entsoe

European Network of
Transmission System Operators
for Electricity

SUPPORTING PAPER FOR THE LOAD-FREQUENCY AND RESERVES NETWORK CODE

WORKING DRAFT

23.01.2013

DRAFT V2

1 PURPOSE AND OBJECTIVES OF THIS DOCUMENT

1.1 PURPOSE OF THE DOCUMENT

This document has been developed by the European Network of Transmission System Operators for Electricity (ENTSO-E) to accompany the consultation of the Load-Frequency-Control and Reserves Network Code (LFC&R NC) and should be read in conjunction with that document.

The document has been developed in recognition of the fact that the LFC&R NC, which will become a legally binding document after comitology, inevitably cannot provide the level of explanation, which some parties may desire. Therefore, this document aims to provide interested parties with the background information and explanation for the requirements specified in the LFC&R NC, as well as the document outlines the following steps of the work.

1.2 STRUCTURE OF THE DOCUMENT

The supporting paper is structured within the framework for all system operation network codes supporting papers as follows:

Background:

- Section 2 introduces the legal framework within which the system operation network codes have been developed as well as the next steps in the process.
- Section 3 explains the approach, which ENTSO-E has taken to develop the network code, outlines some of the challenges and opportunities ahead of System Operation as well as concepts used in the LFC&R NC are clarified in this section.

Explanatory notes:

- Section 4 complies with the requirements of the Framework Guidelines on System Operation (FG SO [1]) regarding LFC&R NC developed by the Agency for the Cooperation of Energy Regulators (ACER).
- Section 5 focuses on the objectives of the LFC&R NC topic by topic, identifying the enhancement of technical requirements with an assessment of their associated benefits. Choices appearing in the code will be justified in this section.
- Section 6 describes the added value of implementing the technical and operational principles set by the LFC&R NC.

Next steps:

- Section 7 summarises next steps in the development of the LFC&R NC.

1.3 LEGAL STATUS OF THE DOCUMENT

This document accompanies the LFC&R NC, but is provided for information only and therefore it has no binding legal status.

1.4 RESPONDING TO THE CONSULTATION

Responses to the public consultation on the LFC&R NC are requested by 31 March 2013. All responses should be submitted electronically via the ENTSO-E consultation tool, explained at https://www.entsoe.eu/resources/consultations/ .

2 PROCEDURAL ASPECTS

2.1 INTRODUCTION

This section provides an overview of the procedural aspects of the network codes' development. It explains the legal framework within which network codes are developed and focuses on ENTSO-E's legally defined roles and responsibilities. It also explains the next steps in the process of developing the LFC&R NC.

2.2 THE FRAMEWORK FOR DEVELOPING NETWORK CODES

The LFC&R NC has been developed in accordance with the process established within the Third Energy Package, in particular in Regulation (EC) 714/2009. The Third Package legislation establishes ENTSO-E and ACER and gives them clear obligations in developing network codes. This is shown below:

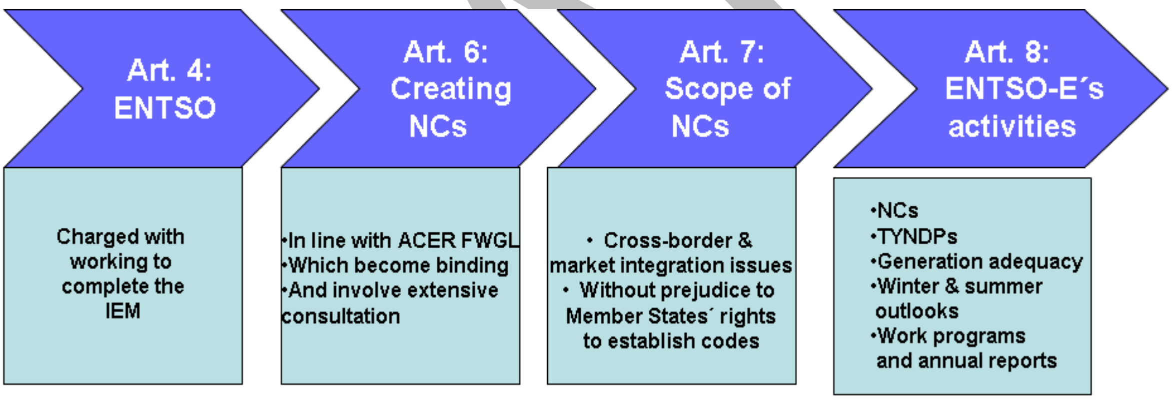

Figure 1: ENTSO-E's legal role in network code development according to Regulation (EC) 714/2009.

Moreover, this framework creates a process for developing network codes involving ACER, ENTSO-E and the European Commission, as shown in Figure 2 below.

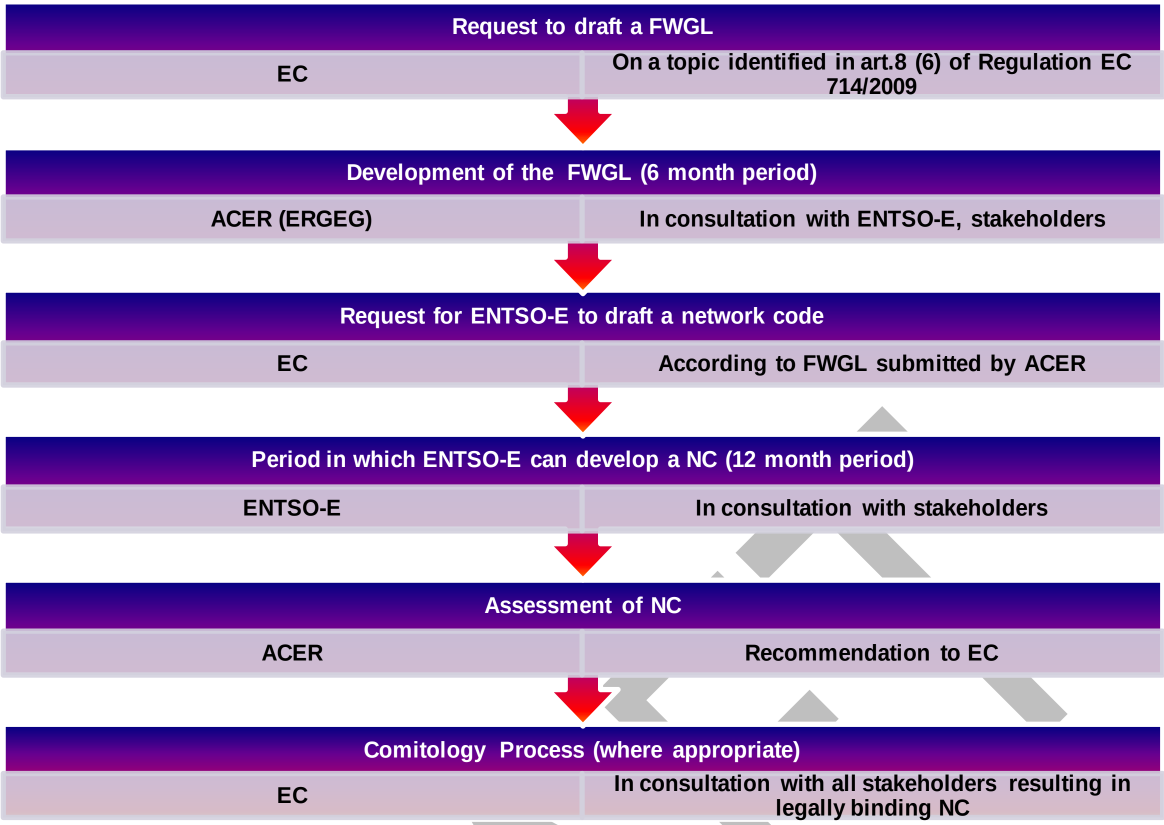

Figure 2: Network codes' development process [Source: ENTSO-E]

The LFC&R NC has been developed by ENTSO-E to meet the requirements of the System Operation Framework Guidelines (FG SO) [1] published by ACER in December 2011. ACER has also conducted an Initial Impact Assessment associated with its consultation on its draft FG SO in June 2011 [2].

ENTSO-E was formally requested by the European Commission to begin the development of the LFC&R NC on 1st July 2012. The deadline for the delivery of the code to ACER is the 1st July 2013.

2.3 NEXT STEPS IN THE PROCESS

ENTSO-E is now consulting on the LFC&R NC. A workshop with the DSOs Technical Expert Group and a public stakeholder's workshop will be held on 13 February and 12 March 2013, in order to present the updates done in the draft LFC&R NC, taking into account comments from the stakeholders after 1st and 2nd workshops respectively 12 July and 25 September 2012. We encourage stakeholders and involved parties to submit comments and to provide proposals for addressing any concerns they have with the current draft to the public consultation tool, available on ENTSO-E webpage https://www.entsoe.eu/resources/consultations/. ENTSO-E will carefully consider all comments which are provided and will update the network code in light of them. The way in which we intend to finally amend the code will be outlined in the 4th Workshop on the LFC&R NC planned for the mid of May 2013. Following agreement and approval within ENTSO-E, the network code will be submitted to ACER in line with the defined deadline of 1st July 2013.

ACER is then expected to assess the LFC&R NC to ensure it complies with the FG SO and will make a recommendation to the European Commission. When the European Commission agrees with the ACER recommendation, the European Commission can conduct the Comitology process which will eventually transform the LFC&R NC into a legally binding integral component of the Regulation (EC) 714/2009.

3 Scope, structure & approach to drafting the LFC&R NC

3.1 Background

ENTSO-E has drafted the LFC&R NC to define the minimum requirements for TSO and Reserve Providing Units ensuring secure and efficient operation of load-frequency control in order to achieve and maintain a satisfactory level of frequency quality inside each Synchronous Area.

Based on the FG SO and on the Initial Impact Assessment (IIA) provided by ACER, the LFC&R NC states the operational planning and scheduling principles in terms of technical needs, considering market solutions compatible and supporting to maintaining the security of supply.

3.2 Guiding Principles

The guiding principles of the LFC&R NCs are to determine common load-frequency control processes and control structures, to ensure the conditions for maintaining a frequency quality level of all synchronous areas throughout the EU, as well as to determine common requirements to reserve providing units for the provision of reserves to the reserve connecting TSO. These principles are essential for the TSOs of a synchronous area to manage their responsibilities to ensure a sufficient level of frequency quality efficiently.

The main goal of the system operation NCs is to achieve a harmonised and solid technical framework - including the implementation of all necessary processes required for it, taking into account the rapid growth of the (volatile) Renewable Energy Sources (RES) generation and their impact on system operation. Consequently, the requirements have been designed in order to ensure the proper functioning of load-frequency control, taking into account the integration of the RES and the effective development of the IEM.

The requirements set out in system operation NCs on TSOs, DSO and grid users are building upon a long history of existing common and best practices, lessons learned and operational needs throughout the European transmission systems. This, together with the fact that the European experience of interconnected transmission systems operation dates back to the 1950-ies (ENTSO-E Regional Group Central Europe (RGCE), former Union for Coordination of (Production) and Transmission of Electricity (UC(P)TE)), 1960-ies (ENTSO-E North, former Nordel), and 1970-ies (TSO Associations of Great Britain and Republic of Ireland, UKTSOA and ITSOA), distinguishes the LFC&R NC and all other system operation NCs from other Network Codes in following terms:

- The work on the system operation NCs does not start from “scratch” but builds upon a wide and deep range of requirements, policies and standards of the previous European transmission system interconnections (synchronous areas), adapting and developing further these requirements in order to satisfy the requirements from the FG SO, to meet the challenges of the “Energy Turnaround” including RES and increasing volatility and dynamics of market operations as well as to support effective and efficient completion of the IEM;

- The subject matter – system operation of the interconnected transmission systems of Europe – is vital, not just for the continuous and secure supply of European citizens with electricity but also for the electricity market to function at all. Therefore, any changes, adjustments and developments based on the new (legally binding after comitology) system operation NC’s

- framework must acknowledge and respect the fact that system operation cannot be interrupted and "restarted" – we are working on a "living grid";

- By their nature and because of the level of technical detail involving all aspects of transmission system operations, the system operation NCs are mainly addressing the TSOs and ENTSO-E; nevertheless, firm links and cross-references, as well as practical dependencies and explanations are established in relation to other NCs, most notably those addressing grid connection, market and regulating power / balancing.

3.3 BACKGROUND AND STRUCTURE OF LFC&R NC

Secure and efficient transmission system operation can be made possible, only if there is an obligation for the Transmission System Operators (TSOs) and the Reserve Providing Units to cooperate and to meet the relevant minimum technical requirements for the load-frequency control operation of the interconnected transmission systems of a synchronous area as one entity. Even though each TSO has its own responsibility area, secure and efficient load-frequency control of a synchronous area is a common task:

- All systems inside a synchronous area contribute to the frequency quality; each TSO inside a synchronous area has to support the frequency quality accordingly and a fault in one area will possibly affect the whole synchronous area. Hence, secure load-frequency control requires close coordination and cooperation.
- Efficient system operation requires close collaboration between all stakeholders; the main purpose of the liberalizing and therefore this harmonizing of the electricity sector was efficiency, and utilizing the resources for balancing the system efficient requires close collaboration and coordination on EU level.

Secure and efficient load-frequency control can be made possible only if there is a well-organized structure of load-frequency control and an application of EU-wide harmonised processes based on commonly shared quality targets. It is aimed to have all means necessary to control the system in real time at disposal of the TSO, when it is either subject to normal changes of operation conditions or facing incidents affecting generation, demand or transmission equipment.

LFC&R NC provides the basis for these harmonised processes, control structure and quality targets. It defines the minimum process requirements for ensuring an effective and efficient load-frequency control applicable to all TSOs and reserve providing units.

LFC&R NC covers the control processes "frequency containment reserve", "frequency restoration reserve" and "replacement reserve". All stakeholders, including TSOs, should respect the common requirements for these control processes and to develop relevant measures required to maintain the quality and stability of the load-frequency control and to support the efficient functioning of the European Internal Electricity Market. These control processes are the basis for the key elements, structure and provisions of this Network Code.

3.4 LEVEL OF DETAIL

The system operation NCs provide minimum standards and requirements related to system operation. The level of detail matches the purpose of the codes: harmonising security principles, clarifying and harmonising methods, roles and responsibilities of operators and grid users as well as to enable and ensure adequate data exchange in order to future proof the system for integrating innovative technologies and sustainable energy sources, operate the system in a safe, secure, effective and efficient manner and applying the same principles and procedures for different systems to establish a wider level playing field for market participants.

In order to achieve the necessary level of European harmonisation, allowing at the same more detailed provisions at the regional / national level where necessary, and with the view of drafting network codes for electricity system operation that are open for future developments and new applications, an approach focusing on pan-European view and most widely applicable requirements has been pursued throughout all the development phases.

The FG SO [1] provided further clarification concerning the issue of European-wide applicability, while pointing out that *"… ENTSO-E shall, where possible, ensure that the rules are sufficiently generic to facilitate incremental innovation in technologies and approaches to system operation being covered without requiring code amendments"*.

Thus, the requirements have been drafted considering a period of approximately 5 years as a reasonable cycle within which changes to the LFC&R NC will have to be implemented, building up a coherent legal mechanism with the appropriate balance between level of detail and flexibility, which focuses on what-to-do, not so much how-to-do.

Regarding LFC&R NC, harmonisation principles are handled through a global framework consisting in the three following levels addressed coherently:

- **European wide level:** Definition of the common control processes "frequency containment reserve", "frequency restoration reserve" and "replacement reserve" and the rules for border-crossing exchange of reserves;
- **Synchronous areas level:** Establishment of the control structure, definition of a common frequency quality target and application of the frequency containment reserve process;
- **LFC Block level:** Definition of a frequency restoration target and application of the frequency restoration reserve process and the replacement reserve process.

Regarding methodologies, the approach adopted is to tune the provisions through a global framework giving high level principles and requirements for detailed specifications to be carried out of the code, in a transparent process and leaving place to further evolutions and improvements.

Whereas the first LFC&R NC picks up as much input from involved parties as possible in order to enable a high level of system security, regional requirements concerning the different synchronous areas, regions or even single TSOs may lead to further and more detailed provisions.

3.5 FIELD OF APPLICABILITY OF THE LFC&R NC

Whereas the requirements of the LFC&R NC are directly applicable in all Member States, it should be noticed that the provisions set in the LFC&R NC should not apply in the following cases:

- In the small isolated systems and micro isolated systems in accordance with the Article 8(7) of Regulation (EC) N° 714/2009
- In the isolated systems which do not present any cross-border network issues nor market integration issues, in the absence of transmission system.
- Power systems operating under synchronous mode in the area, in which not all the systems are bound by the EU legislation, the provisions of this Network Code shall apply only to the extent they could be duly applied and implemented within the entire Synchronous Area as

long as these power systems are operating therein, taking into account the physical and technical nature of frequency regulation implemented in the whole Synchronous Area. This applies to the TSOs of Estonia, Latvia and Lithuania operated in the IPS / UPS system.

3.6 INTERACTION WITH OTHER NETWORK CODES

The Load-Frequency Control & Reserve Network Code (LFC&R NC) is being drafted in parallel with other related network codes. Several processes, methodologies and standards provided in LFC&R NC are influenced by or would influence these related network codes and the coordination of the interactions is an important objective of ENTSO-E. The principal cross-issues with other network codes have been dealt with in the following way:

- The Network Codes on *System Operation* – these codes consist of the Operational Security NC (OS NC), the Operational Planning and Scheduling NC (OPS NC) and the LFC&R NC. The OS NC can be viewed as the 'umbrella' code of the system operation network codes. It therefore sets the overall principles for system operation and reflects on the common issues with the OPS NC and the LFC&R NC while those will describe their specific processes in greater detail.

- The connection codes (RfG NC and DCC) – connection codes establish the technical capabilities of the generation and demand units connected to the grid. LFC&R references to them in those provisions in which information related to technical characteristics are required. The translation of technical capabilities described in connection codes to operational criteria, particularly with regards to the reserve provision, is done in the OS NC.

- *Future network codes* – Particularly challenging is the situation when network codes are not yet under official development: the forthcoming NC on Balancing (BAL NC) is under scoping discussions. The LFC&R NC and the BAL NC are closely related. While the LFC&R defines the technical requirements for the load-frequency control, the latter will define the reserve products and rules for a common market.

