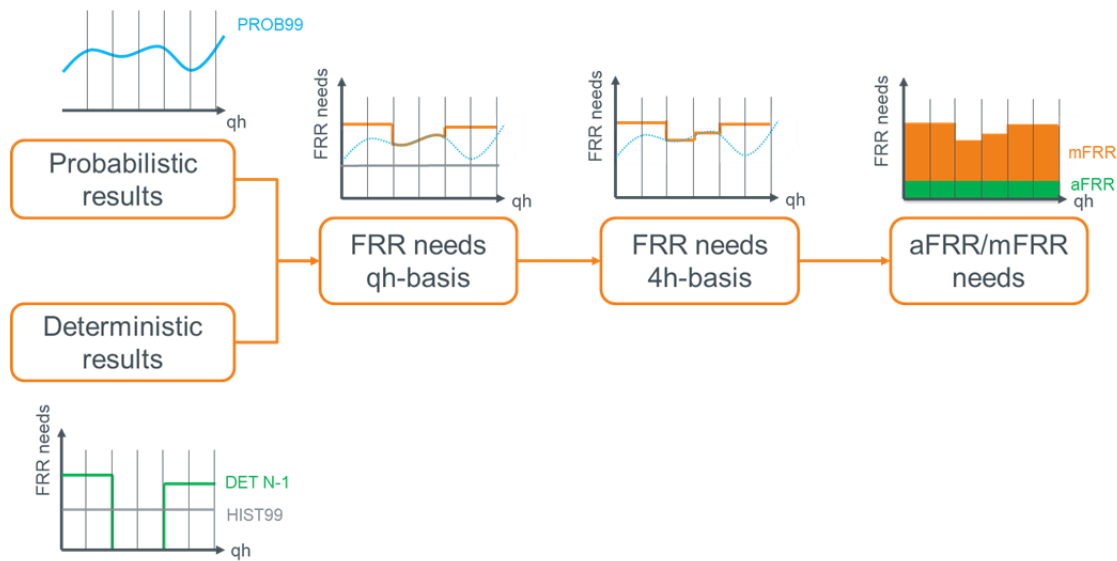


Figure 3 : Calculation process of the FRR/aFRR/mFRR needs

The maximum value over each block of 4 hours per direction is taken in order to obtain a 4-hourly resolution, aligned with the mFRR balancing capacity product. In a final step, this FRR capacity is split into an aFRR and a mFRR need with the methodology elaborated in Section 6.2.

Pursuant to Article 157(2)b, ELIA determines the reserve capacity on FRR of the LFC block in a way sufficient to respect the **FRCE target parameters** in accordance with Article 128 of the SOGL. ELIA will monitor and report on the FRCE target parameters, compliant with obligations as LFC Block Monitor (paragraph 7.1), and regularly assess if the methodology and the resulting balancing capacity meets this requirement.

The probabilistic methodology to dimension the FRR reserve capacity needs is based on a convolution of two distribution curves, one representing the prediction risk (step 1) and another representing the forced outage risk (step 2). After the convolution, the new distribution is decomposed in a distribution of potential positive LFC block imbalances, and a distribution of potential negative LFC block imbalances. This calculation is conducted for each-quarter hour of the next day, and the 99.0% percentile of each probability distribution curve determines the minimum positive and negative required reserve capacity.

This result is then compared with (1) the deterministic methodology to determine the dimensioning incident for each corresponding period which also determines the minimum FRR reserve capacity. The daily FRR dimensioning method is thus elaborated in detail in three steps as represented in Figure 4:

- (1) **step 1: calculation of the prediction risk;**
- (2) **step 2: calculation of the outage risk;**
- (3) **step 3: calculation of the FRR needs**

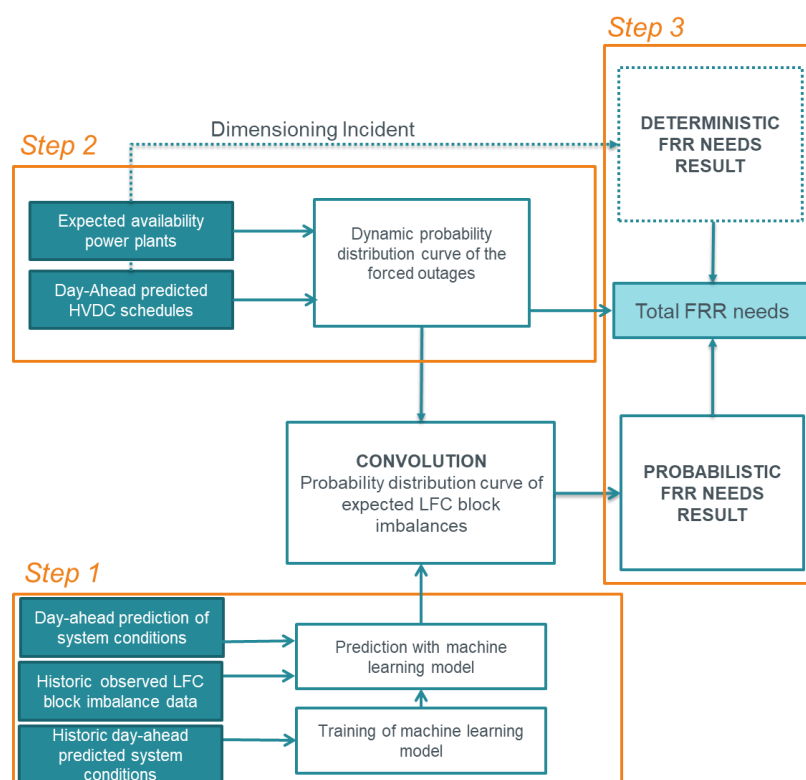


Figure 4 : General overview of dimensioning of the FRR needs

6.1.1 Step 1: Calculation of the prediction risk

The probability distribution representing the **prediction risk (PE)** is based on historic LFC block imbalances, formerly referred to as system imbalances. The LFC block imbalances are based on consecutive historical records with a resolution of 15 minutes and includes a period of two years, ending not before the last day of the second month before the month of the day for which the reserve capacity needs are calculated. For instance, the calculation for February 1, 2019 uses data until at least 31 December 2018. The time series, and thus the probability distribution curve, is thus updated every month, taking into account the latest LFC block imbalances observed⁶.

The time series is filtered to remove periods with (1) forced outages of power plants larger as 50 MW, or NEMO Link for the length of the outage, up to a period of 8 hours, (2) periods with data quality problems (e.g. missing data) or (3) particular events (e.g. market decoupling). This allows to take into account the fact that such events are not representative if assessed over a period of only two years. Note that expected forced outages are taken into account by means of a separate synthetic probability distribution in step 2. The probability distribution of the prediction risk is based on a selection of LFC block imbalances based on the historical records.

An important difference with the former static dimensioning methodologies is that this methodology does not require any extrapolation of the observed system imbalance in order to account for

⁶ The time period between the end of the time series and the calculation of the reserve capacity needs allows the training of the algorithms, conducted one month before the day for which the reserve needs are determined. A monthly training resolution is determined based on a sensitivity analysis in the dynamic dimensioning study: <https://www.elia.be/en/electricity-market-and-system/document-library>

incremental capacity of renewable generation, or potential improvement factors concerning the future LFC block imbalances (following better abilities of BRPs to cope with portfolio imbalances). This is explained as the FRR needs are now determined for the next day, for which latest current system and market assumptions are known and included in the latest historical data of the LFC block imbalances, which are thus representative for the next day for which the FRR needs are dimensioned.

Four methodologies to determine this selection of LFC block imbalances are implemented: an advanced statistical model (referred to as “hybrid”) is used combining two well-known machine learning algorithms to construct the distribution curves, i.e. clustering (referred to as “k-means”) and nearest neighboring (referred to as “knn”) (Figure 5). A combination of two methods allows to make the result less sensitive to varying predictions of system conditions. A “static” method with reduced data requirements is used to determine a monthly fallback value.

In general, each of the machine learning methodologies is based on a monthly training phase, in which historic data is collected and if relevant, the algorithms are trained, and a daily prediction phase in which day-ahead predictions are used to associate the predicted system conditions with the prediction risks. This prediction risk is expressed by means of probability distribution of historic LFC block imbalances. These distributions are modelled by means of Kernel Density Estimator as explained in Annex 6 (Section 6.2.3).

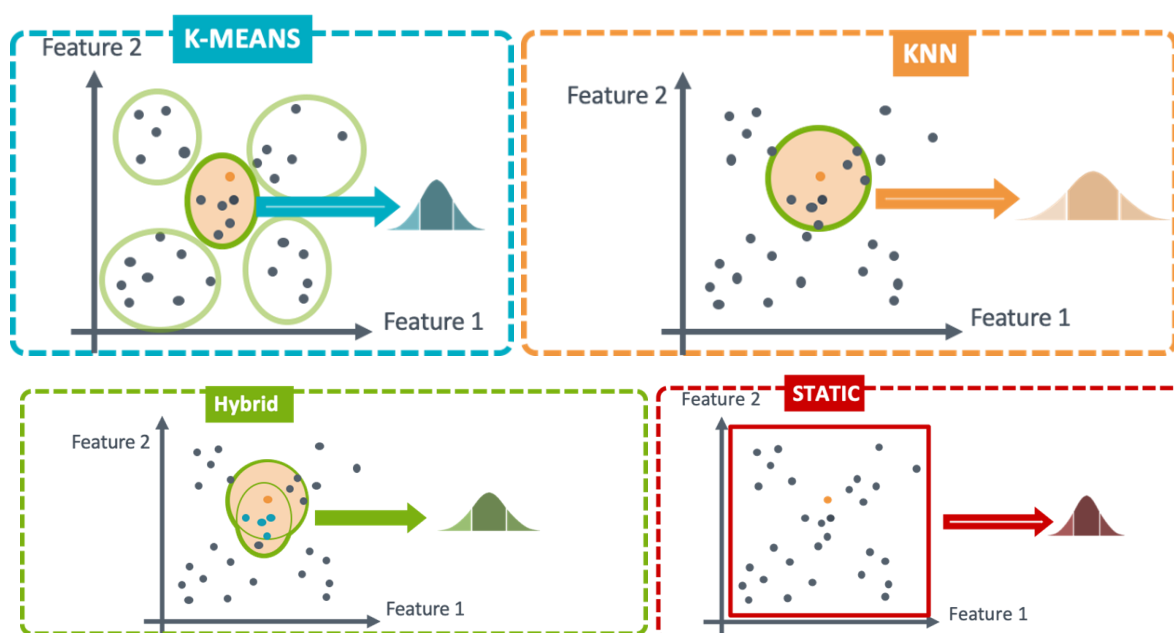


Figure 5 : Graphical representation of the algorithms used to determine the prediction risk

6.1.1.1 STATIC PE

In the static methodology, the time series of filtered historic observations of the LFC block imbalances are considered to build the probability density function of the prediction risk, except of course those filtered out as specified above. By consequence, no relations with system conditions (referred to as features) are taken into account. As illustrated on Figure 5-STATIC, all historical filtered observations are used to build the distribution, no matter the features values.

The probability distribution is determined once per month (the month before the month of the day for which the reserve capacity is calculated) based on all historical records specified above. The distribution remains constant and valid for the next month. The result of this “monthly” static approach is therefore not the same as the former yearly static method applied for a yearly dimensioning, implementing extrapolations to capture the incremental capacity of variable renewable energy sources.

6.1.1.2 KMEANS PE

The KMEANS method estimates the prediction risk of a specific quarter-hour based on the LFC block imbalances of historic observations of LFC block imbalances during periods with similar system conditions (referred to as features). In this method, the filtered historical records of LFC block imbalances are categorized in a predefined set of clusters (i.e. 15) by means of a predefined list of scaled features (i.e. categories of observations that exhibit close system conditions: onshore, offshore, photovoltaic, total load predictions, time of day, predicted solar and load gradients and temperature)⁷. Observations with system conditions belonging to the same cluster are considered to represent the same prediction risk. Each cluster is therefore associated with a probability distribution of the LFC block imbalance observations in that cluster. The output of the algorithm is illustrated in Figure 5-K-MEANS.

