Explanatory Note on Elia’s LFC block operational agreement

October 4, 2019

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INTRODUCTION

The LFC Block Operational Agreements, 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.

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 28/11/2017[1], 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

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

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:

- Part A[2] 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.

1. General Provisions

1.1. 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 reserves[3], 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;

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

[3] *Note 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 contractd*

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).

- ‘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.

1.2. 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.

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.

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.

Until 2019 included, the dimensioning of reserve capacity for FRR was conducted in the framework of another document, referred to as “Dossier Volume” determining the volumes of contracted primary, secondary and tertiary reserves. This document contained the determination of the FRR needs, as well as the FRR means for 2019 and was approved by CREG on October 18, 2018 (Decision B1808) after a public consultation. In order to ensure compliance with SOGL, the dimensioning rules for the FRR needs are determined in this LFC block operational agreement. As from 2020, this document will be replaced by the LFCBOA and the LFC Means, in line with Article 288(2) and 288(3) of the Belgian Federal Grid Code[4].

1.3. Timing for implementation

Article 6(6) of the SOGL requires Elia to define a proposed timescale for implementation. The LFCBOA will enter into force after its approval by the National Regulatory Authority, CREG, at the same day as the Terms and Conditions for the mFRR Service. Until that date, the methodologies and results of the previous version remain valid.

1.4. 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, g, i, j, k, 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.

[4] The provisions of the Royal Decree of 22 April 2019, as amended from time to time, establishing a federal technical regulation for the management of and access to the transmission grid;

The element under g., k. is not applicable as no operational procedure in case of exhausted reserve FRR or escalation procedure are currently implemented in the Elia LFC block. Elia will implement both procedures in a next version of the LFCBOA.

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);
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);
g.	operational procedures in case of exhausted FRR or RR in accordance with Article 152(8) of the SOGL;
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);
k.	the escalation procedure defined in accordance with Article 157(4) and, if applicable, the escalation procedure defined in accordance with Article 160(7)
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);
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);
h.	the FRR dimensioning rules in accordance with Article 157(1);

According to Article 119 of the SOGL the methodologies and conditions in b., 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);
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);

2. Methodologies in accordance with Article 6

2.1. 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 defines 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.

2.2. 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.

2.3. 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 the Network Guidelines on Emergency and Restoration. The link with procedures defined in the Network Guidelines on Emergency and Restoration is only indirect: only when too high ACE gives rise to frequency deviations do we fall within the activation criteria of Article 18 E&R GL "frequency deviation management procedure" or only if there are overloaded (border) lines, Article 19 "power flow management procedure" may be applied.

On the other hand, these concern measures which are taken after (next to) 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 slow start units (units which cannot be activated under the specifications of FRR defined in the SOGL) in combination to the activated FRR means (the latter are activated following the merit order). This in order to avoid the risk of facing an elevated, or enduring FRCE due to the exhaustion of available reserve capacity or due to an extra-ordinary event (such as an offshore storm or other exceptional event) which is not taken into account in the dimensioning methodology specified in Section 3. The conditions for a high FRCE are specified in Article 152(12) and 152(13) of the SOGL.

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.

Under this exceptional measure, Elia mitigates the risk of facing a large FRCE. Within this operational procedure, Elia will activate the slow start units in the most techno-economic efficient way that cannot be called off within the full activation time of mFRR. Elia will activate these units:

- In real-time in order to reduce the FRCE (when exceeding the conditions in Article 152(12) and 152(13)) following the exhaustion of the available mFRR reserve capacity ;
- Ex ante in order to anticipate a high FRCE caused by the depletion of the available mFRR reserve capacity via the creation of additional mFRR reserve capacity. Elia is currently elaborating such measure for offshore storm events ;

For its ex ante measure, Elia takes the decision to activate this flexibility based on following information:

- The relevant forecast (MW);
- The mitigation measures communicated to ELIA by the relevant BRPs and;
- The volume of available FRR reserve capacity at the moment of the expected event.

The volume of flexibility provided by these slow start units activated via this procedure is limited to the residual risk of FRCE. This measure is expected to be used under very specific conditions, and Elia will draft a report for the NRA justifying the decision. Elia expects that reverting to this measure should only happen in exceptional circumstances (and hence being rare) because adequate imbalance prices should give the Balancing Responsible Parties the right incentives to avoid that their portfolio imbalances are triggering such events.

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

With this new version of the LFCBOA, foreseen to enter into force in 2020[5], 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 228(2) of the current Belgian Federal Grid Code. Article 228 specifies that the FRR reserve capacity needs are determined by Elia in the LFCBOA, pursuant to Article 119(1) of the SOGL and the dimensioning methodology is submitted to CREG for approval according to Article 6(3) and 119(2) of the SOGL.