3.7 CLARIFICATION ON CONCEPTS USED WITHIN THE LFC&R NC

The focus of the LFC&R NC is based on the following concepts:

- **EU wide harmonised control processes as a basis for load-frequency control:** the control processes "frequency containment reserve", "frequency restoration reserve" and "replacement reserve" set a basis for an efficient and effective load-frequency control in the EU. The frequency containment reserve aims at containing the frequency drop after an incident inside a pre-defined band. The frequency restoration reserve is designed to restore the frequency to its target value 50 Hz. The replacement reserve replaces the activated reserves to restore the available reserves in the system or for economic optimisation;
- **Common control structure inside a synchronous area:** the set up of a proper control structure sets a basis for an efficient and effective load-frequency control in each synchronous area. It bases on the LFC area as core TSO responsibility area. The frequency restoration quality is defined on the level of the LFC Block that may consist of more than one LFC area. The frequency quality is defined on the level of the synchronous area that may consist of more than one LFC Block. This control structure design sets clear rules for TSO responsibilities offering valuable incentives to co-operate on LFC Block or synchronous area level. The
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control structure chosen by each synchronous area depends on the number of TSO involved and the complexity of the system in terms of congestion management;

- **Common frequency quality target inside a synchronous area:** The common frequency quality target is designed on synchronous area level. This includes frequency target values as well as frequency evaluation criteria. The frequency containment reserve process is set up on synchronous area level as a common reserve. This includes the amount of reserves needed and the share of reserves per TSO;
- **Frequency restoration quality target for each LFC Block:** The frequency restoration reserve process and the replacement reserve process are set up on LFC Block level. This includes the amount of reserves needed per LFC Block. The individual quality target values for the frequency restoration are defined per LFC Block and derived from the common frequency quality target of the synchronous area;
- **The LFC area / the monitoring area as core TSO responsibility area:** The operation of the load-frequency control as a core TSO responsibility is defined on the level of the LFC area (automatic control) and / or monitoring area (manual control);
- **Framework to determine the amount of reserve needed:** the NC delivers the basis to determine the amount of reserves needed per control process "frequency containment reserve", "frequency restoration reserve" and "replacement reserve" in order to deliver the required quality;
- **Border crossing exchange to enhance efficiency and as a basis to the market:** The efficiency of the load-frequency control is enhanced by border-crossing exchange of reserves. This exchange relates to the control processes "frequency containment reserve", "frequency restoration reserve" and "replacement reserve" as well as to imbalance netting. The border-crossing exchange is treated inside a synchronous area as well as cross synchronous areas. The NC sets restrictions to the border-crossing exchange where needed from a technical point of view.

Based on the above, the following categories of requirements have been established in the LFC&R NC as chapters:

- Frequency Quality
- Load-Frequency Control Structure
- Frequency Containment Reserves
- Frequency Restoration Reserves
- Replacement Reserves
- Exchange of Reserves
- Synchronous Time Control
- Co-operation with DSO

These subjects will be described in more detail in chapter 5.

3.8 Working with Stakeholders & Involved Parties

The legally binding nature of network codes, which is achieved through the comitology process, means that they can have a fundamental bearing on stakeholders businesses. As such, the ENTSO-E recognises the importance of engaging with stakeholders at an early stage, involving all interested parties in the development of the code, in an open and transparent manner.

ENTSO-E's stakeholder involvement comprised of workshops with the DSO Technical Expert Group and public stakeholder workshops, as well as ad-hoc meetings and exchange of views with all interested parties as necessary.

Due to the many questions concerning the function of the transmission system from an operational point of view that arose during the public consultation of the RfG NC, the first ENTSO-E stakeholder workshop on system operation was held on 19 March 2012 in Brussels. The aim of the workshop was to present information focusing on the operation of an interconnected transmission system, and the physical basis for scoping and drafting the system operation network codes. Stakeholders also had the opportunity to express feedback and expectations. Material is available in ENTSO-E webpage under link https://www.entsoe.eu/events/system-operation/ .

In line with suggestions by stakeholder organizations and following requests by the EC and ACER, ENTSO-E has envisaged four workshops for LFC&R NC with the DSOs Technical Expert Group and with all stakeholders prior to, during and after the public consultation.

- The aim of the first LFC&R NC Workshop, held on 12th July 2012 was to present and discuss the scope of the draft LFC&R NC.
- The aim of the second LFC&R NC Workshop held on 25th September 2012 was to present updates made to the network code and to achieve an in-depth involvement of the Stakeholders and a commitment to the key elements of the NC

4 RELATIONSHIP BETWEEN THE LFC&R NC & FRAMEWORK GUIDELINES

4.1 THE FRAMEWORK GUIDELINES

The FG SO [1] focuses on three key challenges, which shall be addressed by four objectives as Figure 3shows.

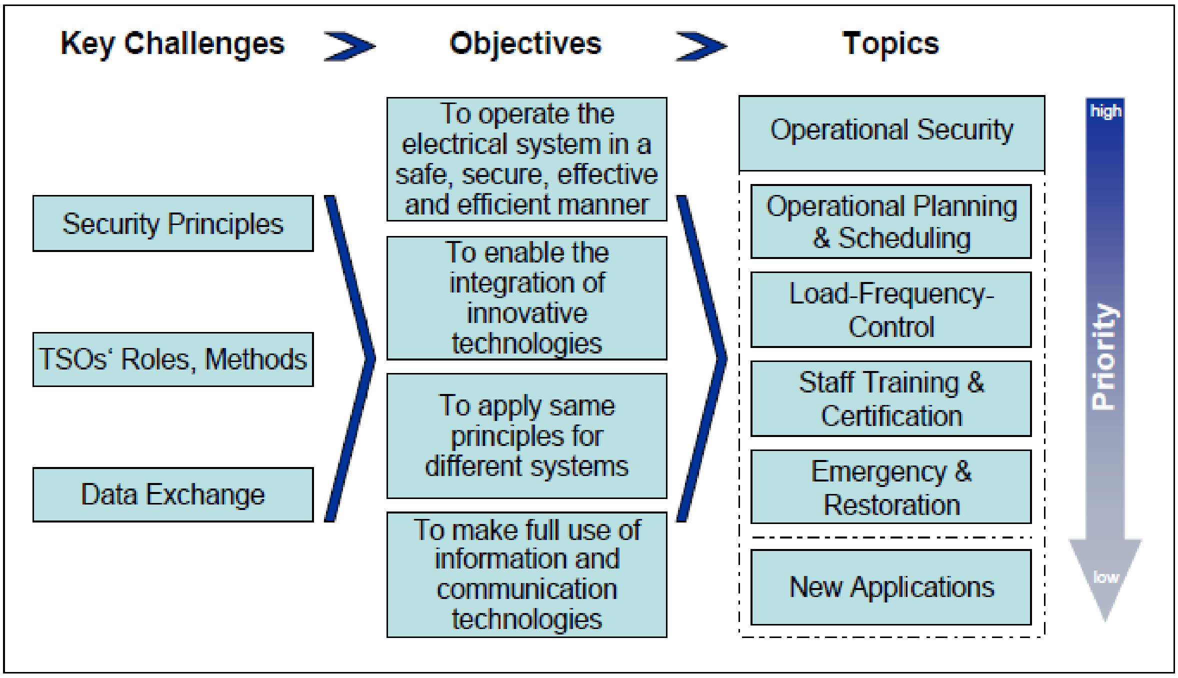


Figure 3: Structure and development flow of the Framework Guidelines on Electricity System Operation.

The overall scope and objectives of the FG SO [1] is *"Achieving and maintaining normal functioning of the power system with a satisfactory level of security and quality of supply, as well as efficient utilisation of infrastructure and resources".* The FG SO [1] focuses on defining common principles, requirements, standards and procedures within synchronous areas throughout EU, especially regarding the roles of and the coordination/information exchange between the TSOs, DSOs and significant grid users.

The requirements described in the LFC&R NC have been formulated in line with the FG SO [1] and the new developments on system operation, with the aim to ensure a satisfactory level of operational security and an efficient utilisation of the power system and resources by providing coherent and coordinated preparation of real-time operation.

4.2 FRAMEWORK GUIDELINES FOR LFC&R NC

The LFC&R NC according to the OS FG defines:

1. Definition of the various terms used in relation to load-frequency control within the different synchronous areas;

2. Technical features of different levels of load-frequency control in terms of time frames, reserve power used and the reaction time in different synchronous areas
3. Frequency quality criteria;
4. Appropriate minimum standards and requirements applicable to TSO and reserve providing units;
5. Requirements for TSO with regards to the implementation of e.g. controllable generation, load characterisation and demand side management;
6. The NC shall foresee that TSO co-ordinate their load-frequency control activities at regional, synchronous area and EU level – as technically necessary and within the most appropriate entities – in order to ensure meeting the objectives and applying the most appropriate measures to prevent and / or remedy system disturbances;
7. Description of principles for exchange of all necessary information between TSO to handle the different load-frequency control activities in a co-ordinated and co-operative manner.

5 LFC&R NC: OBJECTIVES, REQUIREMENTS

This chapter describes in more detail the structure and the content of the LFC&R NC. The LFC&R NC is built up as follows:

- Purpose and objectives (outside chapter numbering)
- Chapter 1: General provisions (Article 1-7)
  - Subject matter and scope
  - Definitions
  - Regulatory aspects
  - Recovery of costs
  - Confidentially obligations
  - Agreement with bordering TSO
  - TSO Cooperation
- **Chapter 2: Frequency Quality (Article 8 – 15)**
- **Chapter 3: Load-Frequency Control Structure (Article 16 - 26)**
- **Chapter 4: Frequency Containment Reserves (Article 27 - 29)**
- **Chapter 5: Frequency Restoration Reserves (Article 30 - 32)**
- **Chapter 6: Replacement Reserves (Article 33 - 34)**
- **Chapter 7: Exchange and Sharing of Reserves (Article 35 - 50)**
- **Chapter 8: Synchronous Time Control (Article 51)**
- **Chapter 9: Co-operation with DSO (Article 52)**
- Chapter 10: Transparency of Information (Article 52 - 59)
- Chapter 11: Final Provisions (Article 60 - 61)

This chapter aims at providing the reader the basis for understanding the requirements set in the chapters marked as **bold** above (of LFC&R NC), i.e. frequency quality (chapter 5.1), load-frequency control structure (chapter 5.2), frequency containment reserves (chapter 5.3), frequency restoration reserves (chapter 5.4), replacement reserves (chapter 5.5), exchange and sharing of reserves (chapter 5.6), synchronous time control (chapter 5.7) and co-operation with DSO (chapter 5.8) in that document below.

5.1 FREQUENCY QUALITY

5.1.1 TSO Co-operation regarding Frequency Quality

In any electric system, the active power has to be generated at the same time as it is consumed. Power generated must be maintained in constant equilibrium with power consumed / demanded, otherwise a power deviation occurs. Disturbances in this balance, causing a deviation of the System frequency from its set-point values, will be offset initially by the kinetic energy of the synchronous rotating generating units and motors connected. Due to the transformation of the kinetic energy of the rotating masses to electrical energy in the Power Generating Units the frequency of rotation will change leading to a Frequency Deviation.

Imbalances between generation and demand leading to Frequency Deviations occur due to the following types of reasons:

- Disturbance / outage of generation or load or HVDC interconnector. This type of imbalance is generally the one used for the calculation of the Reference Incident.
- Stochastic imbalances in normal operation. These can occur due to the continuous variations of demand or renewable energy output.
- Deterministic Frequency Deviations – e.g. ramping at the hour shift.
- Network splitting. These imbalances are generally out of the design of the Synchronous Area as they lead most likely to an emergency situation in a part or in all of the Synchronous Area.

The size and duration of these Frequency Deviations with respect to the Nominal Frequency for a sufficiently long period of time are regarded as frequency quality. System Frequency quality is a common good for all the users of the Synchronous Area which shall be properly monitored and maintained. In this regard, the Network Code on Load-Frequency and Reserves in Article 7 defines the processes that shall be performed by all the TSOs of the Synchronous Area in order to evaluate the quality of System Frequency.

5.1.2 Frequency Quality Design Parameters

Each Synchronous Area has been designed in such a way to guarantee that after a disturbance caused by an imbalance between generation and demand the consequences are within reason. In large Synchronous Areas this implies that large imbalances do not lead to under-frequency load shedding and the System Frequency remains within some design values. The design imbalance which the Synchronous Area shall be able to withstand is the Reference Incident. After the occurrence of this Reference Incident the System Frequency will deviate from the Nominal Frequency and there will be a Frequency Deviation. The System Frequency should behave in time as designed by some parameters named Frequency Quality Design Parameters. They described the different limits that are to be set to the System Frequency. They are represented in Figure 4:

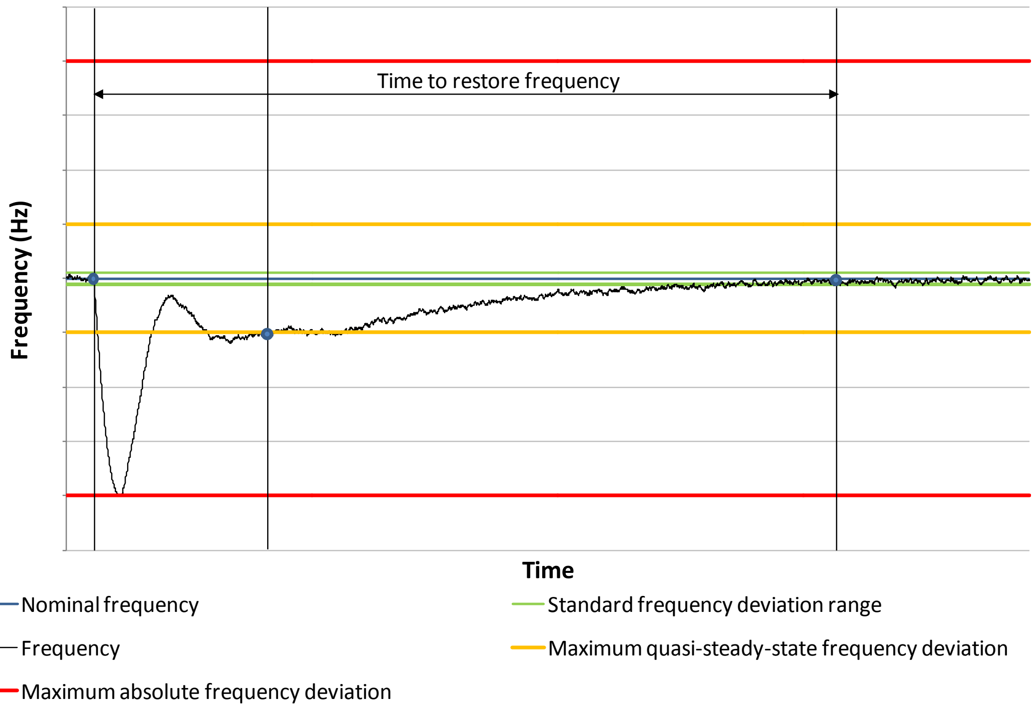


Figure 4: Frequency Quality Design Parameters

The Frequency Quality Design Parameters consist on the following parameters:

- *Nominal Frequency*: The rated value of the system frequency for which all equipment connected to the electrical network is designed.
- *Standard frequency range*: Frequency range within which the system should be operated for defined time intervals. It is used as a basis for System Frequency quality analysis.
- *Maximum Instantaneous Frequency deviation*: Maximum expected instantaneous system frequency deviation after the occurrence of a Reference Incident assuming predefined system conditions.
- *Maximum Steady-State Frequency Deviation*: Maximum expected system frequency deviation at which the System Frequency oscillation after the occurrence of a Reference Incident stabilizes assuming predefined system conditions. This stabilization occurs after the deployment of FCR.

  At the Maximum Steady-State Frequency Deviation FCR must be fully activated. The droop of all reserve providing units participating in FCR should be set in such a way that all the contracted/obligatory FCR are deployed
- *Time to restore frequency*: Maximum expected time after the occurrence of a Reference Incident in which the System Frequency is restored inside a tolerance range which is named Frequency Range within Time to Restore Frequency.

  The specified duration of the full deployment of FCR must be at least the time to restore System Frequency in order to maintain system balance and frequency stability until the FRR are deployed. Once sufficient FRR are deployed to return the System Frequency to the band defined by the tolerance range for FCR activation, the FCR will be restored and therefore no longer needed until the next imbalance
- *Frequency Range within Time to Restore Frequency*: Range to which the System Frequency should be restored after the Time to Restore Frequency has elapsed since a Reference Incident occurs.
- *Time To Recover Frequency* (not shown in Figure 4) means the maximum expected time after the occurrence of an imbalance smaller than or equal to the Reference Incident in which the System Frequency returns to the Maximum Steady State Frequency Deviation;
- *Frequency Range within Time to Recover Frequency* (not shown in Figure 4) means the System Frequency range to which the System Frequency is expected to return after the occurrence of an imbalance equal to or less than the Reference Incident within the Time To Recover Frequency

These Frequency Quality Defining Parameters shall be coordinated between all TSOs of a Synchronous Area in order to ensure proper Synchronous Area behaviour.

The choice of values for each Frequency Quality Design Parameters is highly dependent of each Synchronous Area as these parameters depend heavily on the following Synchronous Area characteristics:

a. Size of consumption and generation of the Synchronous Area and the inertia, both natural and synthetic; synthetic inertia may be a service achieved through power electronics which dynamically and rapidly alter the active power contribution of a connected reserve provider according to system frequency.

b. Grid structure and/or network topology.

c. The behaviour of the loads and the Power Generating Units, primarily their reaction to Frequency Deviations.

d. For all synchronous areas except GB and Ireland, the currently observed System Frequency quality in order to perform the probabilistic analysis that could lead to an evaluation of the risk of having a total imbalance larger than the Synchronous Area is able to withstand while maintaining the System Frequency within the Frequency Quality Design Parameters. Otherwise it is not guaranteed that the Synchronous area could run into a situation with a large scale incident as a consequence of load-generation imbalances. For GB and Ireland a deterministic method is used with continuous re-evaluation of system conditions to ensure appropriate reserve holdings at all times.

Therefore, since each Synchronous Area has its own frequency dynamic, it is not possible to fix the same values for the Frequency Quality Design Parameters in all of them. Furthermore, these parameters are some of the main parameters to which the Synchronous Area is designed and its values have a very high impact on the amount of FCR, FRR and RR that the Synchronous Area shall have available. Therefore it is important that they remain stable with time, but should be reviewed regularly and revised as and when the system characteristics significantly change. The current values are shown in Article 8(2). As stated in Article 8(4), a period in between two revisions not longer than 5 years period seems reasonable.

Frequency Quality Target Parameters

The duration of the total System Frequency deviations is an important parameter as the larger and more persistent appearance of Frequency Deviations, the more likely the Synchronous Area could experience a large unbalance at the time where there is initially a Frequency Deviation leading to an event outside of the design parameters. A common frequency quality model must be set per Synchronous Area as a goal to reach which can assure with reasonable certainty that the risk of an incident or concatenation of imbalance incidents is very low. The frequency quality model of the Synchronous Area implies therefore setting target values to the frequency parameters called Frequency Quality Target Parameters. In Article 8(3) the maximum number of minutes outside the Standard Frequency Range is defined as the minimum Frequency Quality Target Parameters. This parameter shall be common for all Synchronous Areas, but due to the different characteristics of each of them a different number of minutes per year may apply to each.

In any case, other Frequency Quality Target Parameters can be set by each Synchronous Area in order to set goals corresponding to System Frequency quality.

For SA GB the parameter have been set with these values in order to meet the UK statutory requirements of the "National Electricity Transmission System Security and Quality of Supply Standards" and is why the characteristics may be different from the other SAs.

5.1.3 Frequency Restoration Control Defining Parameters

Synchronous Areas may consist of one or several LFC Blocks. In the case of Synchronous Areas with only one LFC Block i.e. RG Cyprus, Ireland, Great Britain and Nordic, the frequency quality is already a measure of the power imbalances. The criteria in the remaining paragraphs of this section defined below will not apply to these synchronous areas.