- In the training phase, the clusters are defined such that the distance between observations belonging to the same cluster are as small as possible. The “k-means clustering” machine learning algorithm of the Scikit-learn library for Python programming is used⁸. A more detailed description of the k-means clustering algorithm is found in Annex. For each of these homogenous clusters, a probability density function of the LFC block imbalance is built by only considering the observations belonging to this cluster.
- In the prediction phase, conducted day-ahead for each quarter-hour of the next day (typically 96), it is determined to which cluster the corresponding period belongs to, based on the value of the features for the corresponding period. As each cluster corresponds with a specific LFC block imbalance risk distribution, the relevant distribution can be selected for that quarter-hour.

6.1.1.3 KNN PE

As in the KMEANS-method, the KNN-method estimates the prediction risk at a specific quarter-hour based on a subset (cluster) of observations with similar system conditions (features). However, the KNN method differs from the KMEANS-method by the fact that each observation will be the center of the cluster with a predefined amount (i.e. 3500) of neighboring observations, as illustrated in Figure 5-KNN. These neighborhood is determined based on the same features as in the KMEANS-

⁷ The amount of clusters and list of features have been selected during the Proof of Concept presented in the dynamic dimensioning study: <https://www.elia.be/en/electricity-market-and-system/document-library>

⁸Specified in the Scikit-learn library for Python programming. <https://scikit-learn.org/stable/modules/generated/sklearn.cluster.KMeans.html> where parameters are determined as: `sklearn.cluster.KMeans(n_clusters=15, random_state=0)`. The `random_state` parameter value guarantees the deterministic behavior of the clustering algorithm, meaning that if the same input is given to the algorithm, it will always produce the same outputs. All other parameters are set at their default value.

method⁹. The observations in the neighborhood of the quarter-hour to predict are used to calculate a probability distribution of LFC block imbalances corresponding to that neighborhood.

- In the training phase, the “k-nearest neighbor” machine learning algorithm of the Scikit-learn library for Python programming is used¹⁰ with its default parameters except `n_clusters=15` and `random_state=0`. A more detailed description of the k-means clustering algorithm is found in Annex.
- During this prediction phase, conducted day-ahead for each quarter-hour of the next day (typically 96), the set of nearest neighbors is determined based on the features related to the specific quarter-hour for which the prediction is conducted. Each set of 3500 nearest neighbors corresponds with a specific LFC block imbalance risk distribution.

6.1.1.4 HYBRID PE

The HYBRID-method combines KMEANS and KNN approaches. Observations belonging to the relevant cluster (KMEANS) and to the relevant neighborhood (KNN) are used to estimate the imbalance risk probability distribution. Some observations (blue dots in Figure 5-HYBRID) are selected by both KNN and KMEANS methods, whereas other observations are selected by only one of the two methods (black dots in orange areas in Figure 5-HYBRID). An observation present in both clusters is counted twice since there is more certainty in their relevance to model the prediction risk. Again, the LFC block imbalance distributions in this new cluster of observations will result in a LFC block imbalance distributions.

6.1.2 Step 2: Calculation of the forced outage risk

In order to ensure an accurate probability distribution of the expected forced outages for the next day, a calculation is conducted representing the forced outages which might occur in the quarter-hour for which the FRR needs are calculated. This calculation takes into account all forced outage risks resulting in positive (i.e. power plant outages and HVDC-interconnector outages) and negative LFC block imbalances (i.e. HVDC-interconnector outages) in one probability distribution curve, as these can compensate each other when simultaneously occurring.

In a dynamic approach, the probability distribution is thus determined on a daily basis, estimating the forced outage risk for each quarter-hour of the next day based on :

- (1) the expected schedule of Nemo Link, i.e. the HVDC-interconnector between the ELIA and NGET LFC block, and potential capacity limitations, as well as the available capacity;
- (2) the expected available maximum capacity of generation units. Indeed, an unavailability of (part of) the capacity of a generation unit, taking into account the technical maximal power available;

⁹The amount of neighbors and list of features have been selected during the Proof of Concept presented in the dynamic dimensioning study: <https://www.elia.be/en/electricity-market-and-system/document-library>

¹⁰Specified in the Scikit-learn library for Python programming <https://scikit-learn.org/stable/modules/generated/sklearn.neighbors.NearestNeighbors.html#sklearn.neighbors.NearestNeighbors> where parameters are determined as: `sklearn.neighbors.NearestNeighbors(n_neighbors=3500)`. All other parameters are set at their default value.

The calculation takes into account all forced outages resulting in positive, as well as negative LFC block imbalances by means of a list of all power plants larger than 50 MW and NEMO Link, specifying for each asset the **available maximum capacity, the outage duration and the outage probability**. Note that unavailability of the offshore generation park is not considered as a forced outage, following the conclusion of an offshore integration study published in 2019¹¹.

The exclusion of offshore storm risk in the calculation of production unit failures following the conclusions of a study on the impact of this risk

The observed correlation of the behavior of the various offshore parks currently connected to the system is very high, especially during storms. This is mainly due to the geographical concentration of the wind farms but also to the technical characteristics of the wind turbines that compose them. In 2017, Elia conducted an analysis to specifically study the behavior of parks in the face of high wind speeds and to determine the predictability of this type of event.

The results of this analysis show that it is possible to anticipate the meteorological phenomena that have the greatest impact on offshore production (e. g. the most powerful storms), at least a few hours in advance. It is therefore possible for BRPs to cover the risk of imbalance caused by a storm. For the situation when the measures taken by BRPs are insufficient, Elia has developed a fall back mechanism.

As a result, the impact of offshore wind generation losses on the imbalance caused by a storm is not taken into account in the calculation of generation unit forced outages. Similarly, this case is not taken into account in the analysis of the dimensioning incident (N-1). Elia is developing specific measures to optimally manage storm events.

In the past, a Monte-Carlo analysis aimed at evaluating the probability density function of the forced outage risk. This distribution is now derived via an analytical methodology. Such a methodology has the advantage to be fully deterministic, i.e. two computations with same parameters will provided the exact same results. This is not the case for Monte-Carlo that is characterized by an inherent randomness.

In the analytical method, the density function is first computed with one single power plant. This density function is derived following the assumption that a power plant can have only two possible values of its contribution to the imbalance: 0 and its pMax. The probability for this power plant to contribute to the LFC block imbalance is based on a multiplication of the outage probability with the outage duration¹². In a second step a second power plant is considered in the distribution. Again, this power plant can only have two possible contributions to the imbalance: 0 or its pMax. All power plants and the Nemo Link are then successively incorporated in the distribution and the final outage risk can be derived.

¹¹ Elia : Study on Study on the integration of offshore wind in the Belgian balancing zone (2017): <https://www.elia.be/en/electricity-market-and-system/document-library>

¹² The exact formula used in the calculation of the probability to contributing to the imbalance due to an outage is $\frac{pd}{1+pd-p}$ where p is the outage probability and d is the outage duration.

The outage duration is predefined at 8 hours and represents the time for which a forced outage is assumed to impact the system imbalance. The outage probability depends on the technology type. Two methods are used to determine the available maximum capacity:

- **Static FO** : in which the probability distribution curve is determined analytically once a month taking into account the rated capacity of each generation unit and the rated capacity of the interconnectors with Great-Britain;
- **Dynamic FO** : where the probability distribution curve is determined daily for each quarter-hour of the next day taking into account :
 - The maximum available capacity of each generation unit taking into account latest information concerning the technical maximum capacity and unavailability of (part of) the installed capacity due to maintenance known at the moment of prediction ;
 - the predicted schedule of the HVDC-interconnector for the next day derived from the algorithm specified in Section 3.1.2.2. Where possible, limitations on maximum capacity known at the moment of the calculation are taken into account.

6.1.2.1 Forced outages of generating units

The loss of power due to a sudden failure of a generating plant is one of the determining factors for the dimensioning of FRR needs. The probability distribution of the unexpected power loss in a generating fleet over a certain period (specified as 8 hours) is obtained by taking into account the probability distributions of the loss of each generation unit larger as 100 MW during this period (a threshold of 50 MW is selected as a good trade-off between accuracy and impact on the calculation time). In this context, it is assumed that a unit can only be lost once in the period considered and that the failure of each power plant is independent of the failure of another power plant.

An independent and constant risk of failure over time is assumed for thermal and nuclear units. In the event of a failure, it is assumed that the unit has previously been operated at maximum power and no longer injects power after the failure. The failure risks of existing units were calculated by plant type based on data published in Elia's latest adequacy and flexibility study (2019) and is based on ENTSO-E transparency platform data (completed with internal data). This makes it possible to apprehend their risk of failure as an exponential function for the period in question, with average values.

Table 4 : average forced outage events per year (Elia adequacy and flexibility study 2019)

Outage rate	Number of FO per year 2020
Nuclear	1.6
Classical	6.1
CCGT	5.2
GT	2.8
TJ	2.2
Waste	1.3
CHP	3.5
Pumped storage	1.9

6.1.2.2 Forced outages of Nemo Link

The power loss due to a sudden failure of the Nemo Link interconnection is, similar to the failure of generating units, a determining factor for the sizing of the FRR. Because Nemo Link is the only

electrical connection between Belgium and the United Kingdom, a sudden loss of Nemo Link will have an effect on the LFC block imbalance.

This effect can be a positive or negative imbalance, depending on the scheduled position of the interconnection. If Nemo Link experiences a failure during export, this will have an effect on the negative imbalance (energy surplus), and vice versa for import (energy deficit). In doing so, Nemo Link is taken into account in the same way as two generation units (the duration of the period is also set at 8 hours): one with a capacity equal to the available import capacity, and one equal to the available export capacity. The average value of the probability of a failure of the HVDC interconnection is considered to be equal to 2 failures per year. This value is considered an acceptable value, based on experience with other HVDC cables. In Belgium, the only asset driving the forced outages in negative direction is the HVDC-interconnector between Belgium and the United Kingdom.

In a dynamic methodology, this results in four possibilities:

- **the interconnector is expected to be scheduled in import:** the interconnector does not affect the forced outage risk resulting in a positive system imbalance, and the interconnector is removed from the forced outage risk on the export-side ;
- **the interconnector is expected to be scheduled in export:** in this case the interconnector does affect the forced outage risk resulting in a negative system imbalance, and the interconnector is removed forced outage risk on the import-side ;
- **the interconnector is expected to be scheduled in maintenance:** in this case, the interconnector does not affect the forced outage risk resulting in a positive or negative system imbalance, and the interconnector is removed as a whole from the forced outage risk both on import and export side ;
- **the prediction on the interconnector's schedule is considered uncertain:** in this case the, the interconnector affect the forced outage risk in both directions.

The challenge lies in predicting the status of the HVDC-interconnector before the market outcome is known. A forecast is determined based on a flow forecasts for Belgium and the United Kingdom provided by an external service provider based on machine learning technology. This flow forecast allows Elia to predict the interconnector in import (expected import flow \geq threshold), export (expected export flow \geq threshold) and indecisive (expected flow $<$ threshold). A maintenance status is also communicated to Elia by the HVDC-interconnector operator in order to be taken into account in the day-ahead calculations.

The threshold is determined and fixed at 50 MW. If the expected flow in one of both directions is lower as 50 MW, the interconnector is considered as uncertain. The 50 MW is a parameter determining the uncertainty margin is determined by Elia by analyzing the ratio of accurate (situation where Nemo Link is correctly predicted in import or export) versus uncertain (situation where Nemo Link is predicted as indecisive) forecasts.

A flow forecast has been decided over a price forecast as for every investigated threshold the new prediction method provides a better forecast in terms of ratio accuracy and undefined. This is demonstrated in Figure 6 (up) showing for different price and flow thresholds the ratio % accurate forecasts (correct forecasts / informative forecasts) versus % undefined forecasts (non-informative forecasts / total). It is shown that the flow forecasts outperforms the price forecasts with higher accuracies and lower undefined forecast.