Article 228(3) of the Belgian Federal Grid Code specifies that ELIA shall submit, after a public consultation, at the same time with its proposal for the above-mentioned methodology for

[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.

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 1):

- **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 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".

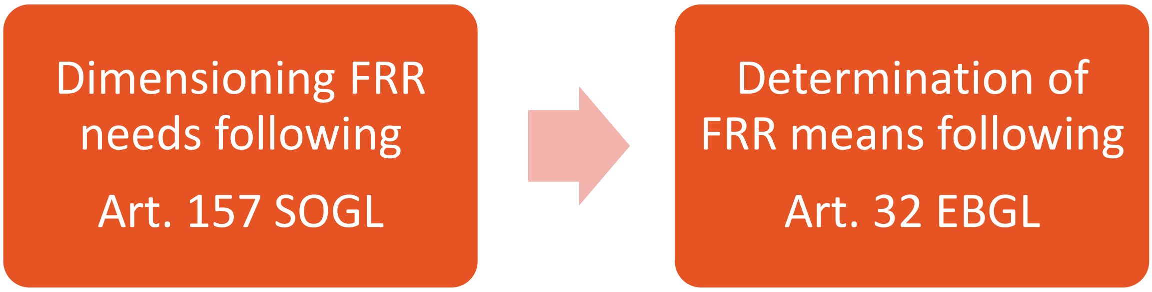


Figure 1 : Distinction between the FRR needs and the FRR means

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.

3.1. 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.

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 2). 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 2 : 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 3.2.

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 4.1), 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 3:

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

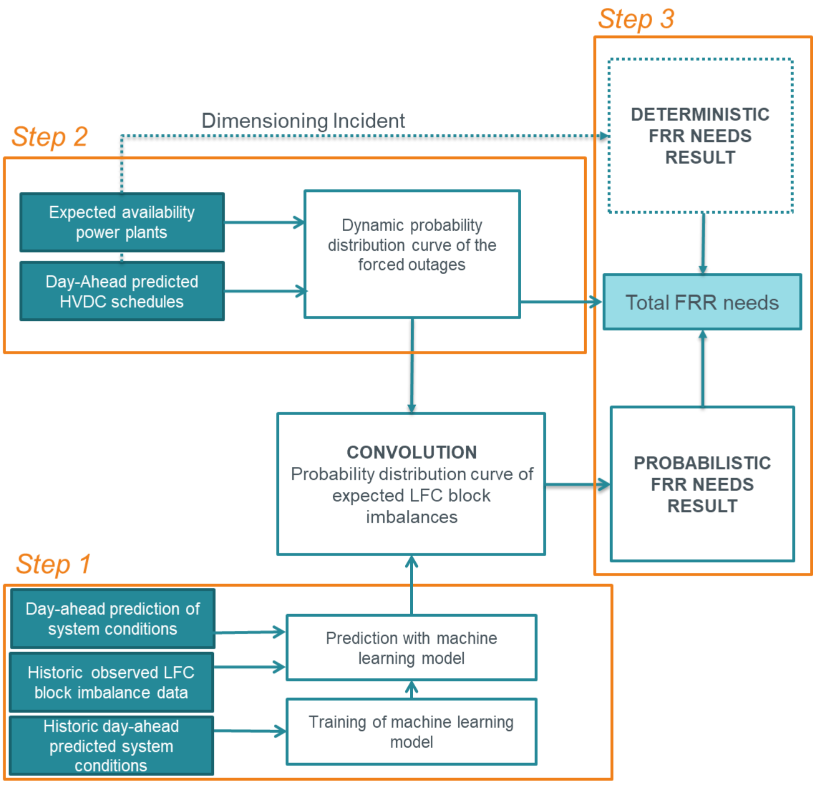


Figure 3 : General overview of dimensioning of the FRR needs

3.1.1. Step 1: Calculation of the prediction risk

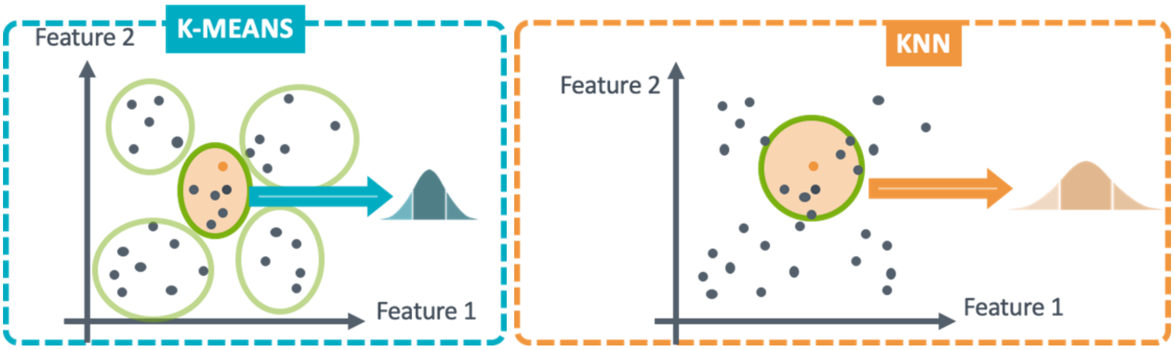
The probability distribution representing the **prediction risk (PE)** is based on historic LFC block imbalances, formerly referred to as system imbalances. The LFC block imbalances are based on consecutive historical records with a resolution of 15 minutes and includes a period of two years, ending 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 observed[6].