In the case of Synchronous Areas with several LFC Blocks, as is the case of RG Continental Europe, System Frequency quality will depend on the combined behaviour of each of the LFC Blocks. The goal of each LFC Block is to maintain the Frequency Restoration Control Error as close as possible to zero. This parameter, which historically has been known as Area Control Error, is a measure of the contribution of the LFC Block to the Synchronous Area frequency quality although its main goal is to maintain power balance within the LFC Blocks to assure system security with the (N-1)-Criterion of the LFC Blocks including the Tie-Lines with other LFC Blocks inside the same Synchronous Area.

In order to achieve the set values of the Frequency Quality Target Parameter it is of the utmost importance that the LFC Blocks keep proper Frequency Restoration Control Error quality. In order to keep the same structure as with frequency quality, there are therefore two Frequency Restoration Control Error Defining Parameters, which are defined in Article 9(1).

In order to define these Frequency Restoration Control Error Defining Parameters it is considered that the Frequency Restoration Control Error behaves like a normal distribution in each of the LFC Blocks and that these normal distributions are independent of each other at any time. With this consideration, and assuming that each of the LFC Blocks behave in similar manner there is a fixed relationship between the standard deviation of the Frequency Restoration Control Error of a LFC Blocks and the standard deviation of the normal distribution of the resulting sum of all of the Frequency Restoration Control Errors of the LFC Blocks within the Synchronous Area [3]:

$$\sigma_{ACE_i} = \sigma_{\Delta f} * \sqrt{K_T * K_i}$$

Being K_T the total network power-frequency characteristic of the whole Synchronous Area and K_i the network power-frequency characteristic or K-factor of the LFC Block *i,* This parameters K_i are calculated with the Initial FCR Obligations. The values for each Frequency Restoration Control Error Defining Parameter, which are Level 1 Frequency Restoration Control Error Range and Level 2 Frequency Restoration Control Error Range are not defined in the Network Code, however in order to assure a fair share of the frequency quality targets between the LFC Blocks, these values should be proportional to the square root of the Initial FCR Obligations of the LFC Blocks.

The values of the Level 1 Frequency Restoration Control Error Range and Level 2 Frequency Restoration Control Error Range will be set deriving from the risk level considered in Article 8(4) (d) of once in twenty years.

Since the Level 1 and Level 2 Frequency Restoration Control Error Range of the LFC Blocks depend of the total K-Factor of the Synchronous Area and the contribution coefficients of each LFC Block their values should be revised yearly to take into account the possible changes in the LFC Blocks or in the Synchronous Area. This requirement is stated in Article 9(2).

5.1.4 Frequency Restoration Control Target Parameters

The values of the Frequency Restoration Control Error Target Parameters will be the ones corresponding to the desired behaviour of the distribution of the Frequency Restoration Control Error of the LFC Block and are defined in Article 9(3).

The Frequency Restoration Control Error Target Parameter corresponding to the Level 1 Frequency Restoration Control Error Range is the maximum number of time intervals outside the Level 1 Frequency Restoration Control Error Range within a time interval equal to the Time to Restore Frequency and shall be equal to 30% or 10 512 15-minute time intervals in a year. The value of 30% is used as an approximation of 31,4% (=100%-68.6%) 15-minute intervals that shall be inside the Level 1 Frequency Restoration Control Error Range.

The Frequency Restoration Control Error Target Parameter corresponding to the Level 2 Frequency Restoration Control Error Range is the maximum number of time intervals outside the Level 2 Frequency Restoration Control Error Range within a time interval equal to the Time to Restore Frequency and shall be equal to 5% or 1 752 15-minute time intervals in a year .

The Frequency Restoration Control Error Target Parameters are defined for each LFC Block. However, in case a LFC Block is composed of several LFC Areas the expected quality for each LFC Area of the LFC Block shall be defined in a TSO multi-party agreement as stated in Article 9(4).

5.1.5 Frequency Quality Data Collection

In order to perform the evaluation of the Frequency Restoration Control Error Target Parameters and the Frequency Quality Target Parameters the necessary data shall be gathered and prepared as described in Article 10. The data comprises:

1. Instantaneous Frequency data per Synchronous Area;
2. 1-minute Average Frequency Data per Synchronous Area;
3. 1-minute Average Frequency Deviation Data per Synchronous Area;
4. Instantaneous Frequency Restoration Control Error Data for each LFC Block in Continental Europe; and
5. 15-minute data of the Frequency Restoration Control Error Data for each LFC Block in Continental Europe.

The measurement period for the instantaneous data shall be 10 seconds which is a value small enough to capture all of the large-scale dynamic behaviour of the System Frequency of the Synchronous Area or the Frequency Restoration Control Error of each LFC Block, but large enough so that the yearly sum of samples is still manageable with widely available analysis tools.

It is important to assure that the collected data is accurate and thus the minimum accuracy is set to 1 mHz in case of System Frequency data or 1% in case of Frequency Restoration Control Error data.

The average data shall be calculated using the arithmetic mean:

$$Average = \frac{1}{n} * \sum_{1}^{n} a_i$$

Being *n* the number of instantaneous samples in the minute or 15 minutes and a_i the value of sample *i* within *n*.

In order to allow the TSOs of a Synchronous Area to exchange and use the collected data a Synchronous Area Agreement shall be done to set the file format of the sampling data and the means of exchange of the data between the TSOs.

5.1.6 Frequency Quality Evaluation Criteria

With the aim of evaluating the frequency quality Article 11 defines the Frequency Quality Evaluation Criteria which area a series of global reliability indicators regarding both the System Frequency quality and the Frequency Restoration Control Error quality in the case of RG Continental Europe. The Frequency Quality Evaluation Criteria are the indicators that are observed by the TSOs of a Synchronous Area and obtain information about how well the Synchronous Area or the LFC Block behaved. Some Frequency Quality Evaluation Criteria show information about the performance of the Synchronous Area and others show information about the performance of a LFC Block.

Some of these Frequency Quality Evaluation Criteria will be used to compare with the values of the Frequency Quality Target Parameters and Frequency Restoration Control Error Target Parameters. However, in order to have a closer supervision of the Frequency Quality Evaluation Criteria the evaluation period is defined to be of 3 months as defined in Article 12(4) whereas the Frequency Quality Target Parameters and Frequency Restoration Control Error Target Parameters are compared yearly.

The process of evaluation of the Frequency Quality Evaluation Criteria is named Criteria Application Process and consists of the gathering of the data needed for the evaluation, specified in Article 10(2), and the calculation of the different values for each Frequency Quality Evaluation Criteria. This process is defined in Article 11(1).

Apart from the Frequency Quality Evaluation Criteria the LFC&R NC requests an assessment of the risk of FCR Exhaustion for each Synchronous Area that should be performed according to Article 11(3) as there is a clear and accountable influence of the relationship between System Frequency quality and the risk that exists in a Synchronous Area of experiencing a situation in which the Frequency Containment Reserve is exhausted, but the imbalance between generation and demand persists. In such a situation the System Frequency will drop further and may reach values in which the automatic under-frequency load-shedding relays may trip leaving partial black-outs within the affected Synchronous Area. This study should be performed annually. A possible methodology is described in Appendix C of [3] (Report of the ENTSO-E AhT Operational Reserve).

The following variables are used in paragraph 5.1.7.1 and 5.1.7.2 to describe the Frequency Quality Evaluation Criteria defined in Article 11(2):

- f_{Av}: average frequency of the 1-minute Average Frequency Data;
- $f_{1\text{-min},i}$: sample *i* of the 1-minute Average Frequency Data;
- $FRCE_{Av}$: average Frequency Restoration Control Error of 15-minute Average Frequency Restoration Control Error Data;
- $FRCE_{15\text{-min},i}$: sample *i* of the 15-minute Average Frequency Restoration Control Error Data;
- n: number of samples in the 3-month period; and
- $\sigma_{f,1min}$: standard deviation of the 1-minute Average Frequency Data.
- $\sigma_{FRCE,15min}$: standard deviation of the 15-minute Average Frequency Restoration Control Error Data.

5.1.6.1 Frequency Quality Evaluation Criteria for the Synchronous Area

There are 5 Frequency Quality Evaluation Criteria defined for the Synchronous Area. The collection of the necessary data and calculation of these Frequency Quality Evaluation Criteria is performed by the Synchronous Area Monitor as described in Article 12. These Frequency Quality Evaluation Criteria are explained in detail along with their calculation formulas if applicable:

- 1-minute Average Frequency Data during a 3-month period for the Synchronous Area (f_{Av});

$$f_{Av} = \frac{1}{n} * \sum_{1}^{n} f_{1min,i}$$

  This Frequency Quality Evaluation Criteria shows whether the distribution of the 1-minute Average Frequency Data is centred in the Nominal Frequency. The value for the 3-month period should be almost exactly 50 Hz and it is proportional to the accumulated electrical time deviation during the 3-month period.

- standard deviation of the 1-minute Average Frequency Data during a 3-month period for the Synchronous Area;

$$\sigma_{f,1min} = \sqrt{\frac{1}{n} * \sum_{1}^{n} \left(f_{1min,i} - f_{Av}\right)^2}$$

This Frequency Quality Evaluation Criteria gives information about the frequency quality of the complete set of 1-minute Average Frequency Data by defining the second order distance of the data with respect to the System Frequency average or 50 Hz.

- absolute Frequency Deviation range corresponding to the 95-percentile of the 1-minute Average Frequency Data during a 3-month period for the Synchronous Area;

  This Frequency Quality Evaluation Criteria is calculated by ordering the 1-minute Average Frequency Deviation Data f_{1min}-f_n from the lowest to the highest value and obtaining the absolute value of the Frequency Deviation that is surpassed in absolute value by 5% of the 1-minute Average Frequency Deviation Data values during a 3-month period.

  This Frequency Quality Evaluation Criteria gives information about the 5% most extreme values of the frequency quality.

- total time during a 3-month period in which the instantaneous Frequency Deviation was greater than the Maximum Instantaneous Frequency Deviation; and

  This Frequency Quality Evaluation Criteria is calculated by multiplying the number of data values in which the Instantaneous Frequency Data minus the Nominal Frequency is greater in absolute value than the Maximum Instantaneous Frequency Deviation and multiplying that value by the measurement period of the Instantaneous Frequency Data during a 3-month period.

  This Frequency Quality Evaluation Criteria gives information about the amount of time in which the Synchronous Area has been in a severe situation, outside of the design of the Synchronous Area, regarding load-generation unbalances. This value shall be kept to zero.

- number of 1-minute Average Frequency Data values during a 3-month period outside the Standard Frequency Range;

  This Frequency Quality Evaluation Criteria is calculated by counting the number of data values in which the 1-Minute Average Frequency Data minus the Nominal Frequency is greater in absolute value than the Standard Frequency Range during a 3-month period.

  The addition of the four values of this Frequency Quality Evaluation Criteria is to be compared to the Frequency Quality Target Parameter defined in Article 8(3).

5.1.6.2 Frequency Quality Evaluation Criteria for the LFC Block

There are 7 Frequency Quality Evaluation Criteria defined for each of the LFC Block in which the Synchronous Area consists. The collection of the necessary data and calculation of these Frequency Quality Evaluation Criteria is performed by the LFC Block Monitor as described in Article 13. These Frequency Quality Evaluation Criteria are explained in detail along with their calculation formulas if applicable:

- average during a 3-month period of the values corresponding to the average within a time interval equal to Time To Restore Frequency of the Frequency Restoration Control Error of the LFC Block;

$$FRCE_{Av} = \frac{1}{n} * \sum_{1}^{n} FRCE_{15min,i}$$

This Frequency Quality Evaluation Criteria shows whether the distribution of Average Frequency Restoration Control Error is centred in zero (in this example measured for 15-minute intervals being the Time to Restore Frequency of the Synchronous Area Continental Europe). If the LFC Blocks decide that the compensation of the past imbalances is performed by returning the imbalance energy of the LFC Block the value for the 3-month period should be almost exactly 0 mHz.

- standard deviation during a 3-month period of the values corresponding to the average within a time interval equal to Time To Restore Frequency of the Frequency Restoration Control Error of the LFC Block;

$$\sigma_{FRCE,15min} = \sqrt{\frac{1}{n} * \sum_{1}^{n} \left(FRCE_{15min,i} - FRCEf_{Av}\right)^2}$$

This Frequency Quality Evaluation Criteria gives information about the Frequency Restoration Control Error quality of the complete set of 15-minute Average Frequency Restoration Control Error by defining the second order distance of the data with respect to the 0 mHz.

- absolute Frequency Restoration Control Error range corresponding to the 95-percentile of the values corresponding to the average within a time interval equal to Time To Restore Frequency of the Frequency Restoration Control Error of the LFC Block during a 3-month period;

This Frequency Quality Evaluation Criteria is calculated by ordering the 15-minute Average Frequency Restoration Control Error $FRCE_{15min,i}$ from the lowest to the highest value and obtaining the absolute value of the Frequency Restoration Control Error that is surpassed in absolute value by 5% of the 15-minute Average Frequency Restoration Control Error values during a 3-month period. This value is given in MW.

This Frequency Quality Evaluation Criteria gives information about the 5% most extreme values of the Frequency Restoration Control Error and should be lower than the Level 2 Frequency Restoration Control Error Range.

- number of time intervals of a period equal to Time To Restore Frequency in which the average of the Frequency Restoration Control Error of the LFC Block is outside the Level 1 Frequency Restoration Control Error Range during a 3-month period;

This Frequency Quality Evaluation Criteria is calculated by counting the number of data values in which the 15-minute Average Frequency Restoration Control Error is greater in absolute value than the Level 1 Frequency Restoration Control Error Range during a 3-month period.

The addition of the four values of this Frequency Quality Evaluation Criteria is to be compared to the Frequency Restoration Error Target Parameter defined in Article 9(3)(a).

- number of time intervals of a period equal to Time To Restore Frequency in which the average of the Frequency Restoration Control Error of the LFC Block is outside the Level 2 Frequency Restoration Control Error Range during a 3-month period;

This Frequency Quality Evaluation Criteria is calculated by counting the number of data values in which the 15-minute Average Frequency Restoration Control Error is greater in absolute value than the Level 2 Frequency Restoration Control Error Range during a 3-month period.

The addition of the four values of this Frequency Quality Evaluation Criteria is to be compared to the Frequency Restoration Error Target Parameter defined in Article 9(3)(b).

- number of events for which after the occurrence of a Frequency Restoration Control Error of a LFC Block outside the Level 2 Frequency Restoration Control Error Range the Frequency Restoration Control Error of the LFC Block is not returned to 10% of the Level 2 Frequency Restoration Control Error Range within the Time to Restore Frequency during a 3-month period.

This Frequency Quality Evaluation Criteria is calculated by counting the number of time in which the following happens (Figure 5):

i. there is an upward crossing of the positive Level 2 Frequency Restoration Control Error Range of the Instantaneous Frequency Restoration Control Error Data;

ii. there is not a downward crossing of 10% of the positive Level 2 Frequency Restoration Control Error Range in the Instantaneous Frequency Restoration Control Error Data until a time longer than the Time to Restore Frequency starting from the upward crossing of the positive Level 2 Frequency Restoration Control Error Range.

or

i. there is a downward crossing of the negative Level 2 Frequency Restoration Control Error Range of the Instantaneous Frequency Restoration Control Error Data;

ii. there is not an upward crossing of 10% of the negative Level 2 Frequency Restoration Control Error Range in the Instantaneous Frequency Restoration Control Error Data until a time longer than the Time to Restore Frequency starting from the downward crossing of the negative Level 2 Frequency Restoration Control Error Range.

This Frequency Quality Evaluation Criteria is the equivalent of the trumpet curve method that has been in use in RG Continental Europe [4]. It shows the number of times in the 3-month period in which the TSOs of the LFC Block to which the data corresponds where not able to return the Frequency Restoration Control Error to a value close to zero. This number should be relatively low. It is expected to be typical that there are several events of this type due to imbalances due to different reasons that happen within a time frame of 15 minutes.

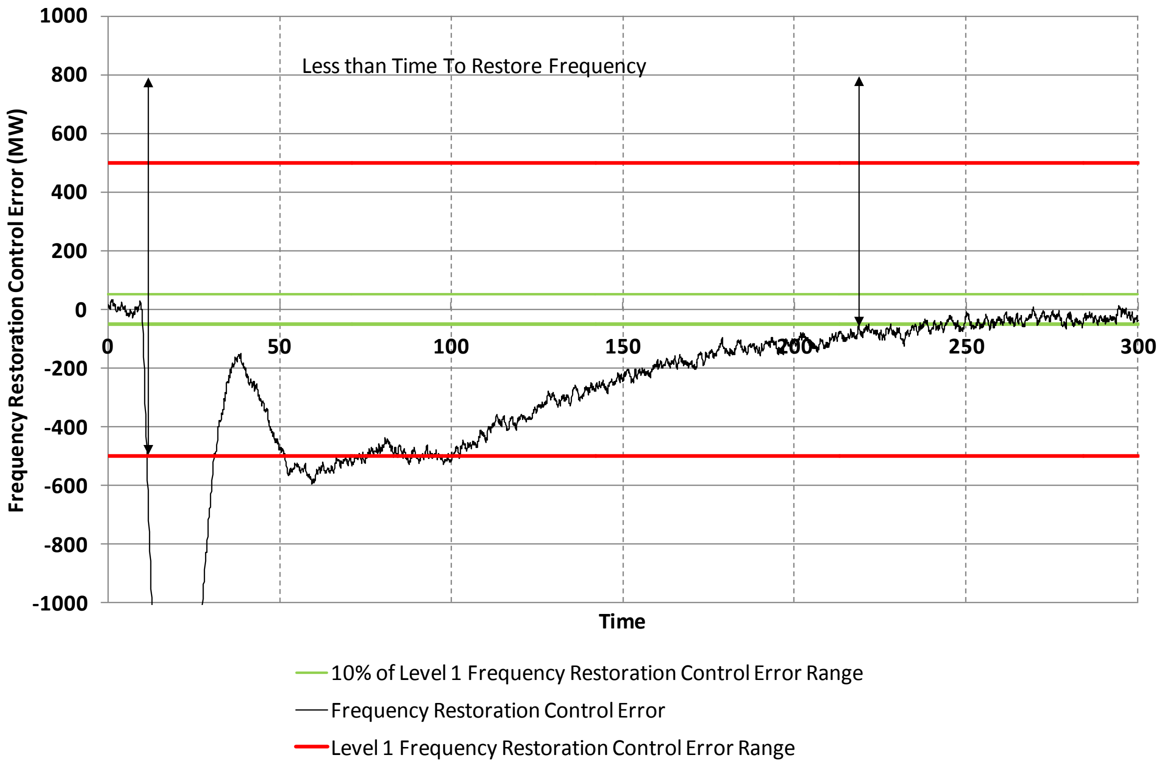


Figure 5: Description of an event to be counted by the Frequency Quality Evaluation Criteria described in Article 11(2)(b)(vii) which applies to Synchronous Areas with more than one LFC Block.