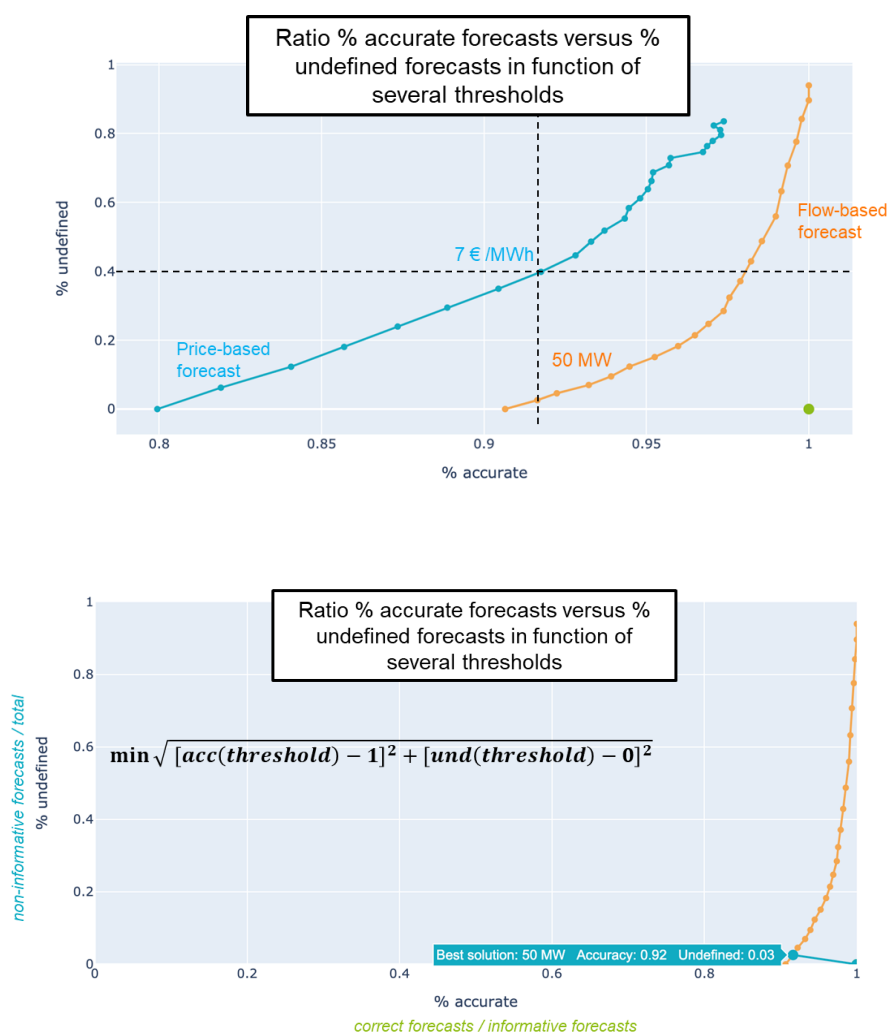


Figure 6 : ratio accurate / undefined forecasts comparing a price-based and flow-based forecasts for different thresholds (up) and methodology to determine the threshold in view of a multi-objective optimization (lower)

The 50 MW threshold determined and fixed at 50 MW based on multi-objective optimization jointly minimizing the absolute distance of the % accuracy and % undefined from the perfect solution, i.e. relatively 1 and 0 as demonstrated on Figure 6 (down). The current value of 50 MW results in an accuracy of 92% while facing only 3% undefined values over the investigated period of analysis (01.08.2020 and 31.03.2021).

Limitations of the maximum import or export capacity (following grid operational constraints) are taken into account at the moment of prediction.

6.1.3 Step 3: Calculation of the FRR needs

Result of the probabilistic methodology.

ELIA will determine the reserve capacity for every quarter-hour based on the convolution of the “HYBRID PE” method and “Dynamic FO” method. If a technical problem occurs with constructing the prediction risk distribution, Elia will fall back to first the KNN PE method, and thereafter the STATIC PE method, always combined with the “Dynamic FO” method. However, when technical problems occur with the forced outage risk, a final fall back is foreseen by STATIC PE and the Static FO value, which is determined during the training on monthly basis.

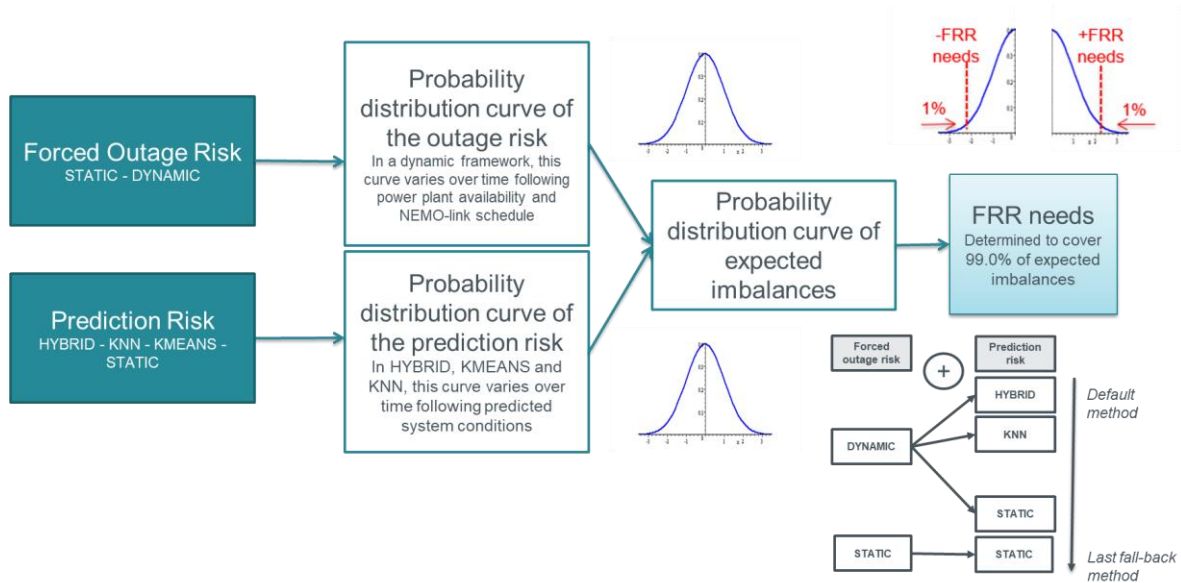


Figure 7 : Overview of the convolution of the forced outage risk and prediction risk for each methodology

Result of the deterministic methodology

For every quarter-hour of the next day, ELIA determines the required positive and negative reserve capacity on FRR in order that it is never less than the positive and negative dimensioning incident of the LFC block. As explained earlier, the potential cut-out of the offshore wind power park following a storm are not considered as dimensioning incident. The dimensioning incident is determined for each quarter-hour of the next day:

- for the positive dimensioning incident based on the highest value of available power of a generating unit (taking into account maintenances and firm maximum capacity modifications known at the time of the day-ahead dimensioning) or the predicted schedule of the HVDC-interconnector with Great-Britain (taking into account unavailability and capacity reductions known at the time of the day-ahead dimensioning) ;
- for the negative dimensioning incident based on the predicted schedule of the HVDC-interconnector with Great-Britain taking into account unavailability and firm capacity reductions known at the time of the day-ahead dimensioning).

Additionally, for each-quarter hour of the next day, ELIA determines an additional minimum threshold for the required positive and negative reserve capacity on FRR in order that it is sufficient to cover at least the positive and negative historic LFC block imbalances for 99.0% of the time in line with Articles 157(2)h and 157(2)i of the SOGL. These thresholds are determined at the same time as the probabilistic and the deterministic methodology and are based on the consecutive historical records specified in Section 3.1.1 and before removal of any periods as discussed in Section 3.1.1.

After taking for each quarter-hour the maximum value between the result of the deterministic and probabilistic methodology, the quarter-hourly profile is further processed to a 4-hour resolution profile by taking the maximum value over each period of 4 hours.

Summary and illustration of the reserve dimensioning method

There are in fact two chronological phases in the dimensioning process. Firstly, one month ahead, the database is collected with historic LFC block imbalances and predicted system conditions allowing to training of the machine learning algorithms. Furthermore, the static fallback value is

calculated based on a static prediction risk and static forced outage risk distribution curve. This static fallback value will take into account the threshold set by the dimensioning incident, based on the installed and available capacity the next month.

Secondly, day-ahead, the dynamic FRR needs are determined with a prediction for each quarter-hour of the next day. For each quarter-hour, this is based on the prediction risk probability distribution which corresponds best to the predicted system conditions for the next day. This is the result from the training of the algorithms. The forced outage risk distribution is constructed based on the estimated scheduled direction of NEMO Link (taking into account potential capacity limitations) and the available capacity of generation units. Also the positive and negative dimensioning can be determined.

For each quarter-hour, a minimum threshold is determined dynamically by the dimensioning incident for that quarter-hour. The latter also depends on the available capacity of generation unit and the estimated direction NEMO Link for that quarter-hour. An additional threshold is set by the 99%-percentile of the historic LFC block imbalances.

Figure 7 illustrates the result for a day. All values are expressed with a resolution of 4 hours, as it will be foreseen in the LFC Means and the publications. One can see that the probabilistic upward result (PROB99) remains below the deterministic (DET N-1) or the minimum threshold (HIST99), which is typically the case. On the other hand the downward probabilistic result becomes determining when NEMO Link is scheduled in import.

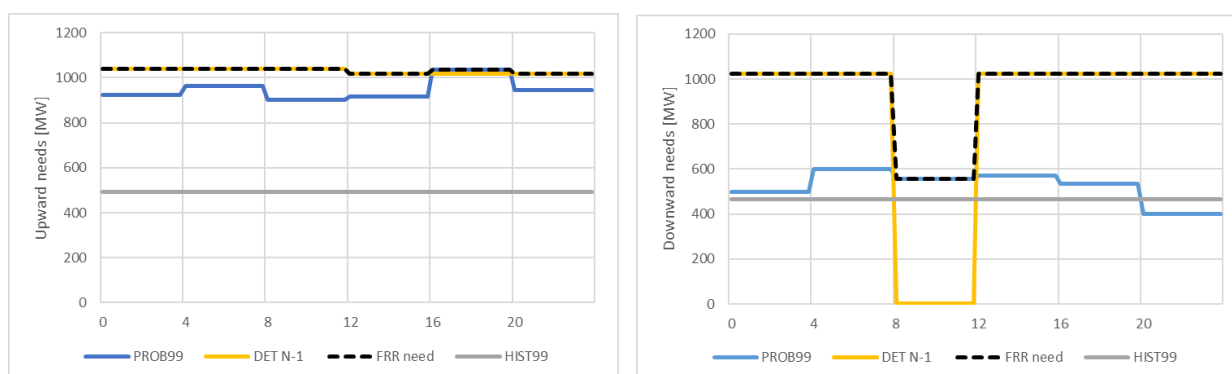


Figure 8 : Illustration of the FRR needs

6.1.4 FRCE quality indicators and historic LFC block imbalances

As explained in Section 7.1, Elia will monitor the **FRCE-quality**. During previous years, Elia relied on the ACE quality indicators of the balance of the control area defined by ENTSO-E. Table 5 represents the average monthly standard deviation of the ACE on a quarter-hourly basis, as well as the target value established by ENTSO-E, for the period 2011-2018. The increase in quality until 2016 can be partly explained by 2 factors:

- a reduction of the LFC block imbalances as the result of the transition of the imbalance mechanism to the "single marginal pricing" mechanism since 2012 and a continuous improvement of Elia's publications and communications towards market players and;
- the implementation of the IGCC process in October 2012. Table 5 below represents the total energy in absolute value activated according to the IGCC expansion process. The increase observed in 2014 is due to an improvement in the border algorithm implemented in October 2013, while the evolution observed in 2016 is explained by the arrival of France into the cooperation, which increased liquidity for the benefit of the entire cooperation.

Table 5 : Average monthly standard deviation of the ACE (σ_{ACE}) on a quarter-hourly basis (and target value), as well as theoretical probability for insufficient aFRR (Pdef) to adjust the variability of the LFC block imbalance

	2011	2012	2013	2014	2015	2016	2017	2018
σ_{ACE} [MW]	91,6	77,4	60,8	40,33	46	36,44	37,80	39,85
Target [MW]	97,5	99	96	96	96	96	95	95
Pdef aFRR theoretic	26,3 %	27,6 %	27,8 %	21,7 %	22%	21 %	21%	21%

Table 6 : total energy (absolute values) activated in IGCC

	2013	2014	2015	2016	2017	2018
IGCC	174 GWh	317 GWh	255 GWh	428 GWh	427 GWh	401 GWh

Nevertheless, a stabilization or even a small increase in the standard deviation is observed as from 2016. In line with SOGL, 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. However, the provisional figures in Table 7 show that FRCE-indicators remain relatively stable, and that the Level 1 and Level 2 target are fulfilled in 2018 (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).