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 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 4). 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).



[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

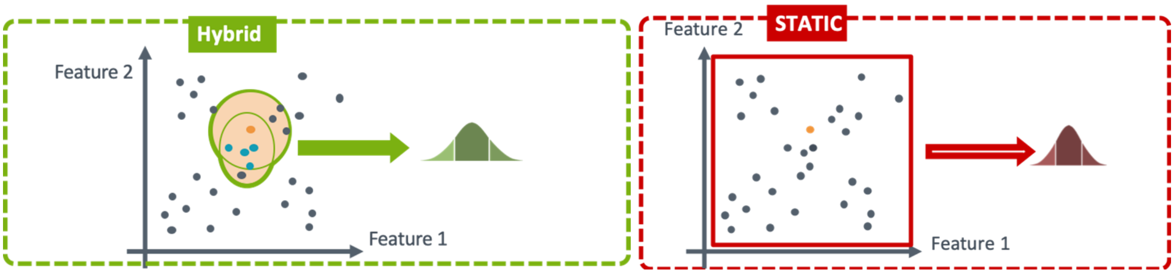


Figure 4 : Graphical representation of the algorithms used to determine the prediction risk

3.1.1.1. 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 4-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.

3.1.1.2. KMEANS PE

The KMEANS method estimates the predication 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 4-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 used[8]. A more

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[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

[8] Specified 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.

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.

3.1.1.3. 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 4-KNN. These neighborhood is determined based on the same features as in the KMEANS-method[9]. 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 used[10] 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.

3.1.1.4. 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 4-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 4-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.

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[9]The 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

[10]Specified 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_neighbours=3500). All other parameters are set at their default value.

3.1.2. 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;

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 2019[11].

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

[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

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 duration[12]. 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.

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 determine 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.

3.1.2.1. 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

[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.

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

3.1.2.2. 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 programmed 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. At the end of 2019, and in the years to come, Elia will have experience on NEMO Link to evaluate this parameter. 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 indecisive:** 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 day-ahead price forecasts for Belgium and the United Kingdom provided by an external service provider which allows Elia to predict the interconnector in import (price BE << price UK), export (price BE >> price UK) and indecisive (low price difference between BE and UK). A maintenance status is communicated to ELIA by the HVDC-interconnector operator in order to be taken into account in the day-ahead calculations.

If the price difference is lower as 7 €/MWh, the interconnector is considered as indecisive. This 7 €/MWh is a parameter determining the uncertainty margin is determined by Elia by analyzing the ratio of wrongful (situation where NEMO Link is wrongfully predicted in import or export) versus informative (situation where NEMO Link is not predicted as indecisive) forecasts. The current value of 7 € / MWh is determined by a sensitivity analysis conducted in the framework of the dynamic dimensioning study[6].

Additional limitations of the maximum import or export capacity (following grid operational constraints) are taken into account when known at the moment of prediction but only when these capacity reductions are firm (i.e. cannot increase between prediction of the FRR needs and real-time.

3.1.3. 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.