5.1.7 Mitigation Procedures

After the evaluation of the Frequency Quality Evaluation Criteria for a certain period, it may be determined that the values obtained are worse than the Frequency Quality Target Parameters or that of the Frequency Restoration Control Error Target Parameters. If such a situation arises, the relevant TSOs shall determine and where a change is required, address the root cause factors that have influenced the quality of System Frequency or of Frequency Restoration Control Error and propose to their respective NRAs and/or ACER the proposal to solve this deficiency.

Article 14 explores the possibilities that TSOs have to propose actions in order to mitigate the impact of any changes that could happen in the Synchronous Area such as Deterministic Frequency Deviations or rapid changes in HVDC interconnectors.

This is especially important to minimize Deterministic Frequency Deviations, which occur when changes of generating units/load do not happen simultaneously. E.g. power difference between the continuous ramp-wise physical load behaviour and discontinuous / step wise power generation behaviour (market-rule-based schedule). These "market induced" effects depend to a large extent on the framework conditions of the respective market rules and have more or less regularly led to significant Frequency Deviations at the hour shift in RG CE and RG Nordic (Figure 6 and Figure 7).

In Figure 6 it can be observed at 6, 16, 17, 20, 21 and 22 how there is a Deterministic Frequency Deviation associated with the change of the hour. Figure 7 shows how the proportion of the extreme values of the Frequency Deviation are much more likely to happen in the hour shift, from minute 55 in the preceding hour to minute 5, than during the other minutes of the hour. This distribution of the proportion of extreme values can be compared to a RG like RG Baltic that does not suffer from Deterministic Frequency Deviations.

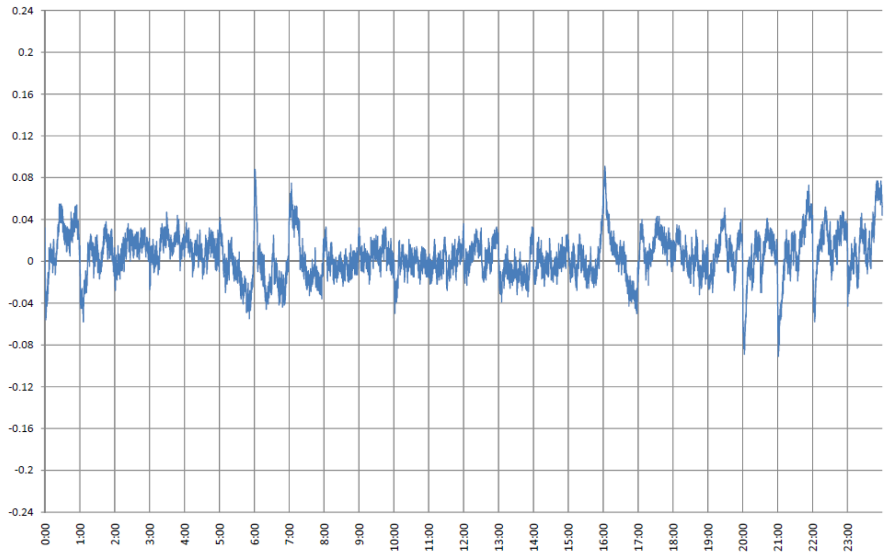


Figure 6: Deterministic Frequency Deviations in RG CE on December 17th 2012.

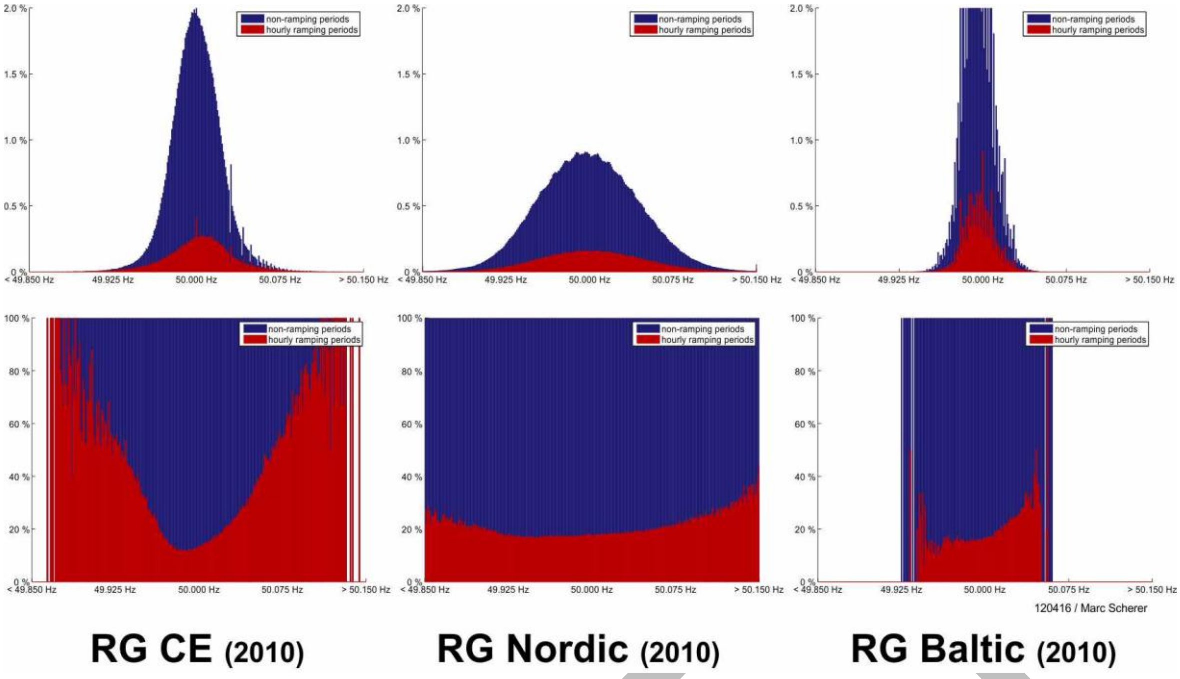


Figure 7: Distribution of Frequency Deviations in RG C, RG Nordic and RG Baltic for 2010 distinguishing all minutes and the minutes around the change of the hour.

Apart for modification of market rules in the markets, including balancing markets, other measures should be taken even ex-ante in order to fulfil the Frequency Quality Target Parameters or the Frequency Restoration Control Error Target Parameters. One efficient measure, especially in smaller Synchronous Areas is to introduce restrictions on the rate of change in the power output or input of Generating Units, HVDC interconnectors and Demand Facilities connected to the TSO network.

These types of limits can be significantly important in the case of rate of change of HVDC interconnectors between LFC Blocks or Synchronous Areas as their output can change rapidly as a result of a program change at the change of the scheduling period.

5.2 LOAD-FREQUENCY-CONTROL STRUCTURE

The continuous maintenance of the power balance is a necessary precondition for achieving the required frequency quality and, therefore, for stable and secure power system operation. This task is performed by a set of Load-Frequency-Control processes which have to be implemented and operated by the TSOs. This chapter provides a common European framework for the Load-Frequency-Control processes by setting technical requirements for the technical control structure and the according responsibilities of the TSOs:

- The first part of the chapter deals with the basic structure of Load-Frequency-Control providing requirements for mandatory and optional control processes as well as different operational geographical area types (area hierarchy) with attached area process obligations.
- The second part of the chapter provides detailed requirements for the design, implementation and operation of the control processes.
- The third part of the chapter deals with the implementation of Imbalance Netting and cross-border reserve activation.
- The fourth part of the chapter provides additional requirements related to Imbalance Netting and cross-border reserve activation in context of area process obligations.

5.2.1 Operational Reserves

5.2.1.1 Frequency Containment Reserves (FCR)

Objectives

Frequency containment aims at the operational reliability of the synchronous area by stabilizing the system frequency in the time-frame of seconds at an acceptable stationary value after a disturbance or incident; it does not restore the system frequency to the set point. The common activation of Frequency Containment Reserve (FCR) in the whole synchronous area modifies the balance between generation and load at the scale of each TSO and hence consequently the power exchanges between the TSOs are varying from their set point.

Means

Frequency containment depends on reserve providing units (e.g. generating units, controllable load resources and HVDC cables) made available to the system in combination with the physical stabilizing effect from all connected rotating machines. As generation resource it is a fast-action, automatic and decentralized function e.g. of the turbine governor, that adjusts the power output as a consequence of the system frequency deviation.

Hierarchy

Frequency containment reserves are activated locally and automatically at the site of the reserve providing unit, independently from the activation of other types of reserves.

5.2.1.2 Frequency Restoration Reserves (FRR)

Objectives

Frequency restoration aims to restore the system frequency in the time frame defined within the synchronous area by releasing system wide activated frequency containment reserves. For large interconnected systems, where a decentralized frequency restoration control is implemented, frequency restoration also aims to restore the balance between generation and load for each TSO, and consequently restore power exchanges between TSOs to their set point.

Means

Frequency restoration depends on reserve providing units made available to the TSOs independently from FCR. Activation of Frequency Restoration Reserve (FRR) modifies the active power set points / adjustments of reserve providing units in the time-frame of seconds up to typically 15 minutes after an incident.

Hierarchy

In each LFC area FRR are activated centrally at the TSO control centre, either automatically or manually.

Frequency restoration must not impair the frequency containment that is operated in the synchronous area in parallel.

5.2.1.3 Replacement Reserves (RR)

Objectives

TSOs need replacement reserves (RR) to prepare for further imbalances in case FCR / FRR has already been activated up to a certain extent, e.g. when market participants have no possibility (neutralisation lead-time) or not the necessary information to compensate by themselves their forecast uncertainties on load, renewable generation, etc.

This amount needed and the time window during which the TSO is restoring the balance on behalf of the market players is highly depending on the market design of each country.

Replacement reserves are activated manually and centrally at the TSO control centre in case of observed or expected sustained activation of FRR and in the absence of a market response. TSO can also use RR to anticipate on expected imbalances.

Means

Replacement reserves depend on reserve providing units made available to the TSOs, independently from FCR or FRR.

Hierarchy

It is used to release FCR and FRR or to prevent its activation in normal operation.

5.2.1.4 Mapping of Processes to Products

Sync. Area	Process	Product	Activation	Local / Central	Dynamic / Static	Full deviation	Full activation
Baltic	FCR	Primary Reserve	A	L	D	±200 mHz	30 s
CY		Primary Reserve	A	L	D	±100 mHz	20 s
IRE		Primary operating reserve	A	L	D / S	>±200 mHz	5 s
IRE		Secondary operating reserve	A	L	D / S	±200 mHz	15 s
NE		FNR (FCR N)	A	L	D	±100 mHz	120 s -180 s
NE		FDR (FCR D)	A	L	D	±500 mHz	30 s
CE		Primary Control Reserve	A	L	D	±200 mHz	30 s
UK		Frequency response dynamic	A	L	D	variable	10 s / 30 s
UK		Frequency response static	A	L	S	variable	variable
Baltic	FRR	Secondary emergency reserve	M	C	S	n.a.	15 minutes
CY		Secondary Control Reserve	A/M	L / C	D / S	n.a.	5 minutes
Ireland		Tertiary operational reserve 1	A/M	L / C	D / S	n.a.	90 s
Ireland		Tertiary operational reserve 2	M	C	S	n.a.	5 minutes
Ireland		Replacement reserves	M	C	S	n.a.	20 minutes
NE		Regulating power	M	C	S	n.a.	15 minutes
CE		Secondary Control Reserve	A	C	D	n.a.	15 minutes
CE		Direct activated Tertiary Control Reserve	M	C	S	n.a.	15 minutes
UK		Various Products	M	n.a.	D / S	n.a.	variable
Baltic	RR	Tertiary (cold) reserve	M	C	S	n.a.	12 h
CY		Replacement reserves	M	C	S	n.a.	20 minutes
IRE		Replacement reserves	M	C	S	n.a.	20 minutes
NE		Regulating power	M	C	S	n.a.	15 minutes
CE		Schedule activated Tertiary Control Reserve	M	C	S	n.a.	individual
CE		Direct activated Tertiary Control Reserve	M	C	S	n.a.	individual
UK		Various Products (mainly STOR)	M	n.a.	D / S	n.a.	from 20 minutes to 4 h

Table 1: Mapping Processes to Products; manual (M) or automatic (A) activation; activated centrally by the TSO (can be manual or automatic) (C) or activation directly at a local reserve provider (L)

5.2.2 Process Activation and Responsibility Structure

The Process Activation Structure defines

- mandatory control processes which have to be implemented and operated by the TSOs in each Synchronous Area; and
- optional control processes which may be implemented and operated by the TSOs in each Synchronous Area.

Accordingly the Process Responsibility Structure defines

- different area types (e. g. LFC Area, LFC Block, Synchronous Area);
- the hierarchical relationship between different areas (area hierarchy); and
- area process obligations, i.e. control processes, quality targets, reserve dimensioning etc., which must be fulfilled by a TSO operating an area.

The area hierarchy is illustrated in Figure 8: Each Synchronous Area consists of one or more LFC Blocks and vice-versa, each LFC Block is a sub-area of a Synchronous Area. A LFC Block consists of one or more LFC Areas (or a LFC Area is a sub-area of a LFC Block), a LFC Area consists of one or more Monitoring Areas etc. Figure 9 shows a stylised example for a possible area hierarchy of a Synchronous Area with three LFC Blocks.

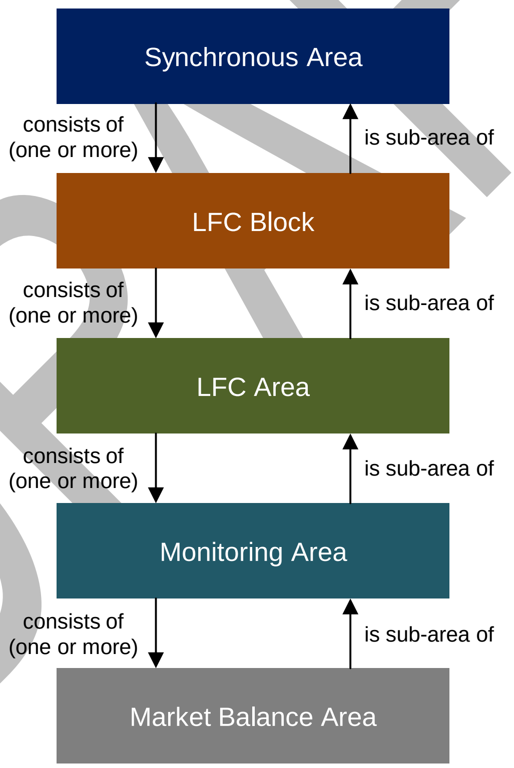


Figure 8: Interdependencies between areas (area hierarchy)

It is worth mentioning that LFC&R NC does not formulate detailed requirements for TSOs operating a Market Balance Area. These requirements are established in the OPS NC. Nonetheless, the schedules provided for a Market Balance Area are a precondition for the Frequency Restoration Process when there is more than one LFC Area in the Synchronous Area.

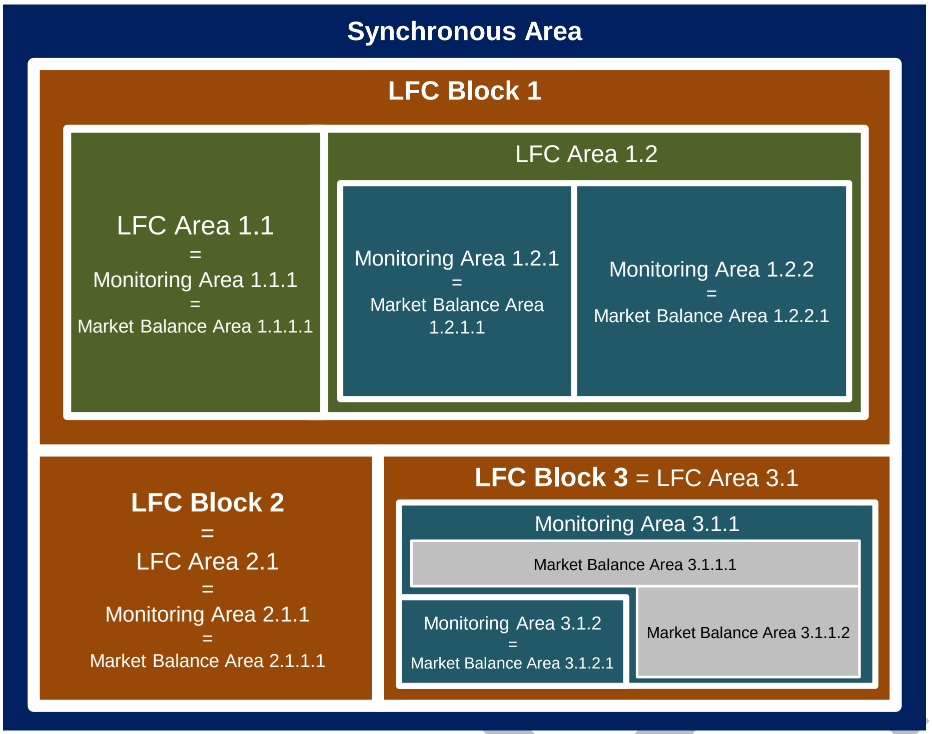


Figure 9: Stylised example for an area hierarchy

There are several examples of different area hierarchies implemented in different Synchronous Areas:

- The Synchronous Areas of RG Ireland, RG Nordic and RG UK consist of only one LFC Block and LFC Area (in terms of Load-Frequency-Control).
- RG Nordic has implemented several Market Balance Areas and Monitoring Areas (Figure 10).
- RG Continental Europe consists of many LFC Blocks (Figure 11). Most of these LFC Blocks consist of one LFC Area (e.g. LFC Blocks operated by RTE, ELIA, TenneT NL, Terna etc.) but there are also several examples of LFC Blocks which consist of more than one LFC Area (Figure 12), e.g.:
  - LFC Block of Spain and Portugal with LFC Areas operated by REN and REE,
  - the German LFC Block with four LFC Areas operated by 50HzT, Amprion, TenneT DE and TransnetBW