Table 7 : FRCE-indicators compliant with article 131 of the SOGL (provisional figures)

FRCE-indicators	2018	FRCE-indicators	2018	Target
The mean value	-1,9	Number of time intervals: average FRCE > Level 1 positive	1059	10512
The standard deviation	47,9	Number of time intervals: average FRCE < Level 1 negative	1417	
1-percentile	-166,6	Number of time intervals: average FRCE > Level 2 positive	262	1752
5-percentile	-75,6	Number of time intervals: average FRCE < Level 2 negative	352	
10-percentile	-40,0	Number of events: FRCE > 60 % FRR capacity- and not < 15 % FRR capacity- within 15 min	0	
90-percentile	32,9			
95-percentile	63,0	Number of events: FRCE < -60 % FRR capacity+ and not > 15 % FRR capacity+ within 15 min	0	
99-percentile	150,1			

Concerning the **historic LFC block imbalance data** published on the website of Elia, Figure 9 and Table 8 show the probability distribution and some key statistics since 2014.

- The Mean Absolute Error (MAE) in Table 8 allow us to conclude that the LFC block imbalances remain stable as from 2016. This in contrast to the decreasing trend before 2016 as the result of continuous efforts/improvements of recent years. However, the average evolving to zero shows that the asymmetry in previous years disappears in 2018.
- On the other hand, the standard deviation, and the 1%-percentile of the LFC block imbalances increase indicating larger variations of the LFC block imbalance. This confirmed when looking at the variability of the LFC block imbalance where MAE, standard deviation and the 1%-percentile observed increase since 2016.

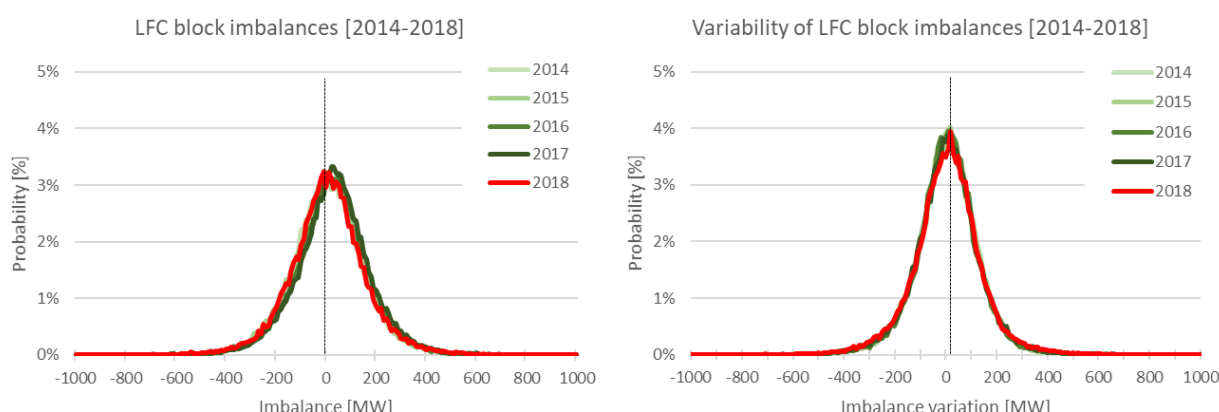


Figure 9 : Probability distribution of the LFC block imbalances between 2014 and 2018 (in steps of 10 MW)

Table 8 : Key statistics of the LFC block imbalances between 2014 and 2018

[MW]	LFC block imbalances					LFC block imbalance variations				
	2014	2015	2016	2017	2018	2014	2015	2016	2017	2018
AVG	2,5	4,0	16,7	23,0	1,5	0,0	0,0	0,0	0,0	0,0
MAE	112,5	112,0	114,8	114,8	115,0	92,0	93,7	91,4	95,2	99,6
ST.DEV	148,1	146,6	151,1	151,4	153,5	122,6	124,7	122,9	127,9	134,6
P1	-365,6	-356,2	-384,0	-375,8	-401,6	-336,3	-342,8	-340,9	-347,1	-364,4

6.2 Determination of the ratio of automatic FRR and manual mFRR

In line with Article 157(2)c of the SOGL, Elia determines the ratio of automatic FRR (hereafter referred to as aFRR), manual FRR (hereafter referred to as mFRR), together with the time for full activation of automatic FRR and the time for full activation of manual FRR in order to respect the FRCE target parameters in accordance with Article 157(2.b). For this purpose, the time for full activation of automatic FRR of an LFC block and the time for full activation of manual FRR of the LFC block shall not exceed the frequency recovery time. Compliant with these specifications, the time for full activation is determined in accordance with Article 11 of the LFCBOA, at maximum 7.5 minutes and 15 minutes (and planned to be reduced to 5 minutes and 12.5 minutes)¹³, respectively for aFRR and mFRR.

In line with Article 157(2)c of the SOGL, Elia determined the aFRR reserve capacity based on a **dynamic probabilistic methodology**, recommended in its aFRR dimensioning study published in 2020. In line with Article 157(2)b specifying that 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, Elia complemented the methodology to determine the aFRR reserve capacity with a **FRCE feedback loop**.

After the calculation of the positive and negative aFRR needs, Elia determines the required positive and negative reserve capacity on mFRR for each period of 4 hours for the next day as the difference between the required positive reserve capacity on FRR and aFRR determined on daily basis.

¹³ Cf. implementation planning specified in Section 1.3.

Elia also refers to the presentation given in a specific session on reserve dimensioning on 15.02.2023¹⁴, presenting the justification of the methodology, as well as the impact assessment in terms of volumes, including projections of the aFRR reserve needs towards 2034.

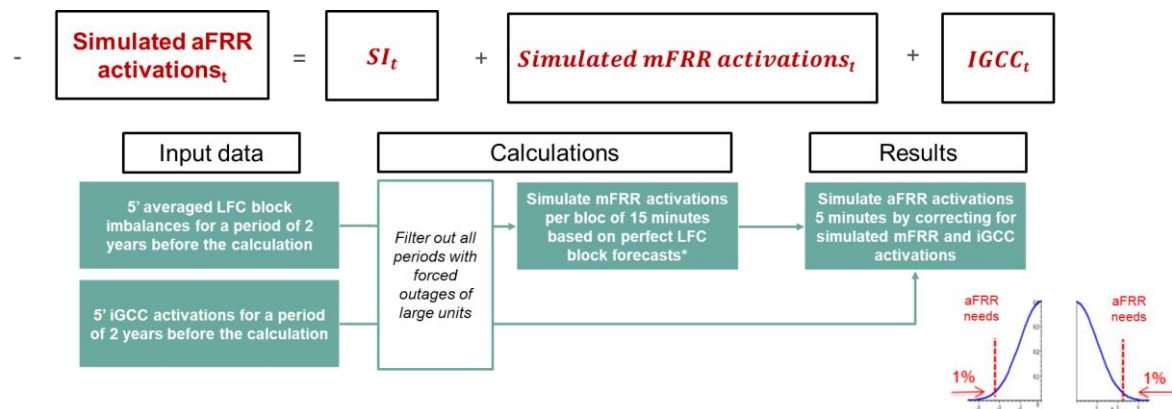
1) aFRR dynamic probabilistic methodology

The dynamic probabilistic methodology is based on a forecast of the aFRR activation risk for every period of 5 minutes of the next day. In this method, *the aFRR needs are dimensioned to cover 99% of simulated aFRR activations based on historic LFC block imbalances (SI), IGCC activations and simulated mFRR activations.*

The simulated aFRR activations ($aFRR_t$) are calculated with a resolution of 5 minutes based on:

- The 5 minute average of historical 1 minute observations of system imbalances (SI_t) for a period of two years, ending not before the last day of the second month before the month of the day for which the reserve capacity is calculated. The resolution is aligned with the foreseen full activation time of aFRR, i.e. 5 minutes.
 - the system imbalances (SI_t) are calculated as the average of the observed 1' system imbalances over each block of 5 minutes. Negative (positive) values represent system shortage (excess);
 - as covering forced outages of power plants or transmission assets is not an objective of aFRR, the time series are filtered to remove periods with a forced outage of Nemo Link or generating units with a loss of power larger than 50 MW (until the end of the forced outage but limited to 8 hours after the start of the forced outage), periods with exceptional events (e.g. market decoupling) and periods with data quality problems (e.g. missing data).
- the simulated mFRR activations ($mFRR_t$) are calculated as the average of the 1' system imbalance over each block of 15 minutes. This corresponds to a perfect forecast of the system imbalance in order to determine minimum aFRR needs. Positive (negative) values represent upward (downward) activations ;
- the IGCC corrected activations ($IGCC_t$) are calculated based on the average of the 1' observed IGCC activations ($IGCC_{obs_t}$) over each block of 5 minutes where positive (negative) values represent import (export) positions. The $IGCC_t$ is corrected to zero when $IGCC_t$ and $SI_t + mFRR_t$ are found to have the same sign and is otherwise equal to:
 - $\text{Min}(IGCC_{obs_t}; -(SI_t + mFRR_t))$ if $SI_t + mFRR_t \leq 0$
 - $-\text{Min}(-IGCC_{obs_t}; SI_t + mFRR_t)$ if $SI_t + mFRR_t > 0$
- The simulated aFRR activations ($aFRR_t$), are calculated for every period of 5 minutes as the difference between the system imbalance (SI_t), the simulated mFRR activations ($mFRR_t$) and the IGCC activations ($IGCC_t$): $-aFRR_t = SI_t + mFRR_t + IGCC_t$. Positive (negative) values represent upward (downward) activations.

¹⁴ Available on : <https://www.elia.be/en/users-group>



The prediction of the aFRR activation risk is based on a **Gradient Tree Boosting algorithm** (a variation of a Random Forest algorithm) which is a type of machine learning algorithm based on an ensemble of individual decision trees. Each decision tree represents “if-else statements” that are used to predict the aFRR activation risk. The algorithm is trained on a set of simulated aFRR activations (calculated based on historical observations of system imbalances and imbalance netting) and corresponding system conditions. The list of system conditions used for the training and prediction of the machine learning algorithms are the same as those for the dimensioning of FRR and specified in Annex (cf. Section 9.2.1). More information on the type of algorithm used is specified in Section 9.1.3.

The Gradient Tree Boosting algorithm is trained to forecast the aFRR activation risk uses a quantile loss function. A separate model is built for the prediction of the positive simulated aFRR activations through the 99% percentile of the probability distribution of the positive simulated aFRR activations, and another model is built for the prediction of the negative simulated aFRR activations through the 1% percentile of the probability distribution of the negative simulated aFRR activations. Nodes are split based on a classical mean squared error with improvement score by Friedman. The number of trees is set at 400, the height of each tree is specified at 4 and the learning rate is fixed at 0.1.

The up- and downward aFRR activation risk is determined each day before 7 AM for every period of 5 minutes of the next day based on predicted system conditions of the next day as specified in Article 8(4)b. The aFRR needs for that day are therefore determined by means of the average value of the positive (negative) reserve capacity on aFRR over all periods of 5 minutes of the corresponding period.

- The calculation will be integrated in the FRR dimensioning process, i.e. the results of the FRR, aFRR and mFRR needs, as well as the aFRR and upward mFRR balancing capacity for the next day will be **published before 7 AM D-1 on Elia’s website**
- In line with the auction design of aFRR, Elia will determine **one separate value for the aFRR upward, and one value for downward for the next day.**

2) FRCE feedback loop

The feedback loop determines the final aFRR needs for the next day by multiplying the aFRR needs determined by means of the dynamic probabilistic methodology with a correction factor determined based on Elia’s performance on the FRCE target parameters as specified in Article 128. This follows discussions with CREG on the role of the FRCE target parameters in aFRR dimensioning, Elia therefore

proposed to complement the method with an FRCE feedback loop based on Elia's performance in the previous month and year. This enables to achieve:

- Absolute aFRR needs reductions when facing structural over-performance on these legal minimum requirements (or vice versa). Elia is currently over-performing as shown in Figure 10.
- Seasonal aFRR needs reductions when facing over-performance in certain months or seasons (or vice versa). Elia observed over the last two years higher performance during summer than winter as shown in Figure 11.