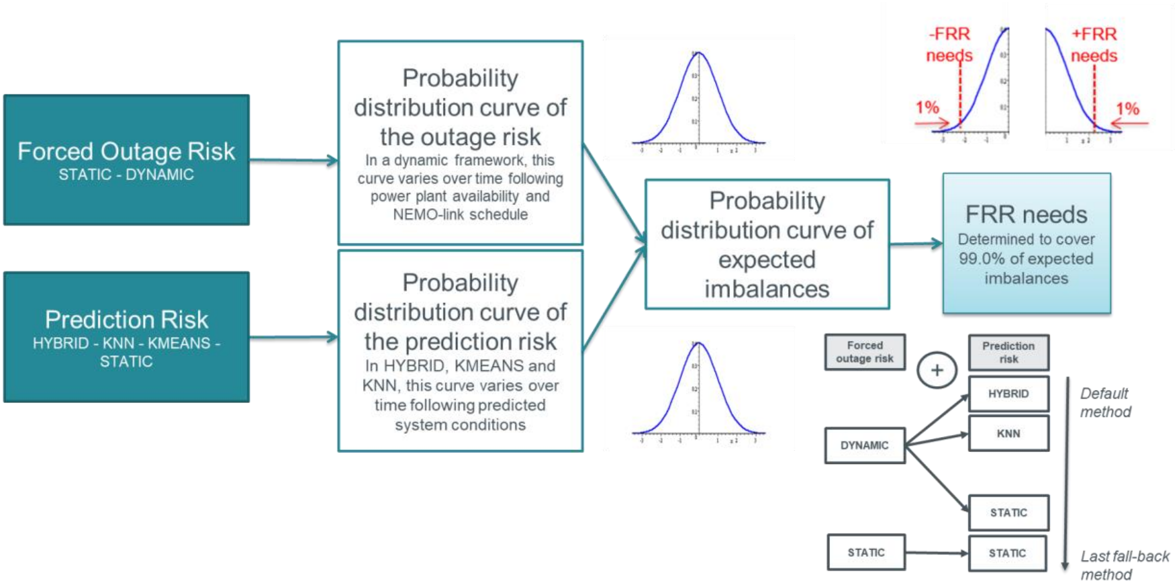

Figure 5 : Overview of the convolution of the forced outage risk and prediction risk for each methodology

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 <u>training</u> 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 <u>prediction</u> 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.

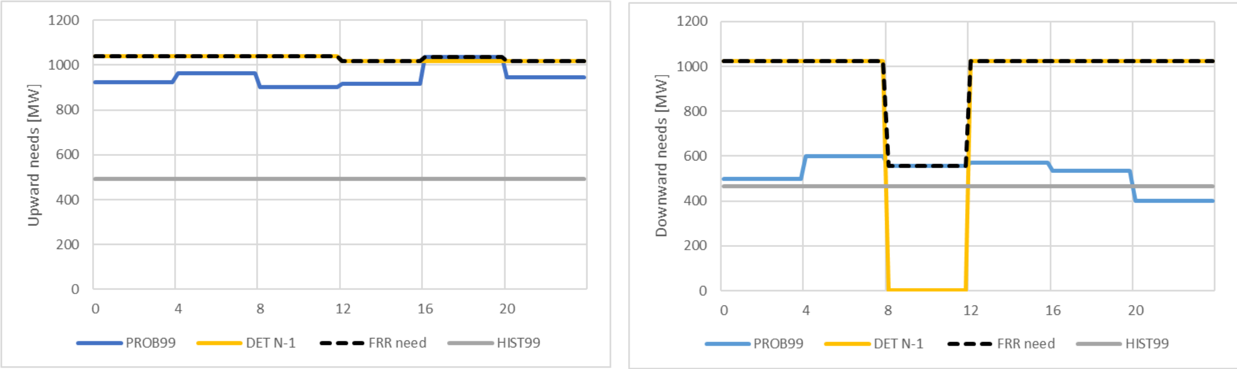

Figure 6 : Illustration of the FRR needs

3.1.4. FRCE quality indicators and historic LFC block imbalances

As explained in Section 4.1, 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
The mean value	-1,9
The standard deviation	47,9
1-percentile	-166,6
5-percentile	-75,6
10-percentile	-40,0
90-percentile	32,9
95-percentile	63,0
99-percentile	150,1

FRCE-indicators	2018	Target
Number of time intervals: average FRCE > Level 1 positive	1059	10512
Number of time intervals: average FRCE < Level 1 negative	1417	
Number of time intervals: average FRCE > Level 2 positive	262	1752
Number of time intervals: average FRCE < Level 2 negative	352	
Number of events: FRCE > 60 % FRR capacity- and not < 15 % FRR capacity- within 15 min	0	
Number of events: FRCE < -60 % FRR capacity+ and not >- 15 % FRR capacity+ within 15 min	0	

Concerning the **historic LFC block imbalance data** published on the website of Elia, Figure 7 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.