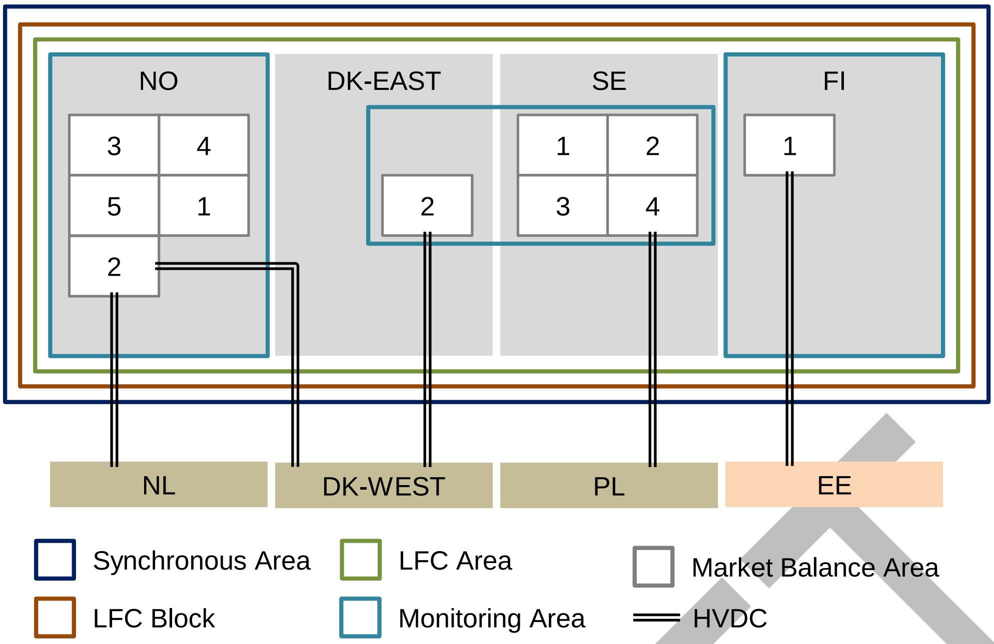


Figure 10: Area hierarchy in RG Nordic

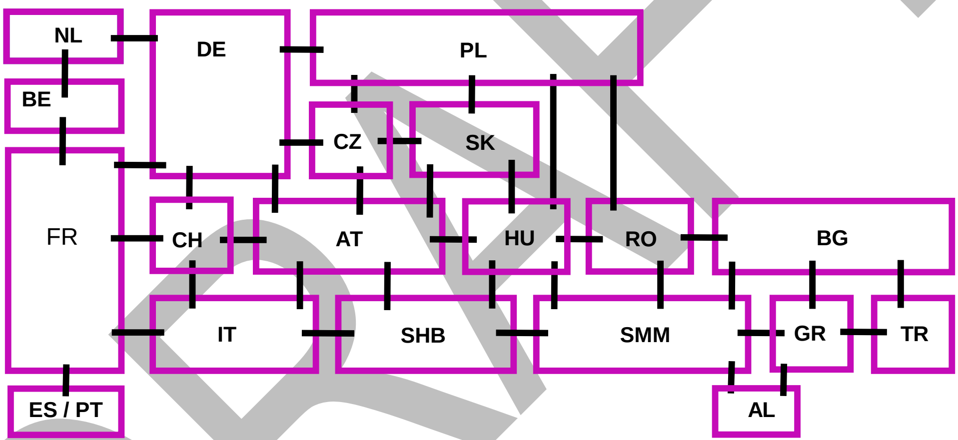


Figure 11: LFC Blocks in RG Continental Europe

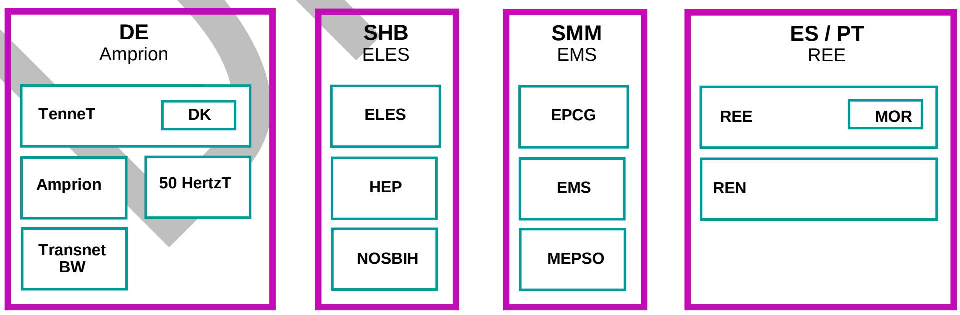


Figure 12: Examples for LFC Blocks consisting of more than one LFC Area

The area hierarchy and the according area process obligations represent the general framework for organisation of Load-Frequency-Control in a Synchronous Area.

Table summarizes the different area process obligations defined in the NC. For instance, a TSO operating a LFC Area has the obligation to collect and calculate the schedule for the area, to perform an online calculation and monitoring of the actual power interchange and the Frequency Restoration

Error as well as to operate a Frequency Restoration Process. At the same time a TSO operating a LFC Area has an obligation to cooperate with TSOs of other LFC Areas to fulfil the area process obligations of a LFC Block, i.e. to fulfil the Frequency Restoration Quality Target Parameters and to organise the availability of a sufficient amount of FRR and RR according to dimensioning criteria (where an LFC Block consists of more than one LFC Area the TSOs shall agree on individual Frequency Restoration Quality Target Parameters).

Where an area consists of more than one sub-area the cooperation of the TSOs operating these sub-areas has to be defined within a legally binding multi-party agreement. This contract shall define responsibilities of each single TSO with respect to the fulfilment of the area process obligations. Especially, all TSOs of a Synchronous Area have to agree on issues related to the Frequency Containment Process, while all TSOs of the same LFC Block have to agree on issues related to the Frequency Restoration Process.

It has to be noted that a control process which is optional in general can also be mandatory for some TSOs if it is a precondition for the fulfilment of the respective area process obligations (e.g. if a TSO receives FRR from providers located in a different LFC Area a Cross-Border FRR Activation Process is mandatory for the involved TSOs). Furthermore, a control process which is optional from the technical perspective of LFC&R NC may become mandatory according to provisions of another NC (e.g. Balancing NC).

The added value of different area types and area process obligations formulated in this NC can be summarized as follows:

- The different area process obligations provide clear responsibilities for TSOs operating different areas.
- The methodology of defining the area hierarchy and area process obligations is flexible and allows a European harmonization of terms and procedures
    - regardless of different physical characteristics of the single Synchronous Areas while
    - at the same time the best practices for single Synchronous Areas are respected.
- The methodology allows flexibility with respect to changing requirements while providing strict principles.

Obligations	Market Balance Area	Monitoring Area	LFC Area	LFC Block	Synchronous Area
Scheduling	MANDATORY	MANDATORY	MANDATORY	MANDATORY	MANDATORY
online calculation and monitoring of actual power interchange	NA	MANDATORY	MANDATORY	MANDATORY	MANDATORY
calculation and monitoring of the Frequency Restoration Error	NA	NA	MANDATORY	MANDATORY	MANDATORY
Frequency Restoration Process	NA	NA	MANDATORY	MANDATORY	MANDATORY
Frequency Restoration Quality Target Parameters			MANDATORY	MANDATORY	MANDATORY
FRR/RR Dimensioning	NA	NA	NA	MANDATORY	MANDATORY
Frequency Containment Process	NA	NA	NA	NA	MANDATORY
Frequency Quality Target and FCR Dimensioning	NA	NA	NA	NA	MANDATORY
Reserve Replacement Process	NA	NA	OPTIONAL	NA	NA
Imbalance Netting Process	NA	NA	OPTIONAL	NA	NA
Cross-Border FRR Activation Process	NA	NA	OPTIONAL	NA	NA
Cross-Border RR Activation Process	NA	NA	OPTIONAL	NA	NA
Time Control Process	NA	NA	NA	NA	OPTIONAL
Mandatory cooperation to fulfil obligations of	Monitoring Area	LFC Area	LFC Block	Synchronous Area	NA

Table 2: Area process obligations

5.2.3 Frequency Containment, Restoration and Reserve Replacement

The framework of the Load-Frequency-Control processes is based on the current best practices in power system operation and in control engineering in general.

Figure 13 illustrates the interdependencies between the Frequency Containment Processes, Frequency Restoration Process and Reserve Replacement Process:

- The Frequency Containment Process stabilizes the frequency after the disturbance at a steady-state value within the permissible maximum steady-state frequency deviation by a joint action within the whole Synchronous Area.

- The Frequency Restoration Process within SA CE controls the frequency to its set-point value and replaces the activated FCR. The Frequency Restoration Process is triggered by the disturbed LFC Area.
- The Reserve Replacement Process replaces the activated FRR, and the FCR in some Synchronous Areas (this process can also support the FRR activation). The Reserve Replacement Process is triggered by the disturbed LFC Area.

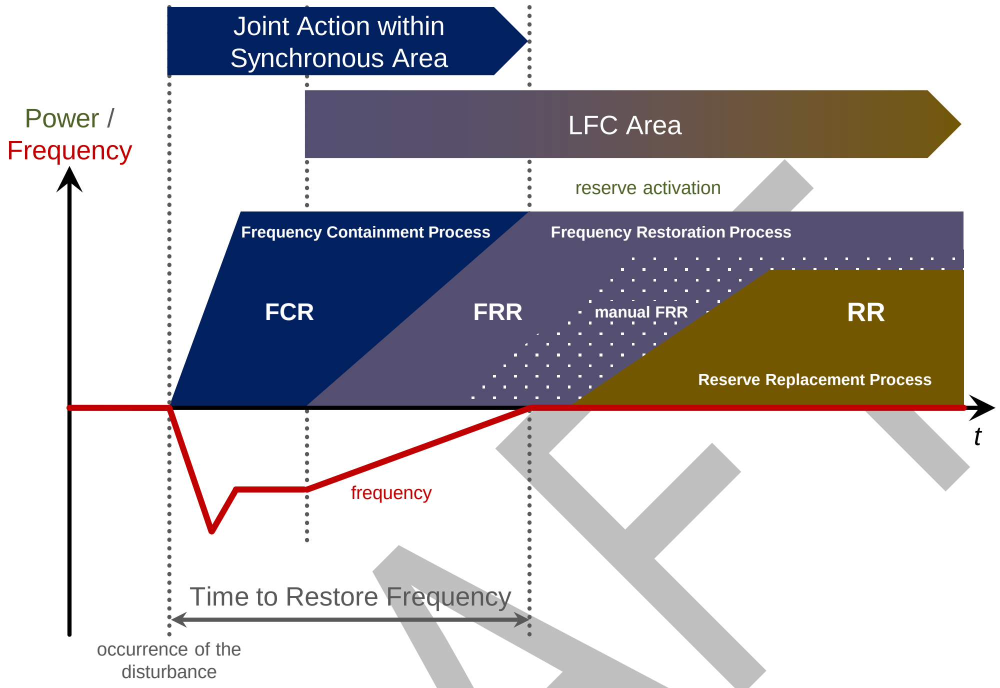


Figure 13: Load-Frequency-Control: Basic process structure

While implementation details (e.g. activation time frames) may differ between Synchronous Areas, the structure provided in the NC is harmonized on the European level.

5.2.3.1 Frequency Containment Process

The FCR is activated by a joint action of FCR Providing Units within the whole Synchronous Area with respect to the Frequency Deviation (Frequency Containment Control Error).

Depending on the best practices for a Synchronous Area the activation requirements for single FCR Providing Units may differ, nonetheless, the overall behaviour shall follow two principles which are illustrated in Figure 14:

- The overall FCR activation is characterised by a monotonically increasing function of the Frequency Deviation.
- The total FCR capacity shall be activated at the maximum steady-state frequency deviation.

The NC provides a European harmonization of Frequency Containment Process design and the according terms while allowing the necessary flexibility for different Synchronous Areas and types of

FCR Providers. Particularly, it enables FCR provision by demand units and different activation ranges.

FCR Provision:

For SA GB there is no specific nodal restriction on FCR holding by a provider as the reserve market operates in a different way from the other SAs. The GB SO instructs reserve providers to provide FCR and FRR based on a number of factors including reserve price, bid-offer price, reserve requirement, reserve provision, provider parameters, and transmission congestion. The GBSO will always know the location of the reserve provision and so will always ensure the dimensioning requirements are met. To restrict holding on a node would restrict the operation of the GB market and increase costs to consumers.

The requirements for reserve providers to replace unavailable units and recover energy reservoirs have not been added to SA GB, as the GBSO replaces unavailable units by requesting another unit itself in the market instead of mandating reserve providers to replace unavailable units themselves. The reserve contracts themselves take account of any energy reservoir limitations so a replacement requirement is not required.

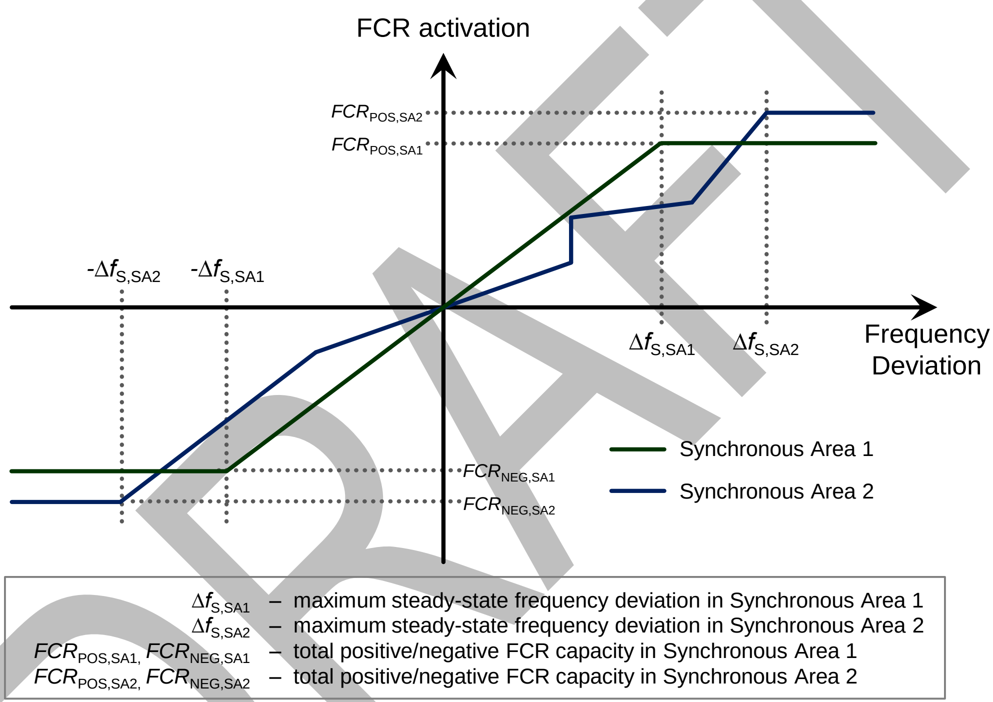


Figure 14: Example for FCR design in two different Synchronous Areas

5.2.3.2 Frequency Restoration and Reserve Replacement Process

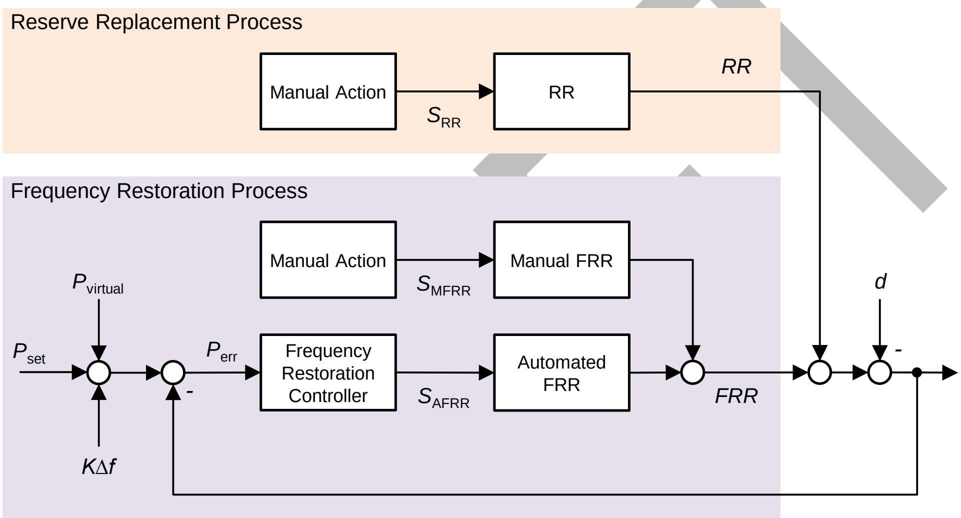
The Frequency Restoration Process is designed to control the Frequency Restoration Control Error to zero by activation of manual and automated FRR within Time to Restore Frequency. In this way, the frequency is controlled to its set-point value and the activated FCR are replaced. The Reserve Replacement Process replaces or supports the Frequency Restoration Process. In contrary, to the Frequency Containment Process the respective set-points for FRR and RR activation are calculated by the TSOs. Figure 15 shows the implementation of the Frequency Restoration and Reserve Replacement Process from control perspective of a LFC Area.

Where a Synchronous Area contains more than one LFC Area the Frequency Restoration Control Error (P_{err}) or Area Control Error (ACE) is calculated from the deviation between the scheduled and actual power interchange of a LFC Area (including Virtual Tie-Lines if any) corrected by the frequency bias (K-Factor of the LFC Area multiplied by the Frequency Deviation). Otherwise the Frequency Restoration Control Error is based solely on Frequency Deviation.

The set-point value for FRR activation can be calculated manually (feed-forward control) and / or in an automated way (feed-back control). The latter requires a Frequency Restoration Controller with proportional-integral behaviour implemented in the control system of the TSO. The Replacement Reserve Process is implemented by manual action. The sum of activated FRR and RR adjust the power balance to its set-point value.

It is worth noticing, that despite the similarity from control point of view, manual FRR activation and RR activation lead to different control performances due to different activation time frames.

Furthermore, the implementation of automated Frequency Restoration Process is not obligatory: Depending on physical properties of the Synchronous Area as well as different power plant dispatch models manual actions may be sufficient to achieve the necessary frequency quality.



P_{set} – scheduled power balance (positive for export and zero if the LFC Area corresponds to the Synchronous Area)
d – deviation from scheduled power balance (positive for deficit)
$K\Delta f$ – frequency bias
$P_{virtual}$ – power exchange over Virtual Tie-Lines (positive for export, not applicable if the LFC Area corresponds to the Synchronous Area)
P_{err} – Frequency Restoration Control Error
S_{AFRR} – set-point value for automated FRR activation
S_{MFRR} – set-point value for manual FRR activation
S_{RR} – set-point value for RR activation

Figure 15: Frequency Restoration and Reserve Replacement Processes

The added value provided by the NC is the harmonization of terms and methodology for the design and implementation of the Frequency Restoration and Reserve Replacement Processes on the European level while allowing the necessary flexibility for different Synchronous Areas. Furthermore, by explicitly considering Virtual Tie-Lines as part of the Frequency Restoration Control Error cross-border processes are also included in Frequency Restoration.

5.2.4 Imbalance Netting and Cross-Border Reserve Activation

The LFC&R NC provides requirements for cross-border reserve activation and Imbalance Netting. The general technical framework relies on the concept of Virtual Tie-Lines as well as adjustment of control programs or adjustment of the active power flows over HVDC links.

The added value provided by the NC lies in the harmonization of terms, methodologies and procedures allowing the maximum degree of cooperation between TSOs on the European level while setting limits with respect to Operational Security.

5.2.4.1 Imbalance Netting Process

The Imbalance Netting Process is designed to reduce the amount of simultaneous counteracting FRR activation of different participating and adjacent LFC Areas by Imbalance Netting Power exchange. The Imbalance Netting Process is applicable between LFC Areas which are part of one or different LFC Blocks within one Synchronous Area or between LFC Areas of different Synchronous Areas. Where there is only one Frequency Restoration Process in a Synchronous Area and the Frequency Restoration Control Error is based on Frequency Deviation (e.g. RG Ireland, RG GB or RG Nordic), the Imbalance Netting Process is implemented implicitly in the control error calculation.