Note that according to article 128(3) of SOGL the number of time intervals per year outside the Level 1 FRCE range (Level 2 FRCE range) within a time interval equal to the time to restore frequency shall be less than 30 % (5%) of the time intervals of the year. Time interval is set at 15 minutes and the current FRCE range for Belgium is determined by ENTSO-E at:

- 98 MW (level 1) and 186 MW (level 2), until May 2023
- 85 MW (level 1) and 160 MW (level 2), as from May 2023

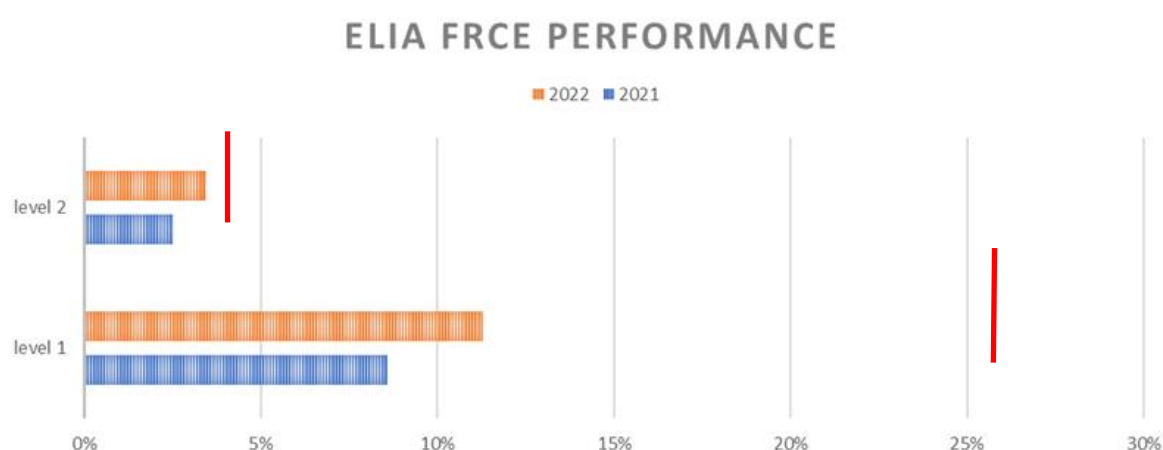
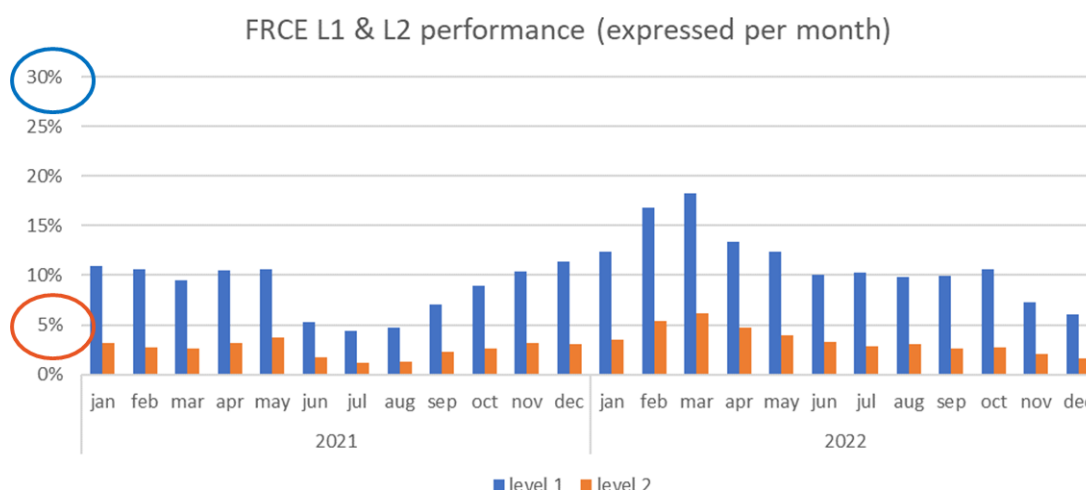


Figure 10 : Elia's historic performance on FRCE target parameters as specified in Article 128 (legal requirement)



*percentages assuming 30 days per month

*performance calculated based on L1 & L2 targets as from May 2023 (85 MW, 160 MW)

Figure 11 : Elia's historic performance on FRCE target parameters if analysed on monthly basis (no legal requirement)

In function of the yearly and monthly FRCE performance discussed in previous paragraphs, the feedback loop corrects the aFRR needs calculated in the probabilistic method in line with the graphical representation in Figure 12. While the probabilistic method ensures that TSOs conduct their best efforts avoid FRCEs which last longer than the time to restore frequency in line with Article 152(9) of the SOGL, the feedback loop calibrates the aFRR needs sufficient to meet the minimum criteria set by the FRCE target parameters in line with Article 128. Note that the feedback loop allows to capture the potential effect of the aFRR balancing energy bids following the dimensioning of the aFRR needs and the procurement of aFRR balancing capacity) on the FRCE target parameters. Nevertheless, the 15' nature of the target parameters makes that it is important to follow up on the ability of aFRR to also meet frequency quality target parameter in line with Art. 127(4).

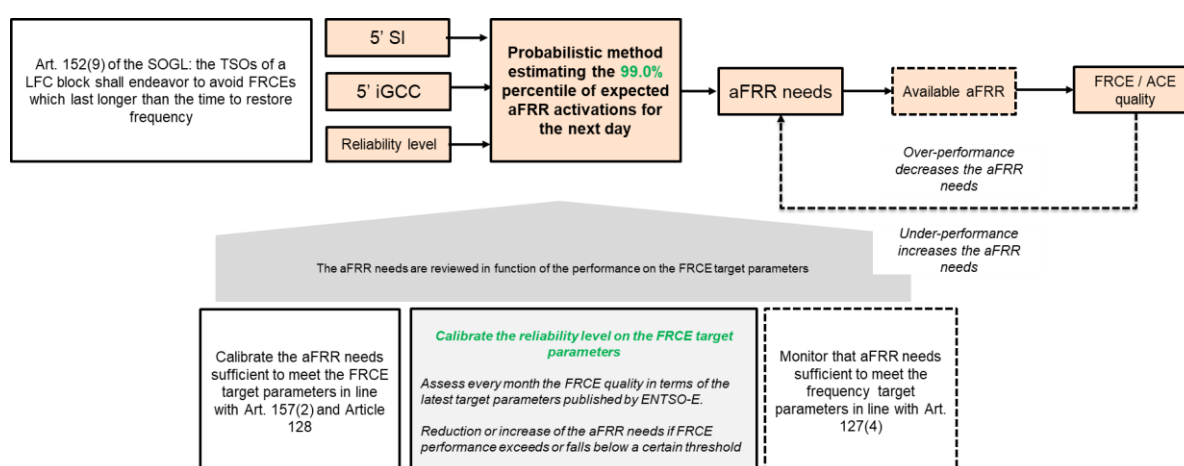


Figure 12 : schematic representation of the aFRR dimensioning method

This way the method allows to:

- 1) Capture absolute performance of FRCE control quality based on the performance on the legal FRCE target parameters in the previous year. This is used to determine a correction factor which increases / decreases aFRR needs for the upcoming year. Note that the Elia LFC block FRCE quality is currently complies with the annual FRCE target parameters in 2021 and 2022 (but shows a deteriorating trend).
- 2) Capture relative performance variations of FRCE control quality within the year based on the performance on the FRCE target parameters in the previous month. This is used to determine a correction factor which increases / decreases aFRR needs for the upcoming month. Note that the Elia LFC block FRCE quality seems to show higher FRCE quality during summer than winter.

By means of implementing **caps and floors on the correction of the probabilistic aFRR needs** brought by the FRCE feedback loop:

- The method recognizes that 15' FRCE target parameters are not the unique dimensioning criteria, but should have an impact in case of over- or underperformance (other criteria like Deterministic Frequency Deviations, 5' interval fluctuations,... are still considered)
- Sudden or extreme variations of the aFRR needs are avoided which may hamper market stability while ensuring a fair contribution to the European frequency stability :
 - ENTSO-E recommends to not use current FRCE target parameters as dimensioning criteria (as such these are included in the method as an automatic correction rather than a dimensioning criterion).
 - The calculation of the FRCE target parameters is currently under discussion within and ENTSO-E and expected to be gradually tightened, with a first revision foreseen as from May 2023.
 - Following evolution of the FRCE quality and FRCE target parameters, the caps and floors can be re-assessed (after assessing evolution of the intra-15' FRCE, and Elia's contribution to frequency deviations) .

Based on the above-mentioned principles, the correction factor of the feedback loop is determined as follows:

- **Step 1: calculate the y-1 and m-1 performance**

Calculate the percentage of time L1 (e.g. 160 MW) and L2 (e.g. 85 MW) range are exceeded and determine this value as a percentage of target parameters (L1 30%; L2 5%), corrected with a margin of 20%, resulting in a corrected target parameter (L1 24%; L2 4%). The margin avoids undesired FRCE quality evolutions following the lag of one month / year.

While the monthly (m-1) performance is calculated based on the 15' FRCE values of the month before the month in which the aFRR needs (for the next day) are calculated. The yealy (y-1) performance is calculated based on the 15' FRCE values of the 12 months ending in the month before the month in which the aFRR needs (for the next day) are calculated. This rolling time horizons minimizes the lag between the observed FRCE quality, and the aFRR needs dimensioning.

- **Step 2 : calculate the final correction factor**

Floor / cap the y-1 and m-1 performance calculated in step 1 to 80% / 120% . Multiply the maximum of the L1 & L2 y-1 performance with the maximum of the L1 & L2 m-1 performance. The *floor / cap of the aFRR needs decrease / increase serves to avoid extreme variations of the aFRR needs (in view of future evolutions of the FRCE target parameters, dynamic probabilistic results, FRCE quality evolutions) in order to maintain market stability.*

- **Step 3 : calculate the corrected aFRR needs**

Multiply the daily probabilistic result with the final correction factor. Floor / cap the final result to 64 / 144 % of the rolling average of the probabilistic result over 12 months ending one month before the month of the day for which the aFRR needs are calculated.

3) Impact assessment

Projections of the probabilistic dynamic results were presented in a specific session of the working group balancing on 15.02.2023. They foresee an average aFRR need (before correction with the feedback loop) of 170 MW in 2024 for Elia's realistic optimistic scenario (as presented in the presentation on reserve projections presented in the Task Force MOG 2 on 10.01.2023, and the special session of the Working Group balancing on 15.02.2023¹⁴. Note that variations of the aFRR needs from day to day are expected between 160 MW and 210 MW.

The feedback loop corrections are calculated based on historic 15' FRCE data for 2021 (to assess y-1 performance)¹⁵ and 2022 (m-1 performance) and their application to the probabilistic dynamic results bring back these average aFRR needs to 119 MW, with minima down to 109 MW and maxima up to 163 MW. In any case, the daily variations cannot exceed an absolute interval of [109 MW; 245 MW], resulting from the floors and caps determined in step 3 (while calculated here based on an average aFRR needs resulting from the dynamic probabilistic method expected for 2024, the real floors / caps will be calculated on the rolling average of the probabilistic result over 12 months). Elia expects that aFRR volumes will increase over time (towards 2026) as the feedback loop corrections should fade away when FRCE target parameters are tightened by ENTSO-E given issues with frequency quality.

Note that the method ensures that a deterioration of the performance compared to the previous month when facing structural over-performance in the previous year will brake potential aFRR increases (cap is 96%, i.e. $80\% * 120\%$). In addition, a deterioration of the performance compared to the previous month when facing structural over-performance will not result in a further decrease of the aFRR needs.

¹⁵ Note that in the yearly correction factor in these projections is based on the performance in the previous calendar year (2021), rather than a rolling 12-month period as foreseen in the implementation of the method.

month	performance l1	performance l2	yearly correction	monthly correction	final correction	aFRR [MW]
2021	36%	63%	80%			
Jan-22	47%	76%		80%	64%	109
Feb-22	52%	87%		87%	69%	118
Mar-22	70%	135%		120%	96%	163
Apr-22	76%	155%		120%	96%	163
May-22	56%	119%		119%	95%	162
Jun-22	52%	98%		98%	78%	133
Jul-22	42%	82%		82%	66%	112
Aug-22	43%	71%		80%	64%	109
Sep-22	41%	78%		80%	64%	109
Oct-22	42%	65%		80%	64%	109
Nov-22	44%	69%		80%	64%	109
Dec-22	30%	52%		80%	64%	109

- L1 and L2 range as from May 2023 (communicated by ENTSO-E)
- Monthly performance L1 and L2 expresses performance of previous month on 80% of the level 1 and level 2 FRCE target parameters (data 2022)
- Yearly performance L1 and L2 expresses performance of previous year on 80% of the level 1 and level 2 FRCE target parameters (data 2021)
- Monthly and yearly correction are floored / capped at 80% / 120%.
- The final correction is calculated as the multiplication of both corrections factors and applied on the estimated average probabilistic result of 170 MW (2024)
- Additional caps of 64% / 144 % are put on the average dynamic probabilistic (after feedback loop) result over the last 12 months

6.3 Determination of maximal reduction of reserve capacity on FRR following sharing of FRR

Article 169 of the SOGL specifies that each TSO of a LFC block has the right to share FRR reserves with other LFC blocks of its synchronous area within the limits set by the FRR dimensioning rules in Article 157 and in accordance with Article 166. It needs to be stressed that such agreements are concluded on a voluntary basis and that there is no obligation on behalf of the TSOs of neighboring LFC blocks to enter into such agreements.