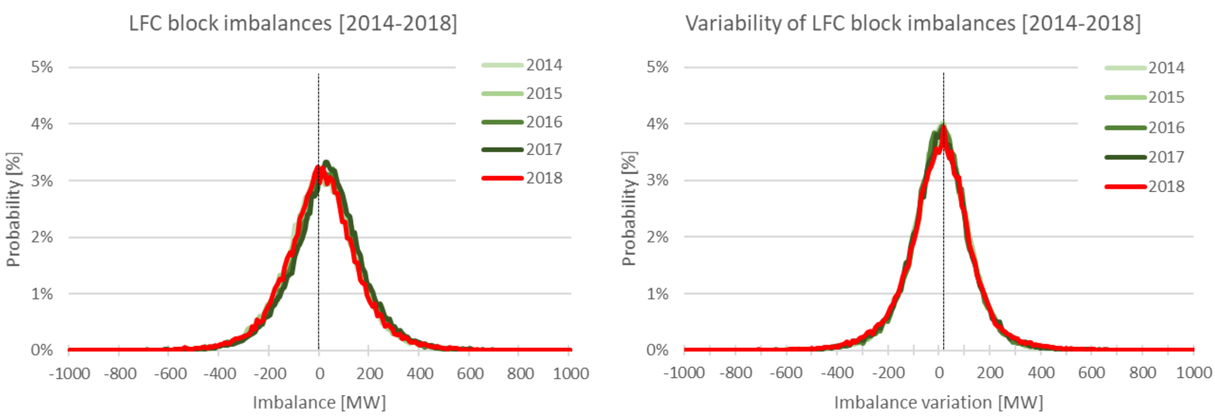

Figure 7 : Probability distribution of the LFC block imbalances between 2014 and 2018 (in steps of 10 MW)

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

3.2. Determination of the ratio of automatic FRR and manual mFRR

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 maximal 7.5 minutes and 15.0 minutes, respectively for aFRR and mFRR balancing capacity.

Elia uses a **'static' probabilistic method** to dimension the aFRR needs, based on a time series of two years of expected variations between quarter-hours of LFC block imbalances. This means the result of the aFRR dimensioning is fixed as from this article enters into force until a new article enters into force by means of a new version of the LFCBOA. After the aFRR needs are determined, the mFRR needs can be calculated dynamically as the difference between total dynamic FRR needs and the static aFRR needs.

The aFRR reserve capacity needs are determined by the capacity that can cover 79% of the absolute variations of LFC block imbalances. This target is fixed since 2016 as found to pursue a sufficient FRCE-quality. The aFRR is used to compensate for arbitrary and rapid variations in the LFC block imbalance, which are modelled by means of the variability of the LFC block imbalance. Due to its automatic nature, the aFRR reserve capacity is very important to ensure a good quality of the FRCE. Manual activations (I/D offers under the CIPU contract, mFRR balancing capacity) serve to compensate for larger long-term imbalances and therefore play a less important role in the observed quality of the FRCE, at least when not analyzing the extreme situations. The iGCC, set up in October 2012, if found to contribute to improving the quality of the FRCE.

Elia foresees to submit a new version of the LFCBOA in Q3 2020 with a new or updated methodology for aFRR dimensioning. It will be investigated at least if this methodology can take into account FRCE-indicators in relation to their quality targets, intra-quarter-hourly LFC block imbalances, as well as allowing a dynamic calculation, i.e. a daily update of the aFRR needs in view of the foreseen system conditions.

3.2.1. Calculation of the expected LFC block imbalances

A time series is constructed based on the same time series of historic quarter-hourly positive and negative LFC block imbalances as specified in Section 3.1.1. As required by Article 152(2.a), the sampling of the historical time series is determined at 15 minutes, covers at least an entire year, and never ends earlier as 6 months before the calculation date. In such a 'static' methodology, the result is submitted for approval to the NRA. This implies that the time series, and thus the probability distribution curve, is not updated after approval of the methodology.

When calculating the aFRR needs, a time series is used from July 1, 2017 to June 30, 2019. In contrast to a dynamic approach where reserve needs are determined daily close-to-real-time, a 'static' methodology fixing a volume for a longer period and therefore requires extrapolations of historic LFC block imbalances towards the future.

The historic time series is extrapolated by taking into account expected system evolutions between the period represented by the historical records and the period for which the FRR needs are determined in the 'static' approach, i.e. 2020. For every quarter-hour, the LFC block imbalance (SI_t) is increased or decreased with the expected forecast errors ($FE_{t,i}$) resulting from the incremental capacity of each technology *"i",* i.e. onshore and offshore wind power, as well as photovoltaic power. Correlations between system imbalances and forecast errors are taken into account by always using the same period "t" for every parameter. For every quarter-hour "*t*", the expected LFC block imbalance in 2020 (Baseline) is calculated as:

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

- ***$FE_{t,i} = (DA_{t,i} - RT_{t,i}) / MC_{t,i}$***
    - *$DA_{t,i}$: day-ahead forecast [MW] as published on the website of Elia*
    - *$RT_{t,i}$: real-time estimation [MW] as published on the website of Elia*
    - *$MC_{t,i}$: monitored capacity [MW] as published on the website of Elia*
- **$A_i = 1 - X_i * Y_i$** : improvement factor representing the forecast accuracy improvements following intra-day predictions (X) and the ability of the BRP to adjust its portfolio following this information (Y).
    - X assumed to be 35% for each technology
    - Y is assumed to be 100% for each technology

  These figures are justified by means of historic observations. The literature shows that the relative theoretical improvement potential of an intra-day forecast compared to a forecast on D-1 is in the range of 30% to 40% maximum[13]. This is also confirmed on actual observation shown in Table 9. Elia does therefore sees no reason to change the value of 35% used in the previous years. However, with improving liquidity on intra-day markets, it is assumed that BRPs can adapt their portfolio in function of this forecast update.