Figure 16 shows the basic principle of the Imbalance Netting Process: The participating TSOs calculate in real time demand for FRR activation based on the power balance of the LFC Area. This value represents the total amount of FRR needed to control the Frequency Restoration Control Error to zero. In the second step these values are transmitted to an algorithm which nets the single FRR demands and calculates the Imbalance Netting Power Interchange for each participating LFC Area according to the requirements of the NC. Where the participating LFC Areas are located in the same Synchronous Area the Imbalance Netting Power Interchange is implemented by a Virtual Tie-Line. The Imbalance Netting Power Interchange can also be implemented by adjusting the active power flow over one or more HVDC interconnectors.

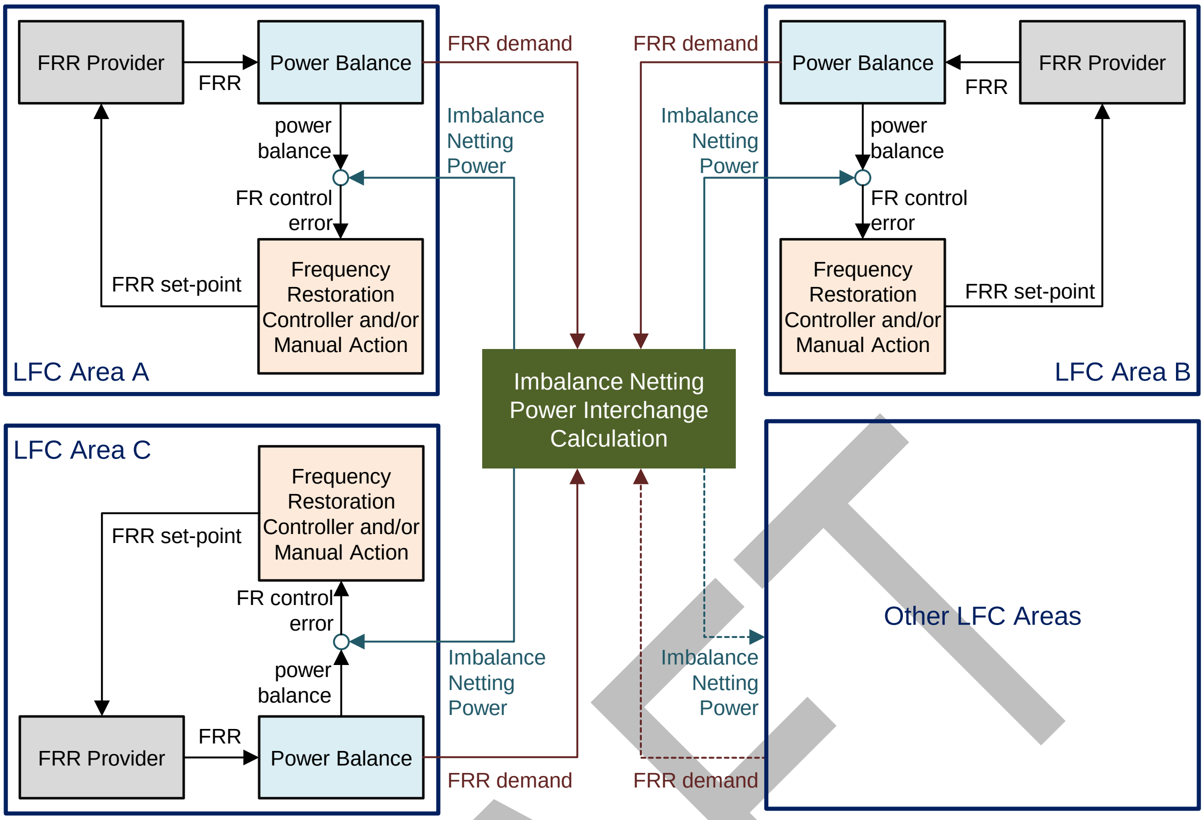


Figure 16: Imbalance Netting Process – basic principle

Figure 17 shows the integration of the Imbalance Netting Process into the Frequency Restoration Process from the perspective of one LFC Area based on the general structure illustrated in Figure 16 (for easier understanding the Reserve Replacement Process is neglected in this figure). The FRR demand is calculated from the sum of the actual Frequency Restoration Control Error minus the Imbalance Netting Power Interchange and the already activated automated FRR. In other words, the FRR demand corresponds to the automated part of the ACE Open Loop (manual FRR and Replacement Reserves are not considered in this calculation). The Imbalance Netting Power Interchange is considered as part of the Frequency Restoration Control Error (Virtual Tie-Line or by adjustment of physical active power flow over HVDC interconnectors).

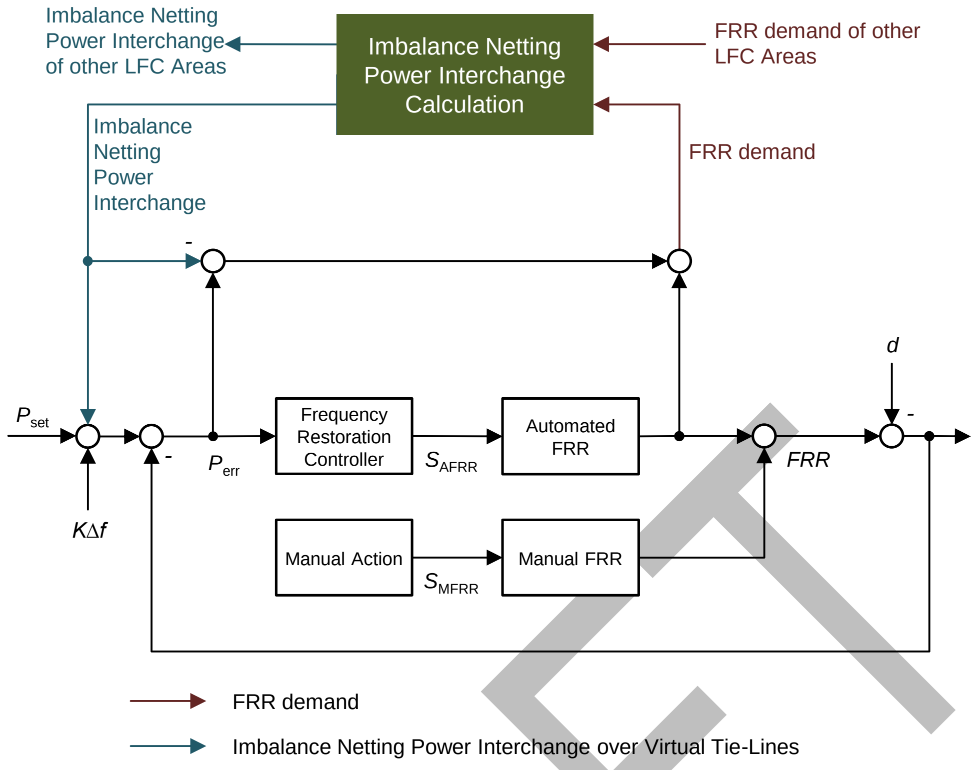


Figure 17: Integration of Imbalance Netting Process into the Frequency Restoration Process

5.2.4.2 Cross-Border FRR Activation Process

The Cross-Border FRR Activation Process is designed to enable a TSO to perform the Frequency Restoration Process by activation of FRR connected to a different LFC Area (Frequency Restoration Power Interchange). The NC foresees two basic models for Cross-Border FRR Activation:

- A TSO calculates directly the set-point value for the FRR activation in a different LFC Area directly (TSO-Provider Activation). The Frequency Restoration Power Interchange and the adjustment of the Frequency Restoration Control Error are calculated on the basis of actual FRR measurements (and/or schedules for manual FRR).
- A TSO (or an algorithm) calculates directly the required Frequency Restoration Power Interchange between participating LFC Areas which is used to adjust the Frequency Restoration Control Error (TSO-TSO Activation). The set-point value for FRR activation is calculated by the Reserve Connecting TSO.

Figure 18 and Figure 19 show the basic principle for the TSO-Provider Activation of automated and manual FRR for two LFC Areas illustrated in Figure 20 (for easier understanding the Reserve Replacement Process is neglected in this figure):

- The TSO of the LFC Area A has contracted two FRR Providers inside his LFC Area (FRR Provider A.1 for automated FRR and FRR Provider A.2 for manual FRR).
- The TSO of the LFC Area B has contracted two FRR Providers inside his LFC Area (FRR Provider B.1 for automated FRR and FRR Provider B.2 for manual FRR).
- Furthermore, the TSO of the LFC Area A has contracted two FRR Providers connected in LFC Area B (FRR Provider B.3 for automated FRR and FRR Provider B.4 for manual FRR).

The set-points for FRR activation by the FRR Providers B.3 and B.4 are calculated directly by the TSO of the LFC Area A (brown arrows). In order to adjust the Frequency Restoration Control Errors the actual FRR activation is subtracted in LFC Area A and added in LFC Area B (based on the sign conventions in the control diagram) using Virtual Tie-Lines (Figure 18).

Figure 19 illustrates the same principle. The difference lies in the consideration of manual FRR activation which is implemented by the adjustment of the respective schedules for the LFC Areas (purple arrows).

The same principle can be applied for the Cross-Border FRR Activation Process using HVDC links. In this case, the Frequency Restoration Power is exchanged by adjusting the flows over one or more HVDC interconnectors.

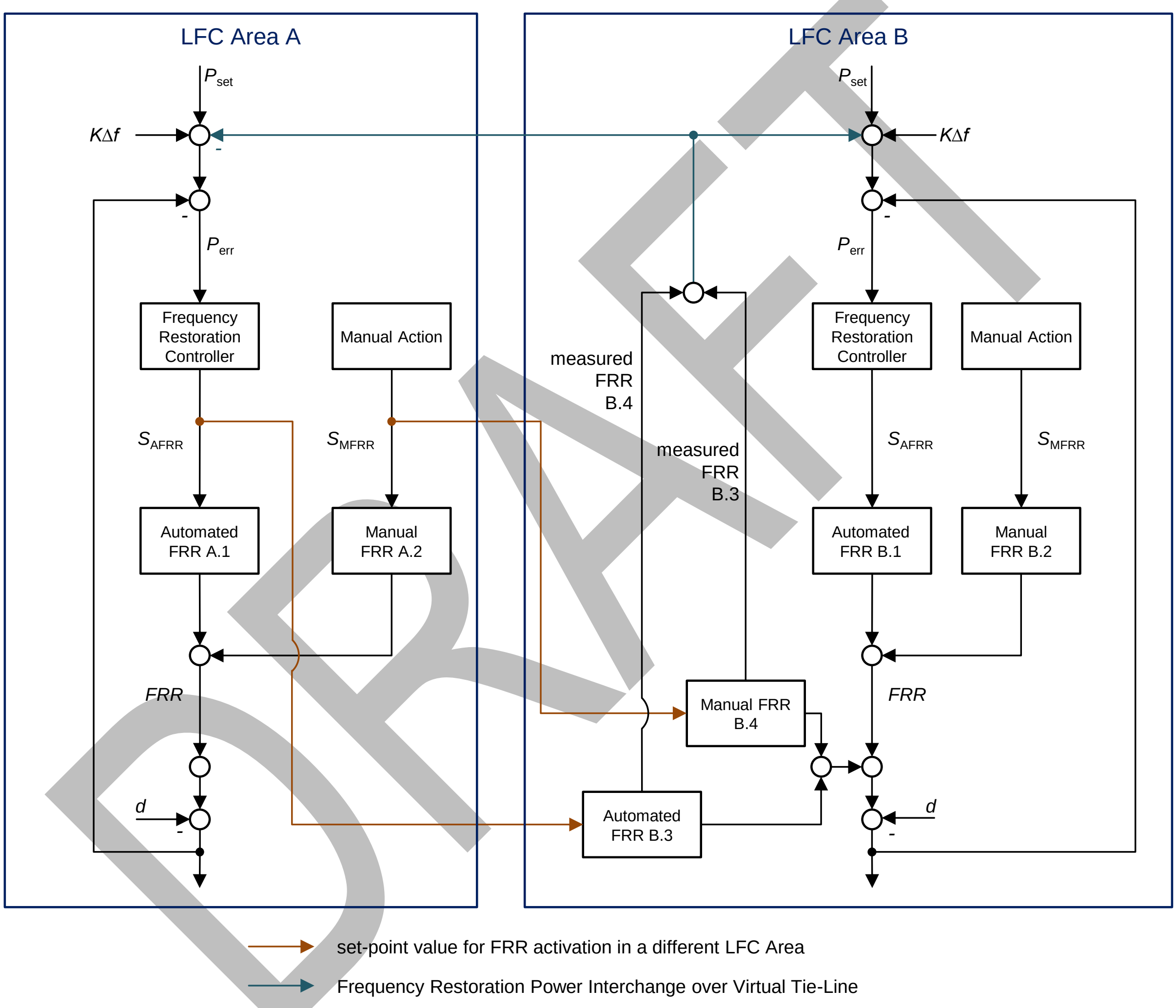


Figure 18: Example for TSO-Provider Activation with Virtual Tie-Lines

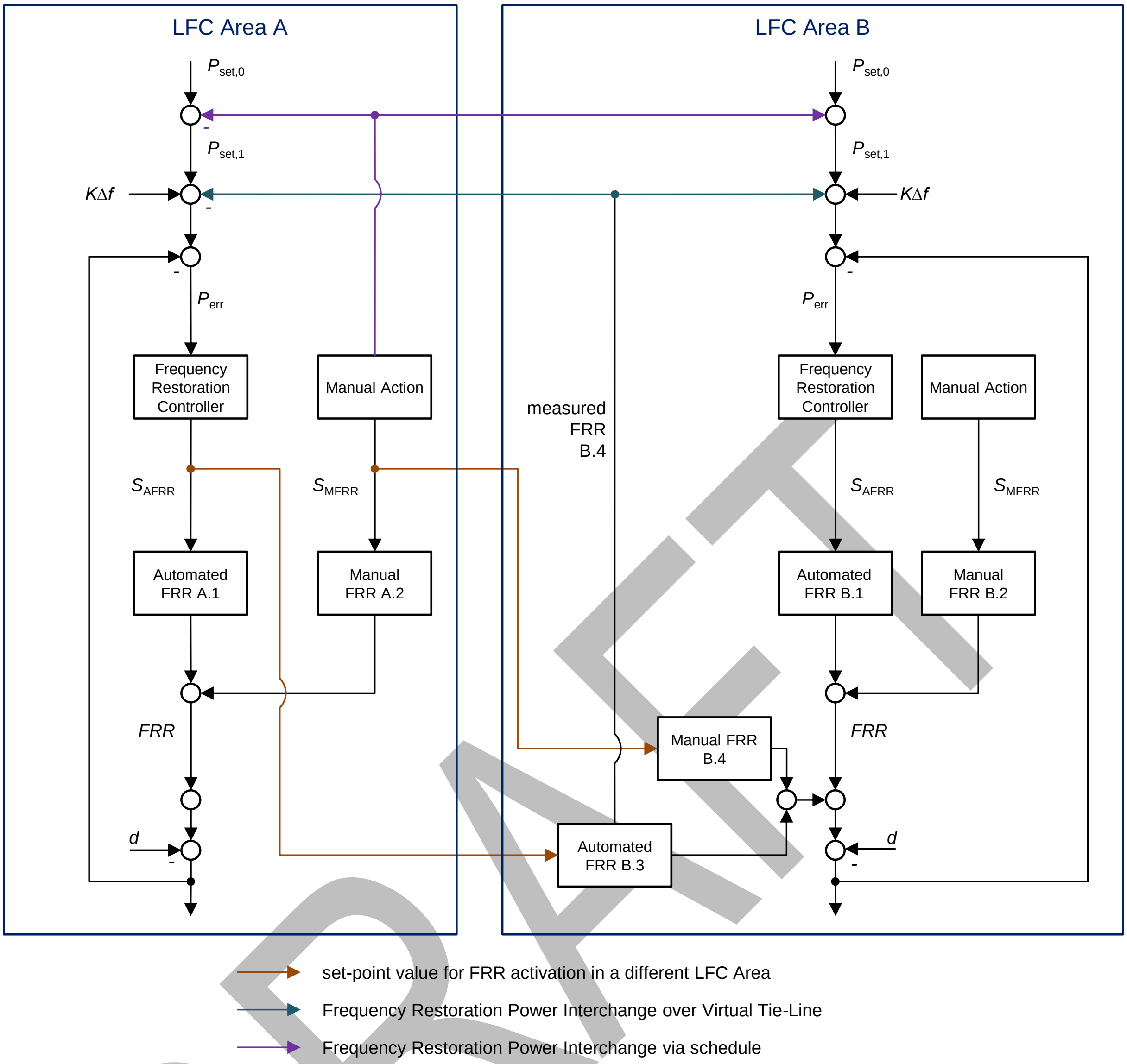


Figure 19: Example for TSO-Provider Activation with Virtual Tie-Lines and schedules

Figure 20 shows the TSO-TSO Activation for automated FRR. The implementation from the control perspective is identical to the implementation of the Imbalance Netting Process (the implementations can be combined by using an according algorithm for the calculation of the power interchange): The Frequency Restoration Power Interchange for automated FRR is calculated based on the respective FRR demand values and implemented using Virtual Tie-Lines.

Figure 21: Example for TSO-TSO Activation for manual FRR with schedules shows the TSO-TSO Activation for manual FRR. The FRR demand is defined manually by a TSO and is transmitted to a respective algorithm which calculates the according schedules for the adjustment of the Frequency Restoration Control Errors and the FRR amounts which need to be manually activated by the TSOs. The TSO – TSO Activation for manual FRR can also be implemented with a Virtual Tie-Line.

Again, the concept is transferable to Frequency Restoration Power Interchange over HVDC links.