Article 152(2)j and 157(2)k of the SOGL allows Elia to reduce respectively the positive and negative reserve capacity by concluding operational agreements with the TSOs of neighboring LFC blocks, and provided that the latter accept, that allow for the sharing of reserves in accordance with the provisions of Title 8 of the SOGL. Elia disposes of such agreements with German TSOs, RTE, Tennet and NGET which are expected to remain valid.

Figure 13 illustrates that the capacity that can be accounted for in the dimensioning is limited by the dimensioning rules in these articles. First of all, article 152(2)k specifies that for the synchronous area CE, the reduction of the positive and negative reserve capacity on FRR of a LFC block is limited to the difference, if positive, between the size of the dimensioning incident (N-1) and the reserve capacity on FRR required to cover the LFC block imbalances during 99% of the time, based on the historical records referred to in article 152(2)a. Additionally, regarding the sharing of positive reserve capacity,

the reduction in reserve capacity may never exceed 30% of the positive dimensioning incident. This limit is not applicable for sharing of negative FRR.

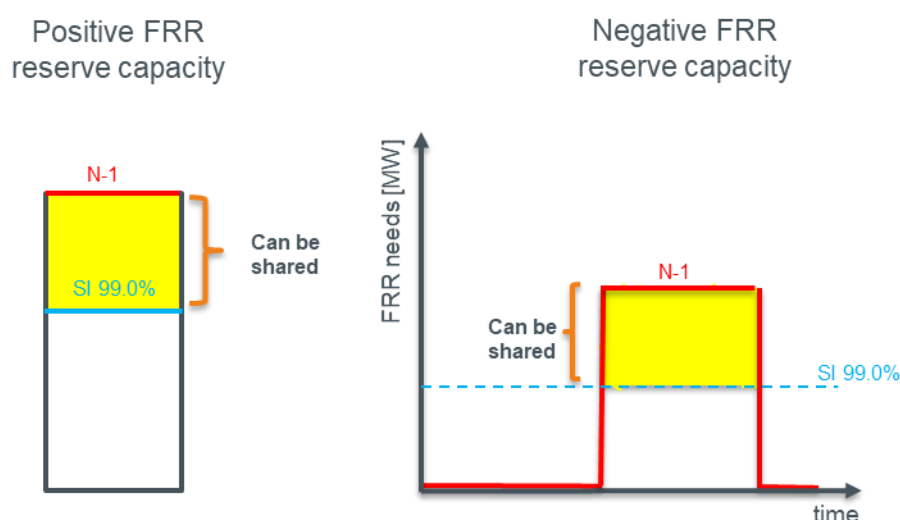


Figure 13 : Visual representation of the maximal sharing potential following SOGL by the surface between dimensioning incident (N-1) and historic LFC-block imbalances (SI 99%) for dimensioning positive FRR needs (left) and negative FRR needs (right)

Based on these principles, the maximum sharing capacity which can be used for the reduction of the positive reserve capacity on FRR can never exceed 312 MW, which is equal to 30% of the size of the positive dimensioning incident, currently determined at 1039 MW¹⁶. This value determines the sharing limit as it is lower than the difference between the size of the positive dimensioning incident, and the reserve capacity on FRR required to cover the positive LFC block imbalances during 99.0% of the time, based on the minimum threshold determined in Section 6.1.

In contrast, the maximum sharing capacity which can be used for the reduction of the negative reserve capacity on FRR depends on the scheduled direction of Nemo Link. For periods when Nemo Link is foreseen to be in export, or when the prediction is indecisive, the maximum capacity which can be taken into account is calculated as the difference between size of the negative dimensioning incident and the reserve capacity on FRR required to cover the positive LFC block imbalances during 99% of the time, based on the minimum threshold determined in Section 6.1. In contrast, in periods where Nemo Link is foreseen to be in import, or in maintenance, the maximum capacity which can be taken into account as sharing is determined at 0 MW

As required by Title 8 of the guidelines on system operation, the operational agreements implementing a reserve sharing mechanism shall specify the amount of reserve capacity on FRR eligible for sharing. Moreover the sharing capacity on FRR is also subject to the available cross-border capacity. As a result the overall quantity of reserve sharing that may be taken into account to cover the FRR means is cumulatively limited by following elements:

¹⁶ Excel with input data for the adequacy study for Belgium for Winter 2019-20 as published on Elia's website: <https://www.elia.be/en/electricity-market-and-system/adequacy/strategic-reserves>

- **The sharing capacity defined in the operational agreements implementing a reserve sharing mechanism:** only the contracted sharing capacity with neighboring TSOs can be considered for covering the required reserve capacity.
- **Operational security limits:** the shared FRR can be unavailable following restrictions related to operational security as reserve sharing may not lead to power flows that violate operational security limits (availability of cross-border capacity after intra-day and taking into account internal congestions in the ELIA grid). ELIA will therefore assess the shared reserve capacity on FRR which can be accounted in the dimensioning.
- **Availability of the shared reserve capacity on FRR:** the shared FRR capacity can be unavailable following the use of the shared capacity by the control capability providing TSO. ELIA will therefore assess the historic availability of the service and can limit the capacity that can be accounted in the dimensioning.

In order to cope with possible uncertainties concerning the above-mentioned elements (it is for instance not possible to run security analysis for a whole year), ELIA can further limit the maximum sharing capacity which can be accounted in the dimensioning following SOGL, and hence can propose in its determination of the FRR means following Article 32 of EBGL to change the reserve capacity accounted in the dimensioning following modifications in the sharing agreements, or upon modifications concerning available margins on cross-border capacity. These limits are defined in the document referred to as the LFC Means.

6.4 Determination of balancing capacity to be procured

The dynamic methodology to determine the FRR reserve capacity needs will result in a daily calculation of 6 values for each period of 4 hours for the capacity of the positive and negative FRR needs. The quarter-hourly resolution of the FRR needs is processed to a 4-hourly resolution by means of taking the highest value over the corresponding quarter-hours.

The dynamic methodology to determine the aFRR reserve capacity needs will result in a daily calculation of 1 value for each period of 24 hours for the capacity of the positive and negative aFRR needs. The quarter-hourly resolution of the FRR needs is processed to a 24-hourly resolution by means of taking the average value over the corresponding 5 minute periods.

The positive and negative mFRR needs of the next day are calculated as the result of the difference between the positive (negative) FRR and aFRR needs which will result in the calculation of 6 values for each period of 4 hours for the capacity of the positive and negative FRR needs. The FRR, aFRR and mFRR needs will be communicated one day before the real-time, and this not later than 7 AM.

However, in order to determine the volume of balancing capacity to be procured for aFRR and mFRR, these reserve capacity needs are to be translated in volumes of balancing capacity to be procured, in accordance with Article 211 of the Code of Conduct. This article specifies that the methodology to determine the balancing capacity to be procured for the different balancing services shall be determined in a separate document submitted to the regulator in parallel with this LFCBOA, and after a public consultation. This document, referred to by Elia as the “FRR Means”, will also contain, if applicable, the result of the calculation when it concerns static calculations, i.e. values which remain fixed for at least one year.

7 Methodologies in accordance with Article 119 of the SOGL, but not referred to in Article 6(3)e of the SOGL

7.1 LFC Block monitor in accordance with Article 134(1)

Elia will obviously, as sole TSO in the Elia LFC Block, be the LFC block monitor. It will collect the frequency quality evaluation data for the LFC block in accordance with the criteria application process referred to in Article 129 of the SOGL. This includes the collection of frequency quality evaluation data and the calculation of frequency quality evaluation criteria.

Besides relevant ENTSO-E publications, Elia will provide the relevant national regulatory authority with a yearly report on FRCE quality in the framework of its reserve reporting, as well as a monthly reporting on FRCE quality as part of Elia's reporting on the balancing mechanism.

7.2 Operational procedures in case of exhausted FRR in accordance with Article 152(8) of the SOGL

Article 152(8) of the SOGL requires Elia to specify, in the LFC block operational agreement, operational procedures for cases of exhausted FRR in the LFC block operational agreement. In those operational procedures the TSOs of a LFC block shall have the right to require changes in the active power production or consumption.

On the one hand, these concern measures which are taken before the measures specified following the emergency states are defined in the NC E&R. The link with procedures defined in the NC E&R is only indirect: only when too high ACE gives rise to frequency deviations this relates to the activation criteria of Article 18 NC E&R "frequency deviation management procedure". If there are overloaded (border) lines, Article 19 "power flow management procedure" may be applied.

On the other hand, it concerns measures which are not expected to be resolved with the activation of FRR (aFRR and mFRR) following the processes described in the SOGL for which the reserve process activation structure is defined in Article 140 of the SOGL. This exhausted FRR operational procedure specified in this section shall therefore only be initiated when Elia detects the risk of facing an exceptional event that is not fully accounted in the FRR needs.

A typical example is a large storm event where - based on received information from BRPs – it is expected that one or more BRPs will not be able to keep the balance of their portfolio up to a point whereby the estimated available FRR means would be insufficient to ensure secure system operations. As a consequence, preventive actions from Elia could be required to reduce the imbalance risk to a level manageable by the FRR means for the concerned delivery period.

As from the detection of an upcoming exceptional event specified below, for each balancing energy market time unit during which the exceptional event is expected to impact the FRCE in the LFC Block, Elia continuously evaluates the residual risk by subtracting (b) and (c) from (a), with:

- the volume at risk, which is calculated as the possible loss of injection / increase of off-take following the event, corrected with mitigation measures if applicable. For sea storm events, the calculation method is described in Appendix 6 of the BRP Contract. For yet unidentified events, a description of the calculation method to cover the volume risk will be submitted to the National Regulatory Authority within one year after the event.
- available balancing means which are calculated as the sum of:

- the procurement of balancing capacity within control area and exchange of balancing capacity with neighbouring TSOs, when applicable pursuant to article 32(1)a of the EBGL,
 - sharing of reserves, when applicable pursuant to Article 32(1)b of the EBGL,
 - the volume of balancing energy bids which are not contracted by Elia as balancing capacity and are expected to be available both within its control area and within the European platforms taking into account the available cross-zonal capacity pursuant to Article 32(1)c of the EBGL.
- the expected impact of the operational procedures for the alert state due to a violation of system frequency limits, as specified in the synchronous area operation agreement pursuant article 152(10) SOGL and article 152(15) SOGL.

When during two or more consecutive periods specified by the 15 minute balancing energy market time unit, the residual risk exceeds the Level 2 FRCE range, for these periods, Elia shall:

- A. publish balancing warning communication with the aim of asking all BSPs to submit additional FRR non-contracted balancing energy bids and informing all BRPs such that they can adapt injections and off-take in their portfolio accordingly;
- B. activate units which are available in line with requirements of the T&C Scheduling Agent, in line with Article 130 of the Code of Conduct, and that cannot be activated via the FRR processes. Once these units are activated, they facilitate the availability of balancing energy bids on these units via the FRR processes;
- C. activate units that do not provide MW schedules in the context of the Terms and Conditions Scheduling Agent, that cannot be activated via the FRR processes and that offer their available active power on a voluntary basis.

The units in point B. and C. above shall be activated at the latest point in time for Elia to take action while taking into account the latest available information following the balancing warnings and the communications with BRP contributing to the residual risk specified, Elia will strive towards techno-economic efficiency by taking into account the duration and magnitude of the definite risk and the maximum and minimum output, start-up time, start-up costs and other technical constraints if relevant.