[13] Projet TradeWind :www.trade-wind.eu et « Balancing and Intraday Market Design: Options for Wind Integration », F. Borggrefe, K. Neuhoff ; CPI ; 2010

Table 9 : forecast error statistics for year 2017 and 2018 (Elia's adequacy and flexibility study 2019)

2017 - 2018	Mean Absolute Error Day-ahead	Mean Aboslute Error Intra-day	Intra-day forecast Improvement
offshore	8,38%	6,08%	27,4%
onshore	4,51%	3,18%	29,5%
photovoltaics	1,95%	1,32%	32,3%

***$IC_{t,i}$* :** for every technology "i", the difference between the installed capacity between the month corresponding to the period "t" in the historic time series of LFC block imbalances, and the corresponding month in 2020. These values are specified in Table 10. The yearly installed capacities for onshore wind and photovoltaics is derived from the Excel with input data on Elia's adequacy and flexibility study 2019. The monthly values result from a linear interpolation from these yearly values. The offshore values results from the planning for commissioning of the offshore wind parks. The data shows a substantial increase in all renewable capacities, including offshore wind power for which prediction errors are generally higher as the other technologies.

Table 10 : installed capacity on wind onshore, wind offshore and photovoltaics (Excel input data for Elia's adequacy and flexibility study 2019 and available planning for commissioning of the offshore wind parks)

Months	2017-18			2018-19			2020		
	PV	Onshore Wind	Offshore Wind	PV	Onshore Wind	Offshore Wind	PV	Onshore Wind	Offshore Wind
jul	3.426	1.808	878	3.788	2.113	1.010	4.805	2.666	1.759
aug	3.458	1.829	878	3.817	2.141	1.091	4.858	2.688	1.759
sep	3.490	1.851	878	3.846	2.169	1.179	4.911	2.710	1.759
oct	3.523	1.872	878	3.875	2.198	1.179	4.964	2.731	1.759
nov	3.555	1.894	878	3.903	2.226	1.179	5.017	2.753	1.759
dec	3.587	1.915	878	3.932	2.254	1.179	5.070	2.775	1.840
jan	3.616	1.943	878	3.974	2.276	1.179	4.486	2.535	1.920
feb	3.645	1.972	878	4.016	2.297	1.207	4.539	2.557	2.001
mar	3.673	2.000	878	4.057	2.319	1.225	4.592	2.579	2.085
apr	3.702	2.028	878	4.099	2.340	1.326	4.645	2.600	2.169
may	3.731	2.056	878	4.141	2.362	1.442	4.698	2.622	2.253
jun	3.760	2.085	937	4.183	2.384	1.529	4.752	2.644	2.253

- **B_i : (1-Z)** : improvement factor representing the improvement in system imbalance following Elia's continuous efforts to incentivize and help BRPs balancing their portfolio. This improvement (Z) is assumed to be 2%.

  As explained in Section 3.1.4, a decreasing LFC block imbalance has been observed until 2016. This trend is the result of continuous efforts/improvements of recent years, amongst which:

  - the effect of the transition from the imbalance mechanism to the "single marginal pricing" mechanism (better incentives);
  - additional efforts concerning the communication on the issue of imbalance to BRPs and market players;
  - efforts made to enable market participants to have a better view of the planned total injection of wind and photovoltaic production. Since 2013, the infeed for injection stations has also been published;

- the efforts made to allow BRPs to deviate from their balances in order to help balance the RFP block, as specified in the BRP contract;
- an expected improvement in tools for forecasting renewable production and demand.

Despite the stabilization of the LFC block imbalance improvement as from 2017, Elia will continue to work in the future to better inform BRPs and market participants about the imbalance in the system (intraday forecasts of wind and photovoltaic production, publication of photovoltaic energy injection, publication of injection data from distribution networks, more efficient incentives through the imbalance tariff, 1-minute publications of imbalance prices), the decline in baseline imbalances is assumed to continue and is expected to remain at 2% between 2017-19 and 2020.

The baseline represents a time series with the expected quarter-hourly LFC block imbalances in 2020. The probability distribution of this baseline, together with its individual components is shown in Figure 7. A new time series is created to represent the 2020 variations, i.e. the difference between two quarter-hours is used to represent the LFC block imbalance variations in 2020. The probability distribution for baseline variations, including different components is given in Figure 8. It can be seen that the impact of the extrapolation of the LFC block imbalance variations is negligible, in contrast to the LFC block imbalances.