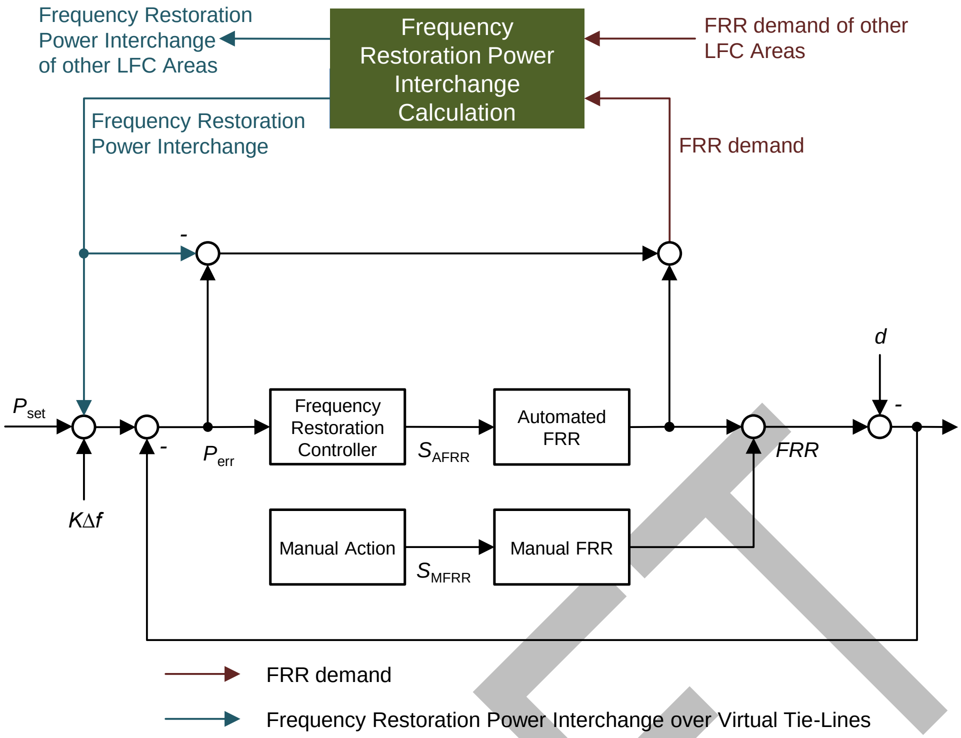


Figure 20: Example for TSO-TSO Activation for automated FRR with Virtual Tie-Lines

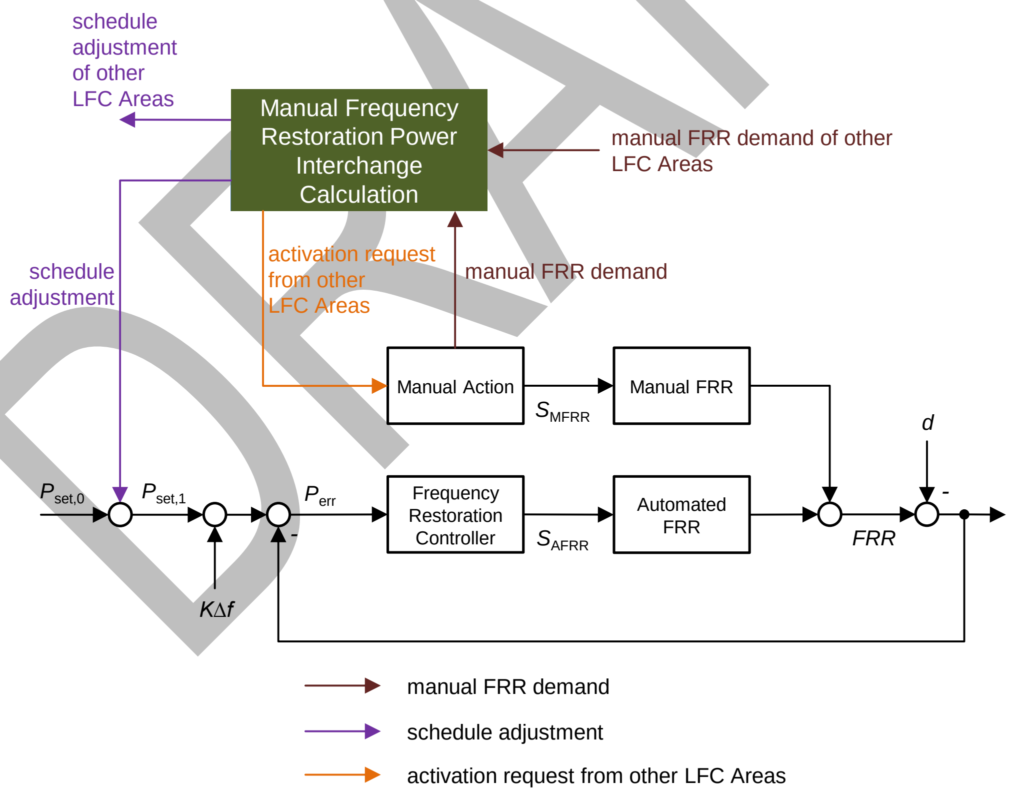


Figure 21: Example for TSO-TSO Activation for manual FRR with schedules

5.2.4.3 Cross-Border RR Activation Process

The Cross-Border RR Activation Process is designed to enable a TSO to perform the Reserve Replacement Process by activation of RR connected to a different LFC Area (Replacement Power Interchange).

While the requirements for the RR are different from FRR requirements, the implementation can follow the principles for manual FRR which are described in the previous section.

5.2.4.4 Operational Security

The NC defines limits for power interchange between the involved LFC Areas: The Imbalance Netting Power, the Frequency Restoration Power and the Replacement Power Interchange shall not exceed the Available Transmission Capacity which is determined based on Operational Security assessment.

5.2.5 Additional Requirements related to Area Types

Processes which are optional in general (cf.

Table) can be mandatory depending on local implementation factors. Considerations which might make aspects mandatory are exemplified below (other conditions may also exist):

- LFC Areas which form a LFC Block and apply a dimensioning procedure based on the disturbances of the whole LFC Block (i.e. netting the disturbances) are obliged to implement the Imbalance Netting Process (as in dimensioning). Furthermore, prior performing the Imbalance Netting Power Interchange with other LFC Blocks, the imbalances have to be netted inside the LFC Block.
- Where the Imbalance Netting Process is implemented for different LFC Blocks, the LFC Blocks shall ensure having sufficient reserves available to meet the respective Frequency Restoration Quality Target Parameters regardless of Imbalance Netting Power Interchange. In particular, this means that if the Imbalance Netting Power Interchange is set to zero (e.g. due to congestions), each LFC Block shall have a sufficient amount of free reserves to offset the disturbances without the Imbalance Netting Process.
- The implementation of the Cross-Border FRR Activation Process is a precondition for sharing or exchange of FRR. The implementation of the Cross-Border RR Activation Process is a precondition for sharing or exchange of RR.
- If one of the cross-border processes is implemented between LFC Areas of different LFC Blocks, all TSOs of the Synchronous Area have to agree on this implementation. One or more TSOs which are not participating in this process may declare themselves as Affected TSOs based on the analysis of the Operational Security and require the provision of real-time values for power interchange between LFC Blocks. Furthermore, additional operational procedures can be implemented allowing the Affected TSOs a limitation of the interchange between the LFC Blocks in real-time.

5.2.6 Measurements and Infrastructure

The NC defines basic requirements for measurements and infrastructure in the ENTSO-E. The details shall be defined within a multi-party agreement on a Synchronous Area level.

5.3 Frequency Containment Reserves

Any imbalance between generation and demand in a synchronously connected grid (Synchronous Area) immediately results in a frequency deviation which continuously increases as long as the respective imbalance exists. Without any countermeasure the system frequency would reach a critical value resulting in the collapse of the synchronously connected grid.

The objective of frequency containment is to maintain a balance between generation and consumption within the synchronous area and thus to stabilize the electrical system by means of the joint action of respectively equipped providers.

Appropriate activation of FCR results consequently in stabilization of the system frequency at a stationary value after an imbalance in the time frame of seconds. As a matter of fact due to the principle of activation FCR cannot restore system frequency (and power exchanges between areas) to their reference values.

5.3.1 FCR Dimensioning

Imbalances in an interconnected system can have different reasons. The following types of reasons for system frequency deviations have to be separated / considered (see also explanations to Frequency Quality):

- Disturbance / outage of generation or load or HVDC interconnector. This type of imbalance is generally the one used for the calculation of the Reference Incident.
- Stochastic imbalances in normal operation. These can occur due to the continuous variations of demand or renewable energy output.
- Deterministic Frequency Deviations – e.g. ramping at the hour shift.
- Network splitting. These imbalances are generally out of the design of the Synchronous Area as they lead most likely to an emergency situation in a part or in all of the Synchronous Area.

Dimensioning of FCR in general has to take into account all of the corresponding effects and has to respect

- Expected magnitude of the imbalance
- Expected duration of the imbalance
- Possible mutual dependency of imbalances
- Limits / thresholds for Frequency Deviations

Whereas the stochastic imbalances and Deterministic Frequency Deviations are transient and vanish after some minutes an imbalance caused by a disturbance / outage or even network splitting is persistent and has to be covered for a comparably longer period of time by an appropriate amount of FCR followed by activation of other operational reserves (see also explanations to FRR, RR).

With regards to persistent power imbalances, the disturbance / outage of generation or load or HVDC interconnector is considered. The basic dimensioning criterion of the Frequency Containment Reserve (FCR) is to withstand the Reference Incident in the synchronous area by containing the system frequency within the maximum system frequency deviation and stabilizing the system frequency within the maximum steady-state system frequency deviation.

The Reference Incident has to take into account the maximum expected instantaneous power deviation between generation and demand in the synchronous area. In large systems such as the Synchronous Area Continental Europe an N-2 scaling criterion (outage of the two biggest generation / consumption / in-feed units is considered to scale the risk of multiple outages within the recovery window of the system. This concept is supported by a probabilistic assessment for the calculation of the Reference Incident.

Stochastic Imbalances and Deterministic Frequency Deviations (resulting from market optimization) occur independently from outages of generation / load and can be estimated by using statistical analysis.

For dimensioning of FCR the different effects have to be combined by using statistical data from the past with the aim to limit the likelihood of insufficient FCR. Thus, dimensioning of FCR has to take into account resulting imbalances that happen with a certain probability.

The value of FCR thereby determined is therefore the needed total FCR per Synchronous Area. FCR is per se a shared portion of the reserve of the total FCR which has to be distributed between TSOs in the Synchronous Area using a distribution key. Since in general the behaviour of generation and load is the basis for the needed FCR the distribution key for the individual TSOs should reflect generation and demand connected in the area of a TSO.

5.3.2 FCR Minimum Technical Requirements

To guarantee appropriate activation of FCR the determination of minimum requirements for the providers are necessary. These requirements encompass the basic parameters

- Accuracy of Frequency measurement – to be able to detect Frequency Deviations exceeding a certain size
- Maximum Insensitivity of the governor of FCR providing Units – to avoid too late activation of FCR
- Full activation time of FCR – to harmonize activation in terms of time and to guarantee a sufficient activation gradient
- Full Activation Deviation – to harmonize activation in terms of Frequency Deviation

Nevertheless determination of additional detailed requirements concerning provision and activation must be possible to be able to react on changing boundary conditions with respect to structure and pattern of load and generation including renewables. Respective additional requirements encompass also specifications for Reserve Providing Groups - e.g. with respect to appropriate monitoring.

In general monitoring of provision and activation of FCR plays an important role in the concept of FCR. Effective monitoring requires respective data from the providers with a sufficient time resolution to be able to detect non-compliant provision or activation.

5.3.3 FCR Provision

FCR provision and activation is crucial for system stability and therefore continuous availability of FCR is very important. Since outages of FCR Providing Unit cannot be excluded and might endanger system security the risk of remarkable reduction of FCR has to be limited by limiting the amount of FCR concentration.

Furthermore FCR should be activated as long as the Frequency Deviation exists. Within SA GB only certain providers are required to meet this requirement. Two aspects have to be considered here.

- Expected activation of FRR and corresponding relief of FCR within Time To Restore Frequency
- Possibly limited storages in FCR Providing Units

The respective requirement in the NC takes both aspects into account by determining the general obligation to activate FCR as long as the Frequency Deviation exists but to also allow for FCR Providing Units with limited storage as long as certain conditions can be fulfilled. Within SA GB there is not a general requirement to activate FCR as long as the Frequency Deviation exists.

5.4 Frequency Restoration Reserves

Frequency Restoration Reserves are activated within the Frequency Restoration Process of an LFC Area to restore the System Frequency in the Time to Restore Frequency of the Synchronous Area and to relieve system wide activated Frequency Containment Reserves. For the special case of the Synchronous Area of Continental Europe which is consisting of more than one LFC Block and performing a decentralized frequency control, FRR are activated to restore the balance between generation and load for each LFC Block and consequently restore power exchanges between TSOs to their set point.

This chapter of the LFC&R NC describes the requirements for TSOs, generating and demand facilities constituting a FRR Providing Unit and FRR Providers with regard to the activation and provision of FRR and gives additional boundary conditions for the operation of the Frequency Restoration Process.

5.4.1 Target and Performance Indicators

5.4.1.1 Target

The TSO's common and individual goal and obligation is to reach a common target. The amounts of FRR and RR needed for this are determined in the TSO's reserve dimensioning process, which shall ensure that the common target can be fulfilled. The fulfilment of requirement for FRR and RR is set at the level of a LFC Blocks. the quality target (jointly or individually) can be measured by performance indicators.

One general target for the individual FRR dimensioning is the availability of sufficient reserves to cope with the dimensioning incident. FRR shall be sufficient to replace the activated FCR within the time to restore frequency after the dimensioning incident (see below).

In addition a common quality target can be defined for "normal operation". As a recommended quality target for a synchronous area the percentage of time intervals equal to the Time to Restore Frequency (e.g. 15 minutes for Continental Europe, 10 minutes for GB, …) outside a given frequency band is measured. A target value for this is defined in Chapter 2 of the LFC&R NC per synchronous area against which this number is evaluated (see below).

This quality target is valid for the control activities of the LFC Block using a combination of FRR and RR.

For FRR and RR an additional target can be defined: the TSO shall not induce systematically an imbalance in the system resulting in a systematic system frequency distortion; the ACE shall be an appropriate measure for this distortion.

The solution to the hour shift ramping problem lies in the market re-design and not in the re-dimensioning of FRR or of RR.

5.4.1.2 Dimensioning Incident

In a synchronous area without any congestion FRR could be theoretically shared by all parties. In reality the FRR dimension and distribution are constrained by congestions inside the synchronous areas.

A TSO shall ensure it has access to sufficient reserves to cope with incidents occurring TSOs within its LFC area according to the rules of the synchronous area. The dimensioning incident is defined as the largest expected N-1 failure of generation, load or HVDC-interconnector within the LFC Block.

The dimensioning incident determines the minimum required volume of FRR to cope with instantaneous failures within the LFC area.

As a performance indicator a monitoring of the system frequency behaviour after imbalances shall be in place within each synchronous area. After imbalances the system frequency must be restored to the band defined by the tolerance range for FCR activation within the time to restore frequency. The monitoring will be based on a performance indicator measuring the exceeding of a certain threshold. The threshold is defined on the level of synchronous areas.

TSOs are allowed to perform cross-border exchange of reserves with other TSOs or to share reserves in order to cope with the dimensioning incident under the conditions defined in Article 29 and Chapter 7 of the LFC&R NC. In this case congestions and the respective probability of being short of FRR due to FRR exchange limitations have to be taken into account. This issue has to be addressed within the reserve dimensioning.

In case of reserve sharing the final responsibility to cope with the dimensioning incident remains with the TSO affected by the incident. In case of insufficient operational reserves the TSO has to take appropriate measures to balance its own demand (for example, emergency load or generation reduction according to the type of imbalance).

In line with the 5 pillars approach the follow up of the fulfilment of this target has to be addressed in the compliance monitoring. In order to judge the fulfilment the following information is needed: the size of dimensioning incident and how it is covered. This information can be shared ex ante after the occurrence of the incident.

5.4.1.3 Monitoring the Quality Target

5.4.1.3.1 Frequency as Unique Performance Indicator

As introduced in section above as a general quality target for a synchronous area the percentage of time units outside a given frequency band is measured. A time frame equal to the Time to Restore Frequency of the Synchronous Area is taken as the relevant time unit since it relates to the reaction time of FRR.

During an observation period, the number of 15-minute time frames, where the average system frequency deviation is outside a given threshold f_{THRS}, is counted. The percentage value (rate) r(f_{THRS}) is calculated by dividing this count by the total number of 15-minute time frames in the observation period. The observation period is typically 1 year.

As an ENTSO-E wide, unique performance indicator it is proposed to take a unique limit value for the percentage value (rate) r(f_{THRS}), but different values for the allowed frequency range f_{THRS} per Synchronous Area. The choice of these limit values is performed per synchronous area separately.

5.4.1.3.2 ACE as De-Central Performance Indicator

In large synchronous areas like RGCE, a de-central load-frequency-control of LFC Blocks is applied. To satisfy the desired overall system frequency quality in this case the ACE of the individual LFC Blocks must to be kept within defined limits on a continuous basis.

The FRR performance indicator in case of a de-centralised approach is based on the Area Control Error (ACE_i) of the LFC Block i. The 15 minute time frame is taken as the relevant time unit since it relates to the reaction time of FRR. .

The performance of de-centralised load-frequency control is measured by the combination of two indicators – an indicator measuring the compliance with the principle on non-intervention and another indicator measuring the severity of ACE deviation (area imbalances contributing to a frequency deviation increase are more severe than imbalances contributing to mitigation). The observation period is typically 1 year. This methodology serves as an indicator.

Indicator measuring the compliance with the non-intervention.

During the observation period, the number of 15-minute time frames, when the average ACE_i is outside the given threshold ACE_{THRS}, is counted. The percentage value (rate) r(ACE_{THRS}) is calculated dividing this count by the total number of 15-minute time frames in the observation period. The observation period is typically 1 year. This methodology serves as an indicator.

Using these metrics is in compliance with required control policies and the principle of non-intervention, in which each LFC Block should compensate its ACE (its domestic imbalance) to acceptable limits. It also reflects the fact that the prescribed obligatory PI controller for load- frequency control reacts only to ACE and therefore its performance should be evaluated by appropriate metrics over ACE.

Based on overall system frequency quality requirements, individual ACE thresholds ACE(f_{THRS}) per LFC Blocks can be calculated. Maximum relative time when those limits are exceeded remains constant among all LFC Blocks and equals the value r(f_{THRS}).

The frequency threshold f_{THRS} for a whole synchronous area with a K-factor KT is translated and decomposed in to the individual ACE_{THRS} thresholds for one LFC Block with K-factor of K_i by this formula:

$$ACE_{THRS} = f_{THRS}\sqrt{K_T K_i}$$

Indicator of ACE deviation severity

During the observation period the sum of average ACEs in 15 minutes periods is counted separately when the area imbalances contribute to mitigation of frequency deviation and when imbalances contribute to frequency deviation increase. The ratio greater than 1 of the two previous values shows that the area tends to stabilise the system frequency while ratio lower than 1 shows that the area tends to worsen the frequency. The indicator of severity will complete the conclusions that come from the observation of the previous indicator.

5.4.2 FRR Dimensioning

This NC obliges the TSOs to perform a dimensioning of FRR and RR on the level of LFC Blocks. At the same time it sets boundary conditions for the FRR and RR dimensioning with the aim to ensure that the FRR and RR available to the TSOs of LFC Block are sufficient to guarantee a safe operation and to enable the TSOs of any LFC Block to respect its quality target. In effect these boundary conditions aim to achieve the desired frequency quality within the Synchronous Area.

In general the dimensioning of reserves, in particular the dimensioning of FRR and RR in the context of this document is to be seen as a trade-off between the availability of reserves and the costs related to the procurement of these.

The reserve dimensioning of the individual TSO has to take into account the targets defined in section Chapter 2 of the LFC&R NC. There is no direct link to calculate the reserve needed from this target, but there are state-of-the-art methodologies that can support the choice of the right level of reserves.

An overview, especially for the well accepted statistical and stimulatory approaches for Reserve Dimensioning, shall be given in the following. The use of the following methodologies by the TSOs is recommended but not mandatory. The suitable dimensioning approach differs from LFC Block to LFC Block due to which the final choice is intentionally left to the TSOs of the LFC Block. The LFC&R NC focuses to give guidance and boundary conditions for the performance of the dimensioning process.