A typical example of such an activation is the start-up of a large gas-fired power plant facing a start-up time which exceeds the full activation time of mFRR. When this unit is not scheduled to be running, it cannot provide any mFRR flexibility during these periods, and cannot contribute to the available balancing means. However, when the unit is activated following this exceptional balancing measure, and scheduled at a level below maximum power, this unit can provide the remaining margin between maximum power and scheduled power as mFRR balancing energy bids. This will therefore increase the available balancing means during the period where a residual risk is identified.

The units determined for activation are effectively activated taking into account the start-up time of the selected units in order to control the FRCE during the periods with definite risk as specified by the residual risk calculation, or if not possible, as soon as possible after the beginning of the anticipated event. The units remains activated for the entire period of the definite risk. The activation period can be shortened or prolonged depending on the calculation of the residual risk.

Elia will prepare, at least on annual basis, an overview with a list of events following the triggers specified above, as well as a short motivation on the use of one or more of the above-mentioned measures.

At the latest 15 working days after the day of use of the above-mentioned measure B. and/or C., Elia shall submit a report containing a description and justification for this action to the relevant regulatory authority. The report shall at least contain:

- a description of the exceptional event;
- the result of the evaluations carried out in accordance with the residual risk calculation, including the values of the parameters mentioned and the timing of those evaluations;
- the result of the evaluations carried out during the activation of the above-mentioned measures B. and/or C., including the timing of the evaluations;
- the energy activated per unit and per period specified by the time to restore frequency and the attained techno-economic efficiency, including a justification for deviating from the techno-economic optimum, if applicable;
- any actions Elia intends to take, or is taking, in order to verify or enforce the compliance of market parties with their contractual obligations towards Elia;
- the lessons learned from the exceptional event and, if relevant, concrete recommendations that could ease the operations of the following exceptional events.

In addition, Elia shall prepare, at least on annual basis, a report with a list of events where only the balancing warning is used, as well as a justification why the activation of additional units, as specified above, was not required.

7.3 Escalation Procedures in accordance with Article 157(4) of the SOGL

Article 152(8) of the SOGL requires Elia to specify, in the LFC block operational agreement, an escalation procedure for cases of severe risk of insufficient reserve capacity on FRR in the LFC block.

Similar to the other exceptional balancing measures, these concern measures which are taken before the measures specified following the emergency states are defined in the NC E&R. The link with procedures defined in the NC E&R is only indirect: only when too high ACE gives rise to frequency deviations it relates to the activation criteria of Article 18 NC E&R "frequency deviation management procedure". If there are overloaded (border) lines, Article 19 "power flow management procedure" may be applied.

On the other hand, it concern measures which are not expected to be resolved with the activation of FRR (aFRR and mFRR) following the processes described in the SOGL for which the reserve process activation structure is defined in Article 140 of the SOGL if the FRR means required to cover the FRR needs following the dimensioning of FRR are not available. For this reason, Elia will evaluate on a continuous basis for each period specified by the 15 balancing energy market time unit, the residual risk by subtracting (b) from (a), with:

- FRR needs as calculated in the FRR dimensioning (Title 3) and
- available balancing means which are calculated as the sum of:

- the procurement of balancing capacity within control area and exchange of balancing capacity with neighbouring TSOs, when applicable pursuant to article 32(1)a of the EBGL,
- sharing of reserves, when applicable pursuant to Article 32(1)b of the EBGL,
- the volume of balancing energy bids which is not contracted by Elia as balancing capacity and is expected to be available both within its control area and within the European platforms taking into account the available cross-zonal capacity pursuant to Article 32(1)c of the EBGL.

When during two or more consecutive periods specified by the 15 balancing energy market time unit, the residual risk exceeds the Level 2 FRCE range, for these periods, Elia may:

- A. publish a balancing warning communication with the aim of:
 - asking all BSPs to submit additional FRR non-contracted balancing energy bids;
 - informing all BRPs such that they can adapt injections and off-take in their portfolio accordingly;
- B. activate units which are available in line with requirements of the T&C Scheduling Agent, in line with Article 130 of the Code of Conduct, and that cannot be activated via the FRR processes. Once these units are activated, they facilitate the availability of balancing energy bids on these units via the FRR processes;
- C. activate units that do not provide MW schedules in the context of the Terms and Conditions Scheduling Agent, that cannot be activated via the FRR processes and that offer their available active power on a voluntary basis.

The units in point B. and C. above shall be activated at the latest point in time for Elia to take action while taking into account the latest available information following the balancing warnings and the communications with BRP contributing to the residual risk specified, Elia will strive towards techno-economic efficiency by taking into account the duration and magnitude of the definite risk and the maximum and minimum output, start-up time, start-up costs and other technical constraints if relevant.

A typical of such activation is the start-up of a large gas-fired power plant facing a start-up time which exceeds the full activation time of mFRR. When this unit is not scheduled, it cannot provide any mFRR flexibility during these periods, and contribute to the available balancing means. However, when the unit is activated following this exceptional balancing measure, and scheduled at a level below maximum power, this unit can provide the remaining margin between maximum power and scheduled power as mFRR balancing energy bids. This will therefore increase the available balancing means during the period where a residual risk is identified.

The units determined for activation are effectively activated taking into account the start-up time of the selected units in order to be available to provide additional capacity during the periods where identifying a residual risk, or if not possible, as soon as possible after the beginning of this period. The unit remains activated, at least at minimum power, for the entire period of the forecasted event.

The activation period can be shortened or prolonged following the updated evaluation of the residual risk.

Elia will prepare, at least on annual basis, an overview with a list of events following the triggers specified above, as well as a short motivation on the use of one or more of the above-mentioned measures.

At the latest 15 working days after the day of use of the above-mentioned measures B. and/or C., Elia shall submit a report containing a description and justification for this action to the relevant regulatory authority. The report shall at least contain:

- a description of the exceptional circumstances;
- the result of the evaluations carried out in accordance with the assessment of the residual risk, including the values of the parameters mentioned and the timing of those evaluations; the result of the evaluations carried out in accordance with the activation procedures of measures B. and/or C., including the timing of the evaluations;
- the energy activated per unit and per period specified by the 15 balancing energy market time unit frequency and the attained techno-economic efficiency, including a justification for deviating from the techno-economic optimum, if applicable;
- any actions Elia intends to take, or is taking, in order to verify or enforce the compliance of market parties with their contractual obligations towards Elia;
- the lessons learned from the exceptional event and, if relevant, concrete recommendations that could ease the management of the following exceptional events.

7.4 FRR availability requirements and on the control quality, defined in accordance with Article 158(2) of the SOGL

Article 158(2) of the SOGL specifies that Elia shall specify FRR availability requirements and requirements on the control quality of FRR providing units and FRR providing groups for their LFC block in the LFC block operational agreement pursuant to Article 119. As single TSO in the Elia LFC block, Elia currently specifies the FRR availability requirements and requirements on the control quality of FRR providing units and FRR providing groups in the Terms and Conditions for BSPs.

The control quality criteria are specified in the terms and conditions for BSPs as availability (as described below), exclusivity (no activations are allowed for own use) and start-up requirements to ensure the full-activation time (as described in paragraph below). FRR providing units and FRR providing groups shall demonstrate their compliance with control quality criteria by means of a prequalification process as described in the terms and conditions for BSPs.

The availability requirement specified in the Terms and Conditions for BSPs require full availability, i.e. at 100% of the time (at least for contracted balancing capacity). This is facilitated by ELIA by means of a secondary market allowing to transfer FRR obligations in case of unavailability, as well as tests and corresponding penalties to ensure availability of the service.

As explained in Section 6.2, the control quality is defined at 5 minutes full activation time and 12.5 minutes full activation time for aFRR, respectively mFRR. FRR providing units and FRR providing

groups shall demonstrate their compliance with control quality criteria by means of prequalification process as described Terms and Conditions for BSPs compliant with SOGL Article 158.

Note that:

- the 12.5 minute full activation time for mFRR replaces the former 15 minute full activation time as from the entry into force of the next version of the T&C BSP mFRR which specifies Elia's connection to the European balancing energy exchange platform for mFRR.
- the 5 minute full activation time for aFRR replaces the former 7.5 minute full activation time as from the entry into force of the next version of the T&C BSP aFRR which specifies Elia's connection to the European balancing energy exchange platform for aFRR.

7.5 Roles and responsibilities for sharing of FRR in accordance with article 166(7) and article 175(2) of the SOGL

Article 166(7) and 175(2) of the SOGL specifies that ELIA shall specify in the LFC block operational agreement the roles and responsibilities of the control capability providing TSO, the control capability receiving TSO and the affected TSO for the sharing of FRR with TSOs of other LFC blocks.

This as well for potential sharing arrangements with LFC blocks within the same synchronous zone (in this case France, The Netherlands and in the future possibly Germany), and with LFC blocks of other synchronous zones (in this case Great Britain). At this moment, new interconnections with Germany are foreseen, which opens the possibility to have additional sharing arrangements if the corresponding TSO agrees to develop these.

TSOs that are sharing reserves should specify among other things the **roles and responsibilities** of the **control capability** providing TSO, the control capability receiving TSO and the affected TSO for the sharing of FRR in the following documents:

- a bilateral operational agreement;
- the Synchronous Area Operations Agreement (all TSOs art 118(1.v), 118(1.w), 171(2) for sharing of FRR between synchronous areas);
- the LFC block agreement (only for each TSO involved in reserve sharing art 119(1.o) and 119(1.p) for sharing of FRR between synchronous areas).

From a technical perspective and due to the different nature of the borders (AC or DC), the roles and responsibilities cannot be exactly the same if we go to a lower level of details. Consistency with Synchronous Area Operational Agreement (SAOA) is ensured.

Each TSO involved in reserve sharing can request the activation of reserves or can be requested to activate reserves thus taking the role of control capability receiving or providing TSO respectively depending on the situation. The control capability receiving TSO is the TSO benefiting from the activation of the reserve capacity of the control capability providing TSO. He may request the activation of balancing energy from the control capability providing TSO by stating the requested volume of balancing energy, and timing of delivery. The control capability receiving TSO shall calculate the available cross zonal capacity before making such a request in order to ensure that the activation of balancing energy will not lead to power flows that violate the operational security limits. The control capability receiving TSO shall adapt the input of its LFC controller in order to take into account the activation of balancing energy by the control capability providing TSO.

Elia, as control capability receiving TSO takes into account reserve capacity which is accessible through a control capability providing TSO in its dimensioning of reserve capacity on FRR in accordance with the methodology described in Section 3.4.

The control capability providing TSO shall trigger the activation of its reserve capacity for a control capability receiving TSO in accordance with the conditions set out in the operational agreement referred to in paragraph 1 of this article. Prior to the activation of balancing energy, the control capability providing TSO shall confirm to the control capability requesting TSO the availability or unavailability of its reserves and the necessary cross zonal capacity after an activation request. The control capability providing TSO is responsible for the proper delivery of balancing energy by its connected BSPs. He shall adapt the input to its LFC controller in order to take into account the activation of balancing energy activated for the control capability receiving TSO.

Furthermore, Elia will adapt the remaining cross-border capacity after an activation of shared reserve capacity in which Elia acts as control capability providing TSO or control capability receiving TSO. This adaptation is still to be implemented by Elia and will be done by 14/5/2020 the latest.

8 Final Provisions

The LFCBOA is published in English, Dutch and French. In case of discussion on interpretation of the methodologies presented in the LFCBOA, the French and Dutch version prevail over the English version

9 Annex – Description of the machine learning algorithms

For each historical quarter-hourly observation of the system conditions, a vector x_i is defined for each quarter-hour i . The length of this vector corresponds to the number of features (such as the predicted renewable generation or time of the day and further specified in in Section 9.2) used in the machine learning algorithm: *[offshore prediction, onshore prediction, time of day, ...]*. With two years of data, this results into a set (x_1, x_2, \dots, x_n) of vectors with n determined by the amount of quarter-hours in the dataset, after filtering our certain periods as explained in Section 6.1.1. On top of this, the observed LFC block imbalances are also gathered into one single object $(si_1, si_2, \dots, si_n)$ where si_i corresponds to the LFC block imbalance having occurred at the same period as system conditions x_i .