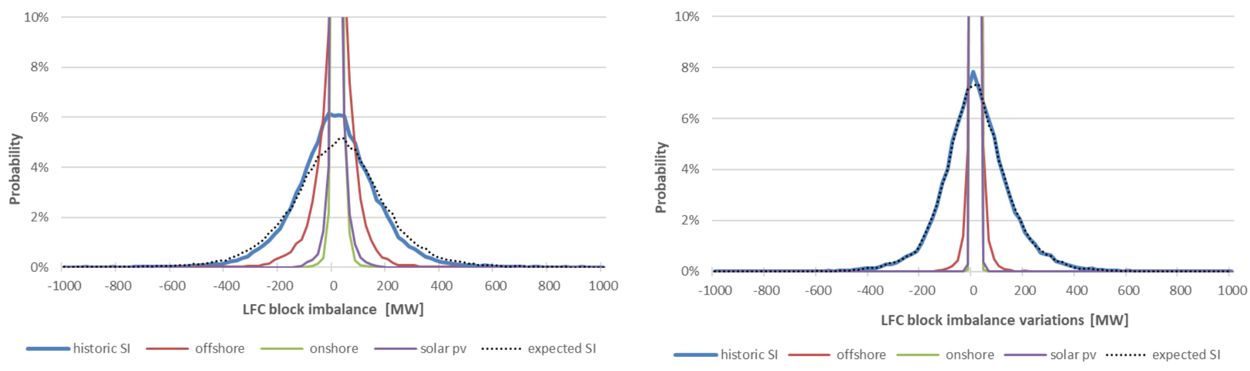

Figure 8 : Extrapolation of the LFC block imbalance towards the expected LFC block imbalance (SI) for 2020

3.2.2. Calculation of the required aFRR needs

The required positive and negative (symmetric for both directions) reserve capacity on aFRR is determined to cover 79% of the absolute values of the LFC block imbalance variations. This target is used since 2016 and is found to attain sufficient FRCE quality, above ENTSO-e standards, as discussed in Section 3.1.4. The current methodology result in an aFRR needs of 151 MW. Figure 9 shown an inverse cumulative probability distribution of the LFC block imbalance variations, showing that there is 21% probability that the LFC block imbalance variation over two quarter hours will be larger as 151 MW.

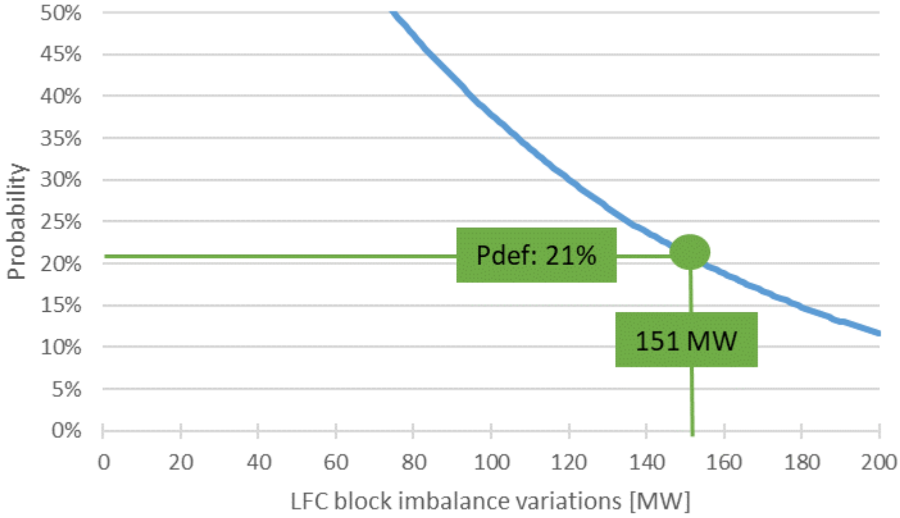

Figure 9 : inverse cumulative probability distribution of the LFC block imbalance variations

As mentioned, Elia foresees to investigate if this methodology can be improved towards future years. Therefore, Elia will present in a next version of the LFC BOA a new methodology to assess the aFRR needs. As Elia is currently investigating a better methodology to determine the aFRR needs, and current FRCE-indicators remain well under targets set by ENTSO-e, it might not be justified to increase the aFRR needs. Therefore, Elia will limit the maximal positive and negative aFRR needs at the same value as calculated in 2019, i.e. 145 MW.

After this step, 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 determined on daily basis and the fixed aFRR needs.

3.3. 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 RTE, Tennet and NGET which are expected to remain valid in 2020 and thereafter.

Figure 4 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.

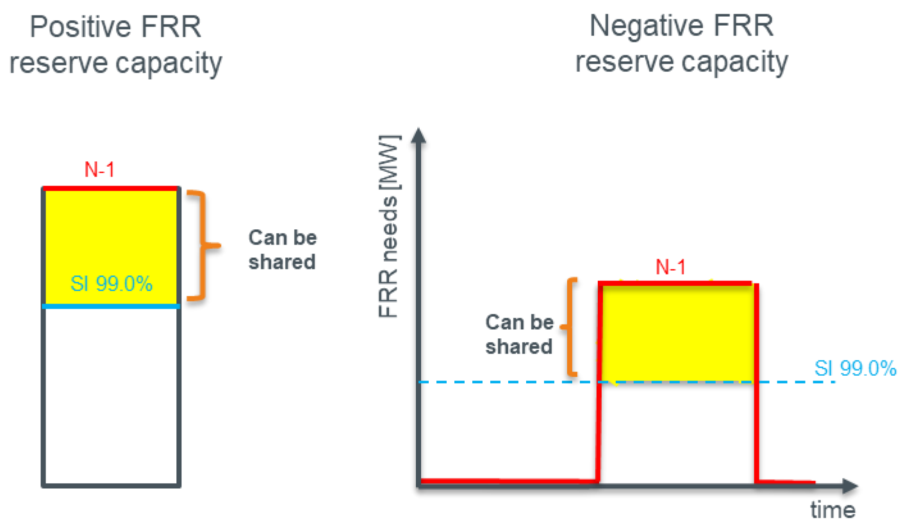

Figure 10 : Visual representation of the maximal sharing potential following SOGL by the surface between dimensioning incident (N-1) and historic LFC-block imbalances (SI 99%) for dimensioning positive FRR needs (left) and negative FRR needs (right)

Based on an analysis of the historic LFC block imbalances from July 1, 2017 until June 30, 2019 :

- the 99% percentile of the positive LFC block imbalances is calculated at 492 MW;
- the 99% percentile of the negative LFC block imbalances is calculated at 464 MW.

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 MW[14]. This value determines the sharing limit as it is lower as the difference between 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, i.e. 547 MW (1039 MW – 492 MW).

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 as sharing is determined at 532 MW. This value 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, i.e. 560 MW (1024 MW – 464 MW). In contrast, in periods where NEMO Link is foreseen to be in import, or in maintenance, the difference, if positive, 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

[14] 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

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:

- **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 asses 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.

3.4. 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 and the positive and negative mFRR needs of the next day, and this not later than 7 AM. 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 'static' aFRR needs is determined and fixed in Section 3.2.

However, in order to determine the volume of balancing capacity to be procured for aFRR and mFRR, these capacities are to be transformed in Article 228 of the Federal Grid Code which 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 the result of the calculation when it concerns static calculations, i.e. values which remain fixed for at least one year.

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

4.1. 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.

4.2. 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 3.2, the control quality is defined at 7.5 minutes full activation time and 15 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.

4.3. 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.

5. 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

6. 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 6.2) used in the machine learning algorithm: *[offshore prediction, onshore prediction, time of day, …]$_i$*. 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 3.1.1. 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 subset[15] 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 consequence, this vector $(si_i)_{i \in I}$ 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).

6.1. Algorithm descriptions

6.1.1. 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 si_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 partition[16] 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

[15] For the KNN method, see Section 6.1.2, this subset I is always of fixed size 3500 (parameter choice: n_neigbors = 3500). For the K-MEANS method, subsets can be of different sizes and typically contains several thousands of observations.

[16] A 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 $I_1 = (1,4,5)$ is a partition of (1,2,3,4,5)

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

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

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=0[17]. 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:

(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 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.

6.1.2. 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 $(x_1, x_2, \ldots, x_n)$ and historical LFC block imbalances $(si_1, si_2, \ldots, si_n)$ 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:

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[17]Specified in the Scikit-learn library for Python programming. https://scikit-learn.org/stable/modules/generated/sklearn.cluster.KMeans.html

(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)[18]. Note that this algorithm is per nature deterministic since it simply consists in computing the 3500 closest observations.

6.2. Parameter description

6.2.1. Features

Table 11 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 11 : 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[19]

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

[19] 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

6.2.2. 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 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: $f_{j,scaled} = \frac{f_j - mean(f)}{std(f)}$.

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:

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

6.2.3. 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 $f(x) = \frac{1}{2}\left(kde(x-2.5) + kde(x+2.5)\right)$ for x=-2500,-2495,…,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 11. 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')[20].

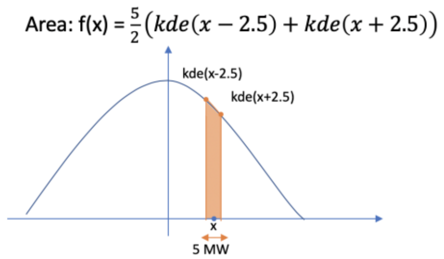

Figure 11 : Once a kernel density estimator is built, the trapezoidal method is used to store the distribution of each value between -2500 and +2500 MW with a step of 5 MW.

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.

[20] See documentation of scikit Python library https://scikit-learn.org/stable/modules/density.html