For each quarter-hour of the next day, a vector x^{new} containing the system conditions of the corresponding quarter-hour is defined. Note that these system conditions are in fact predicted system conditions as they are known at the moment of the prediction, i.e. one day in advance, since they consist in day-ahead forecasts. The objective of the developed machine learning algorithms (as well for KMEANS, KNN and HYBRID) is to select a subset¹⁷ of observations $I \subset \{1, \dots, n\}$ such that the corresponding system conditions $(x_i)_{i \in I}$ are close to the new vector x^{new} containing the system conditions of the quarter-hour for which the prediction is conducted. Once this subset is defined, the associated vector of LFC block imbalances $(si_i)_{i \in I}$ is selected. Since system conditions in $(x_i)_{i \in I}$ are close to x^{new} (e.g. they all exhibit high wind forecast), the imbalance risk of historical observations in I is expected to be close to the imbalance risk of the quarter-hour of x^{new} . By

¹⁷ For the KNN method, see Section 9.1.2, this subset I is always of fixed size 3500 (parameter choice: `n_neighbors = 3500`). For the K-MEANS method, subsets can be of different sizes and typically contains several thousands of observations.

consequence, this vector $(s_i)_{i \in I}$ of LFC block imbalance can be used to estimate the probability density function of an imbalance during that quarter-hour.

It is useful to stress that in the static method, all observations are used to estimate the density function $I = \{1, \dots, n\}$ whereas in machine learning methods only a relevant subset of observations is used, this subset being selected based on system conditions. Furthermore, the subset I is a function of the vector x^{new} , meaning that for a different x^{new} , the subset may be different. By consequence, each of the 96 quarter-hours of the next day may potentially have a different associated I and thus a different prediction. This is the case in the KNN method, as well as the KMEANS method whereas the latter limits the number of different clusters/subsets to a predefined number (parameter choice: n_clusters=15).

9.1 Algorithm descriptions

9.1.1 KMEANS PE

The KMEANS-method (k-means clustering algorithm) estimates the prediction risk at a specific quarter-hour based on a subset of observations based on a predefined cluster with similar system conditions (features).

In the training phase, conducted in the month before the month for which the calculation is conducted, the algorithm uses the filtered time series of historic LFC block imbalances s_i together with corresponding time series of system conditions x_i referred to as features. The values of these features are scaled as explained and the set (x_1, x_2, \dots, x_n) of scaled system conditions is defined. A k-means algorithm is then used to divide the data into a predefined number of disjoint clusters, i.e. 15 clusters, defined by a partition¹⁸ of sets I_1, I_2, \dots, I_{15} and their associated system conditions $(x_i)_{i \in I_1}, \dots, (x_i)_{i \in I_{15}}$. This division is done by minimizing the within-clusters sum-of-squares

$$(I_1, \dots, I_{15}) = \underset{I_1, \dots, I_{15}}{\operatorname{argmin}} \sum_{k=1}^{15} \sum_{i \in I_k} \|x_i - \mu_k\|^2$$

where μ_k is the center of cluster k defined as $\mu_k = \frac{1}{\text{size of } I_k} \sum_{i \in I_k} x_i$.

Finding the optimal clusters, the one minimizing the equation given above, is a computational problem for which heuristics algorithms have to be used. The “k-means clustering” machine learning algorithm of the Scikit-learn library for Python programming is used with all default parameters except the number of clusters (n_clusters=15) and the random_state=0¹⁹. The latter parameter value guarantees the deterministic behavior of the clustering algorithm, meaning that if the same input is given to the algorithm, it will always produce the same outputs.

In the prediction phase, conducted day-ahead for each quarter-hour of the next day, it is determined to which cluster the corresponding day-ahead prediction of the same features belongs, based on the value of the scaled features for the corresponding period. For each quarter-hour of the next day, the relevant cluster is defined as follows:

¹⁸A partition of a set is a grouping of the set's elements into non-empty subsets, in such a way that every element is included in exactly one subset. For instance, $I_1 = (2,3)$ and $I_2 = (1,4,5)$ is a partition of $(1,2,3,4,5)$

¹⁹Specified in the Scikit-learn library for Python programming. <https://scikit-learn.org/stable/modules/generated/sklearn.cluster.KMeans.html>

- (1) define x^{new} the scaled system condition of the specific quarter-hour;
- (1) compute the distance $d_k = \|x^{new} - \mu_k\|$ to each cluster;
- (2) select the cluster that exhibits the smallest distance d_k and derive the corresponding subset of indices I .

The probability density function of the LFC block imbalances associated to that cluster is then extracted and used as prediction risk distribution. Each period will result in a prediction risk distribution.

9.1.2 KNN FE

The KNN-method (k-nearest-neighbors) estimates the prediction risk at a specific quarter-hour based on a subset of observations with similar system conditions (features). The KNN method differs from the KMEANS by the fact that the amount of clusters is not predefined, but that the size (amount of observations) of each subset is predefined. However each new observation result in a new subset with a fixed amount of 'similar' historic observations. The subset of observations in the neighborhood of the quarter-hour (for the same features) are used to calculate a probability distribution of LFC block imbalances corresponding to that quarter-hour.

In the training phase, the same databases of historical scaled system conditions (x_1, x_2, \dots, x_n) and historical LFC block imbalances (si_1, si_2, \dots, si_n) as in the k-means method are constructed. Since each observation has its own cluster, most of the computations are conducted in the prediction step.

In the prediction phase, for each quarter-hour of the prediction data, the knn-algorithm determines the set of nearest neighbors (i.e. 3500) based on the scaled features of the training data and of the specific quarter-hour. Mathematically, the prediction phase works as follows:

- (2) define x^{new} the scaled system condition of the specific quarter-hour;
- (3) compute the distance $d_i = \|x^{new} - x_i\|$ to each historical observation;
- (4) select the 3500 smallest values of d_i and derive the corresponding subset I of indices.

The corresponding 3500 historical system imbalances ($si_i)_{i \in I}$ are then used to estimate the imbalance risk distribution of the corresponding period. Each set of nearest neighbors results in an imbalance risk distribution.

The "unsupervised nearest neighbors" machine learning algorithm of the Scikit-learn library for Python programming is used with all default parameters except for the amount of neighbours ($n_neighbors=3500$)²⁰. Note that this algorithm is per nature deterministic since it simply consists in computing the 3500 closest observations.

²⁰ Specified in the Scikit-learn library for Python programming <https://scikit-learn.org/stable/modules/generated/sklearn.neighbors.NearestNeighbors.html#sklearn.neighbors.NearestNeighbors>

Gradient Tree Boosting

The Gradient Tree Boosting method uses a boosting ensemble of decision trees to improve the accuracy and robustness of predictions. Boosting is a sequential process that trains multiple weak learners (i.e., simple decision trees), in a way that focuses on the samples that were not well predicted in the previous learner. In Gradient Boosting, each decision tree is trained on the residuals (i.e. the difference between the output of the model and the actual realization) of the previous tree.

The Gradient Tree Boosting method is used to predict the sizing variable with a predetermined confidence interval for every 5-minute intervals. Similar to KNN, this supervised learning algorithm tries to minimize the residuals (i.e. the difference between the actual and predicted values) based on a loss function (quantile), which can also be interpreted as a distance metric.

In the training phase, conducted in the month before the month for which the calculation is executed, the algorithm uses the computed sizing variable for aFRR (sv_i) together with corresponding time series of system conditions x_i referred to as features. The model is trained such as minimizes the quantile loss function $L(y_i^p, y_i)$, defined mathematically as:

$$L(y_i^p, y_i) = \max [q * (y_i^p - y_i), (q - 1) * (y_i^p - y_i)]$$

Where:

- y_i^p is the prediction by the algorithm for each observation i for a reliability level q
- y_i is the actual value of the sizing variable for each observation i
- q defines the quantile level (0.99 for predicting downward volumes, 0.01 for prediction downward volumes)

The quantile loss function measures the deviation of the predicted quantile from the actual target value, penalizing underestimation and overestimation differently. When q is set to 0.5, the loss function is equivalent to reduce the Mean Absolute Error (MAE). When q is set to 0 or 1, the quantile loss function reduces to the Mean Squared Error (MSE) loss function.

In the prediction phase, conducted day-ahead for each 5-minutes of the next day, it is determined a prediction associated the corresponding day-ahead prediction of the same features belongs, based on their value. The process can be summarized as:

1. For each 5-minutes prediction, the day-ahead conditions are fed into the trained model.
2. The model applies the pre-defined set of decision trees, one tree at a time, and generates a set of predictions for each tree.
3. The prediction generated by each tree are then combined to generate the final prediction, by summing the predictions from each tree, with each tree weighted by a learning rate²¹
4. Therefore, the final prediction is the sum of the weighted predictions from all the trees in the ensemble

²¹ The learning rate is a hyperparameter that determines the contribution (or importance) of each tree to the final prediction. It scales the prediction of each tree before they are combined.

The “Gradient Boosting Regressor” machine learning algorithm of the Scikit-learn library for Python programming is used with the default hyperparameters, with the exception of the number of estimators (400), and maximum depth (4)²².

9.2 Parameter description

9.2.1 Features

Table 9 provides a list of features used by the machine learning methods. All data is publicly available on ELIA’s website. On top of the observed system imbalances, the features presented in the table are thus used by the K-MEANS, KNN and HYBRID algorithms.

Table 9 : list of features used by the machine learning algorithms

The machine learning methodologies rely on the following features	
Observed LFC block imbalances	Observed LFC block imbalances (in MW) as published on the website of ELIA.
Renewable generation and load forecasts	The day-ahead forecast (in MW) of onshore, offshore, solar photovoltaic and total load as published on the website of ELIA
Renewable generation and load forecast variations	The gradients (in MW) of solar and total load calculated as the difference between two quarter-hour day-ahead predictions
Temperature predicted	The day-ahead predicted temperature (in °C)
Time of day	The hour of day (in h). Cosinus and sinus features are used to capture the cyclic aspect ²³

9.2.2 Scaling

The machine learning methods use a scaling methodology. Unscaled features may have different orders of magnitude. For instance, the load feature typically spans from 6000 to 14000 MW, whereas the temperature feature spans from –15 to 35 °C. Computing the distance with unscaled features

²² Specified in the Scikit-learn library for Python programming <https://scikit-learn.org/stable/modules/generated/sklearn.ensemble.GradientBoostingRegressor.html>

²³ 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.

would be equivalent to give much more weight to features with large order of magnitude, like the total load.

To avoid this unwanted effect, it is important to use a proper scaling. A “normal” scaler is chosen: let $f = (f_1, \dots, f_n)$ be the vector of observations of one specific feature of the training data. The scaled feature is defined as follows: $f_{j,scaled} = \frac{f_j - \text{mean}(f)}{\text{std}(f)}$.

The machine learning methods also use the distance between two observations for clustering or neighboring. The distance is computed as the Euclidean distance between the corresponding vector of features:

$$d(obs_1, obs_2)^2 = \sum_{j=1, \dots, \#features} (f_{1,j} - f_{2,j})^2.$$

9.2.3 Kernel Density Estimator

Finally, all probability distributions of LFC block imbalances are based on a **Kernel Density Estimator**. with imbalance steps of 5 MW. Distributions are stored in vector of length 1001 spanning from -2500MW to +2500 MW by step of 5 MW with the stored density value computed as $f(x) = \frac{1}{2}(kde(x - 2.5) + kde(x + 2.5))$ for $x = -2500, -2495, \dots, 2500$, where $kde(.)$ is the kernel density estimator function. This trapezoidal rule is a typical technique for approximating integral functions. It is illustrated in Figure 14. The kernel density estimator is used to derive the distribution of the LFC block imbalances in a cluster or neighbourhood. The “kernel density” algorithm of the Scikit-learn library for Python programming is used with parameters except for the amount of neighbours ($n_neighbors=3500$; width: ‘default’; type: ‘cosinus’)²⁴.

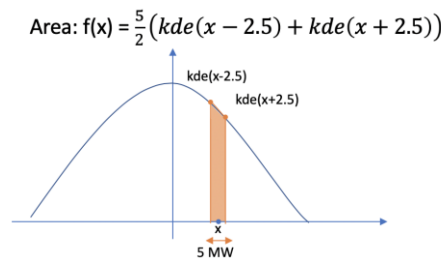


Figure 14 : Once a kernel density estimator is built, the trapezoidal method is used to store the distribution of each value between -2500 and +2500 MW with a step of 5 MW.

²⁴ See documentation of scikit Python library: <https://scikit-learn.org/stable/modules/density.html>