In short the boundary conditions set to the TSOs of a LFC Block with regard to the dimensioning of FRR and RR:

- It shall be based on historical records for at least one full year (Article 29.2.a))
- It shall enable the TSOs of a LFC Block to comply with the quality targets (Article 29.2.b))
- It shall be based on a probabilistic approach. This could e.g. be a statistical analysis or a simulatory approach as explained in more detail in the following (Article 29.2.b))
- It shall take all relevant influencing factors into account. (Article 29.2.b))
- It shall include the calculation of the amount of FRR which is required as Automatic FRR and which is required as Manual FRR
- During the dimensioning process the Automatic and Manual FRR Full Activation Times shall set according to the needs of the LFC Block
- Based on the available transmission capacity a certain distribution of FRR and RR within a LFC Block may be required.
- if shall ensure that the FRR capacity is sufficient to outbalance the largest expected instantaneously occurring imbalance within a LFC Block separate for positive and negative direction. In general this is the tripping of the largest generation unit for the positive direction and the largest demand facility for the negative direction. In certain LFC Blocks an HVDC interconnection might be the determining element for the Dimensioning Incident.
- It is subject to a minimum requirement for the FRR and RR requirement based on the LFC Block imbalances. The minimum need for positive FRR is defined by the 99% quantile of the LFC Block imbalances. The minimum need for negative FRR is defined by the 1% quantile. These values are to be understood as lower limits for the chosen dimensioning approach and constitute an absolute minimum.
- A LFC Block is allowed to reduce its FRR by sharing of FRR or RR with neighbouring LFC Blocks. To limit the dependency of LFC Blocks due to these sharing rules the reduction is strictly limited according to Article 29.2.j) and k). In effect the sharing of reserves is only permitted for small LFC Blocks for which the covering of the Dimensioning Incident is the largest challenge. In any case the shared amount of FRR is limited to 30 % of the dimensioning incident.

As examples a qualitative description of the statistical and the simulatory approaches for reserve dimensioning are given in the following.

5.4.2.1 Statistical Methodology for Reserve Dimensioning

Within the statistical methodology probability density functions (PDF) of different system characteristics are modelled in order to define the need for FRR and RR for each activation direction. Although in general the determining factors are comparable across synchronous areas and across LFC Blocks, it largely depends on the system itself which characteristic is to be judged as relevant or irrelevant. Hence each TSO has to choose the relevant characteristics for Reserve Dimensioning in its system.

Due to the fact that RR can be substituted by FRR, but not vice versa the statistical methodology for the dimensioning of FRR and RR can be apportioned into a two-step approach. In the first step the overall need for reserves (full value for the FRR / RR being FRR and RR as a sum) is determined. In the second step from that the need for fast and flexible reserves (i.e. FRR) is determined. The difference, the remaining need for reserves that does not need to be covered by FRR can be covered by RR.

Whereas for the dimensioning of RR in general the long term market forecast error is predominantly relevant, the need for FRR and hence its dimensioning is influenced, amongst others, by the following system characteristics:

- Short term forecast errors
- Unit outages
- Load noise
- Steps of the exchange programs
- Activation delay of RR

Renewable Energy Sources (RES) can affect both the need for FRR and RR, but the above mentioned characteristics can already include their effects.

In order to perform the dimensioning PDF for the relevant system characteristics are needed. Usually the PDF are extracted on the basis of observations from the past (e.g. for the last 12 months). If the characteristic's occurrence is too seldom and not systematic (like for unit outages) the PDF has to be created theoretically.

The overall probability density function of the system (relevant for FRR and RR or only FRR) is calculated by a mathematical combination of each of the single PDFs (convolution). From the resulting total probability density function the probability of having a certain power deficit in the system can be derived for each level of reserve procurement. Reserving this consideration the volume of the reserve needed can be chosen by defining a deficit probability, which is sufficient to fulfil the quality target.

To estimate the market forecast errors (short term and long term as a sum) for reserve dimensioning the open-loop ACE ($\mathrm{ACE}^{\mathrm{OL}}$) is likely to be used[1]. Historical values of open loop ACE can be obtained by summing up the LFC Block's ACE and all activated reserves:

$$\mathrm{ACE}^{\mathrm{OL}} = \mathrm{ACE} + \text{all actvated reserves}$$

Open loop ACE for dimensioning is constructed from several components:

$$\overrightarrow{\mathrm{ACE}_{\mathrm{OL}}} = \overrightarrow{\mathrm{ACE}_{\mathrm{OL1}}} + \overrightarrow{\mathrm{ACE}_{\mathrm{OL2}}} + \overrightarrow{\mathrm{ACE}_{\mathrm{OL3}}} + \ \ldots$$

It is each TSO's decision what components are reflecting the LFC Block's behaviour the best and hence have to be taken into account in the dimensioning or have to be removed from the database.

[1] Please note that in some market arrangements, e.g. centrally dispatched pool based markets, it is not possible to calculate easily open loop ACE as in these markets balancing actions are taken by TSOs in the framework of the same mechanism as redispatching actions and thus they are difficult to differentiate ex post.

Typical components of the $\mathrm{ACE}^{\mathrm{OL}}$ are:

$\overrightarrow{\mathrm{ACE}_{\mathrm{OL1}}}$ representing fast load noise

$\overrightarrow{\mathrm{ACE}_{\mathrm{OL2}}}$ representing slow load noise and short term market forecast errors

$\overrightarrow{\mathrm{ACE}_{\mathrm{OL3}}}$ representing long term market forecast errors

$\overrightarrow{\mathrm{ACE}_{\mathrm{OL4}}}$ representing unit outages

$\overrightarrow{\mathrm{ACE}_{\mathrm{OL5}}}$ representing fast and slow RES effects in case when RES influence is not included in $\overrightarrow{\mathrm{ACE}_{\mathrm{OL1}}}$, $\overrightarrow{\mathrm{ACE}_{\mathrm{OL2}}}$components.

For each of these components a time resolution needs to be chosen. For most of the components a quarterly hour time resolution might be sufficient, however e.g. for the fast load noise and the short term market forecast errors a smaller time resolution might be needed in order to reflect the relevant characteristics.

After the convolution of all of the relevant PDFs of these data the overall PDF of power imbalances is known. It can be used to calculate the probability of having a certain power deficit in the system for the sum of both kinds of reserves FRR and RR.

The convolution of the PDFs relevant for fast and flexible reserve, the volatile part is only a part of $\mathrm{ACE}^{\mathrm{OL}}$, is used to calculate the need for FRR.

Choosing an ultimate value for the deficit probability in combination with the overall PDF gives the full value for the FRR / RR needed in the system. The need for Reserves should in this case be determined for each activation direction separately, thus the deficit probability needs to be attributed accordingly to the activation directions. According to the market possibilities the TSO decides about the “sourcing”, i.e. which part of the maximum value for the FRR / RR is reserved as “firm capacity” and which part can with an acceptable security be delivered by market parties. A TSO with no possibility to activate reserves from the market may have to contract the full value for the FRR / RR as “firm capacity”.

5.4.2.2 Simulation Methodology for Reserve Dimensioning

The statistical methodology models each time unit independently (i.e. non-sequential). It does not allow an analysis of the results of a course of events. This limitation can be overcome by the simulation methodology.

With this methodology the dynamic reaction of the whole system can be analysed. The basis is a pre-defined set of events. Typically these events are designed on the basis of experiences from the past. New probable phenomena not observed in the history can be also simulated.

The results of the simulation give the ACE of the system, which can be analysed with regards to the performance indicator. Thus quality target and reference incident reaction can be evaluated from simulation.

Typically during simulation a probable time series of open-loop ACE (or system frequency deviations in smaller system) is generated and activations/deactivations of operational reserves simulated.

Simulation model can be used for simulation of one run throughout investigated period or for a more complex Monte Carlo simulation. The advantage of Monte Carlo simulations is its ability to investigate a broad range of possible situations in a power network.

Ideally at least a whole year period is simulated, however to reduce computation time for Monte Carlo simulation representative shorter periods (typically months) could be used.

If Monte Carlo simulations are performed, it is recommended not only to evaluate system behaviour from by averaging all simulation run but also to choose few representative realisations for evaluation purposes, because averaging leads to some sort of result blurring. A pre-defined worst case is regarded as recommended security approach. Thus simulations results falling around 90 % quintile should be used for dimensioning operational reserves.

5.4.3 FRR Minimum Technical Requirements

The FRR Minimum Technical Requirements may differ depending on the Synchronous Area or LFC Block. In addition the Reserve Connecting TSO, i.e. the TSO to which the Reserve Providing Unit is connected has the possibility to set requirements. The need for different requirements depending on the level arises from the technical conditions that may largely differ from Synchronous Area to Synchronous Area and within these from LFC Block to LFC Block.

The LFC&R NC hence differentiates requirements for Reserve Providing Unit, Reserve Providing Groups or Reserve Provider which are:

- Unique across all Synchronous Areas
- Unique for all LFC Block of a Synchronous
- Unique for all Reserve Providing Units within a single LFC Block
- Requirements set by the Reserve Connecting TSO

5.4.4 FRR Operation

In Article 31 in Chapter 5 of the LFC&R NC the basic rules for the operation of the Frequency Restoration Process are defined. Whereas the general rules with regard to the design of the Frequency Restoration and Reserves Replacement processes are set in Chapter 2 and Chapter 3 of this NC. The real-time operation of these processes may face additional challenges as unexpected high imbalances of frequency deviations. For the mastering of these this NC sets rules and gives the TSOs additional tools if certain predefined limits are reached. The rules are formalized as common rules for the operation of the FRP on Synchronous Area level and on LFC Block level.

With regard to the operation of the Frequency Restoration Process(es) within a Synchronous Area this NC differentiates three operation states depending on the general risk level measured by the System Frequency Deviation.

- High Synchronous Area State
- Elevated Synchronous Area State
- Normal Synchronous Area State

Whereas the Normal Synchronous Area State is to be seen as a situation with usual Frequency deviations, the Elevated Synchronous Area State and the High Synchronous Area State constitute situations in which the operation of the Synchronous Area faces extraordinary challenges. This NC obliges the TSOs of a Synchronous Area to avert situations with Elevated or High Synchronous Area States and obliges the TSO to collaborate with TSOs of the same but also from different Synchronous

Areas. For this collaboration during times with Elevated or High Synchronous Area States the principle of non-intervention may be disregarded, whereas is stays valid for all other situations.

In addition to the described general operation states within a Synchronous Area, the operation of the Frequency Restoration Processes of the individual LFC Block is categorized into different thresholds.

- Level 2 LFC Block Threshold
- Level 1 LFC Block Threshold
- Normal LFC Block Threshold

Depending on the threshold the LFC&R NC gives the TSOS opportunities or obliges the TSOs to take additional measures.

5.4.5 Statistical Analysis of LFC Block Imbalances

In order to assess the adequacy of the amount of operational reserves the behaviour of each LFC Block shall be analysed by the responsible TSO.

In this respect the $\mathrm{ACE}^{\mathrm{OL}}$ representing the overall sum of imbalances within a LFC Block is of special significance. $\mathrm{ACE}^{\mathrm{OL}}$ is related to the overall need of reserves (FRR and RR) of a LFC Block. The following rule applies in general: the higher the $\mathrm{ACE}^{\mathrm{OL}}$ of a LFC Block - the higher is the need for operational reserves.

Additionally the $\mathrm{ACE}^{\mathrm{OL}}$ and its derivative $\mathrm{ACE}^{\mathrm{OL}\prime}$ – defined as the change of the $\mathrm{ACE}^{\mathrm{OL}}$ from the previous time stamp – can be analysed. In relation to the ACE these two parameters give insight into the intrinsic behaviour of the analysed TSO system.

5.4.5.1 Analysis of Open-Loop ACE

When plotting ACE against $\mathrm{ACE}^{\mathrm{OL}}$ in its quarterly hour dependency the following distribution is assumed to be typical.

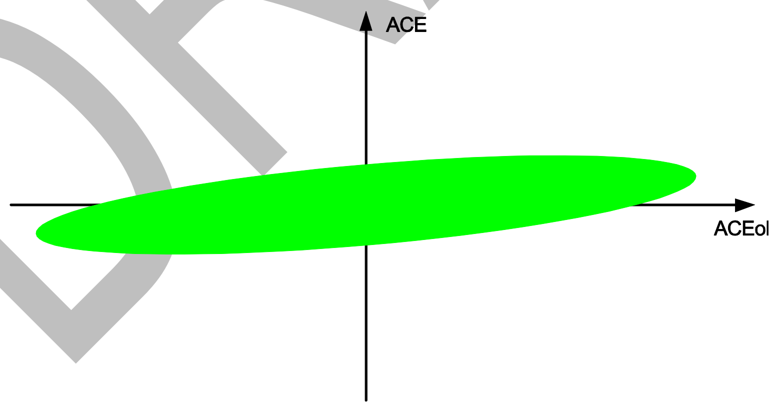


Figure 22: Typical point distribution

One can observe an equal distribution of ACE and $\mathrm{ACE}^{\mathrm{OL}}$ to positive and negative values. Each of their probabilities abates with size and nearly follows a Gaussian distribution, defined by its variance σ and its mean value μ. The points are concentrated near the x- and the y-axis (μ = 0). While assuming no interrelation between the ACE and $\mathrm{ACE}^{\mathrm{OL}}$ being independently distributed according to a Gaussian distribution no patterns are recognizable (i.e. no statistical dependency). In this diagram the x–axis represents the "influence of the market" whereas the y–axis represents the result of the TSO control activities.

If the operational reserves available to the TSO are smaller than the highest observed $\mathrm{ACE}^{\mathrm{OL}}$ the pattern as depicted in the following diagram is to be expected. It can be seen as a piecewise defined function. The flanks show saturation of reserve capacity.

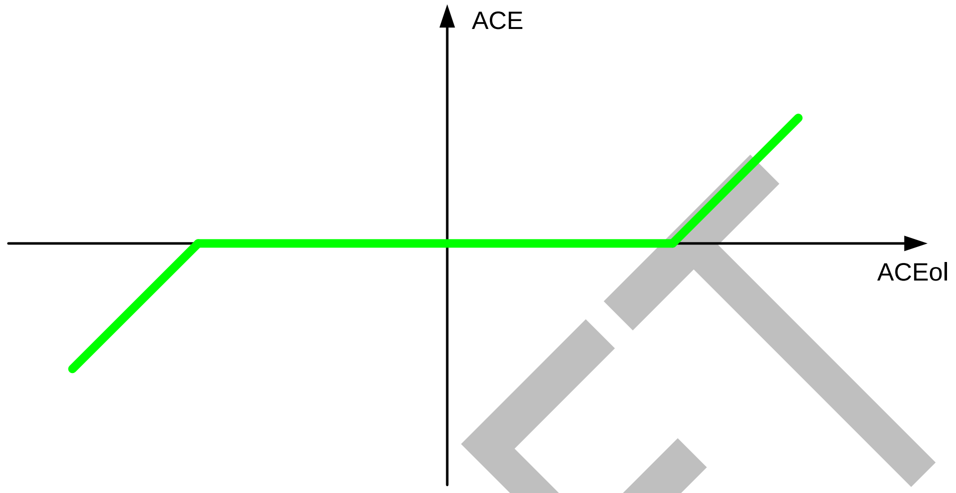


Figure 23: Saturation of reserves with instantaneous control

5.4.5.2 Analysis of the Fast Changing and Unpredictable Part of the Open-Loop ACE

The derivative of the $\mathrm{ACE}^{\mathrm{OL}}$ being $\mathrm{ACE}^{\mathrm{OL}\prime}$ (defined as ACEol'(t) = ACEol(t) –ACEol(t-1)) can be seen as a proxy for the fast changing and unpredictable part of the $\mathrm{ACE}^{\mathrm{OL}}$ and can be used to estimate the need for flexible reserves (e.g. FRR). The assumption is taken that the predictable and slow part of the $\mathrm{ACE}^{\mathrm{OL}}$ can be outbalanced by slow reserves (e.g. RR), hence the remaining part has to be outbalanced by FRR.

A realistic point distribution is depicted in the following diagram. A linear relationship between $\mathrm{ACE}^{\mathrm{OL}\prime}$ and ACE (ACE ~ k * $\mathrm{ACE}^{\mathrm{OL}\prime}$) due to the "reactive" control (i.e. reaction of the control on an ACE different to zero) is recognizable. The steepness k is a measure for the overall control speed of the system.

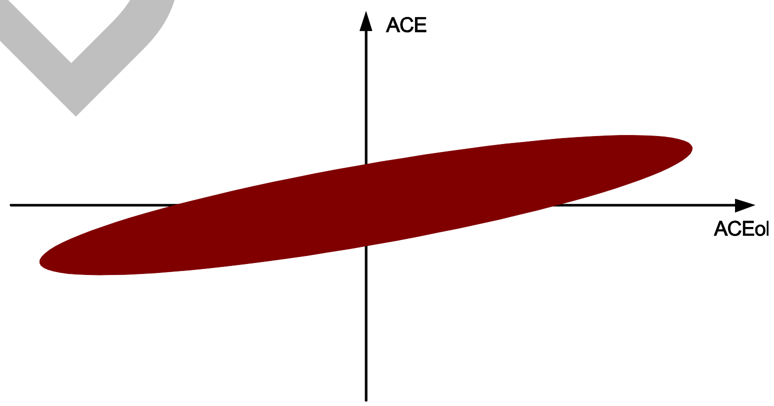


Figure 24: Realistic distribution

If the control speed was extremely fast the following pattern would be observed.

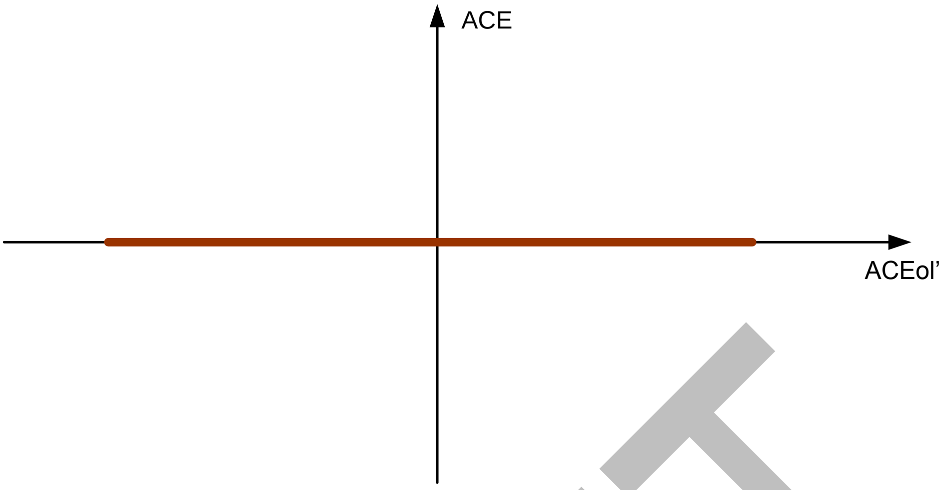


Figure 25: Fast control

If the control speed was limited and lower than the highest observed differentials of the $\mathrm{ACE}^{\mathrm{OL}}$ it would be only possible to outbalance the differential $\mathrm{ACE}^{\mathrm{OL}\prime}$ within the same quarter of an hour up to a certain speed. If this speed is reached the remaining change goes directly in the ACE (visible as flanks in Figure 26: Limited speed of control).

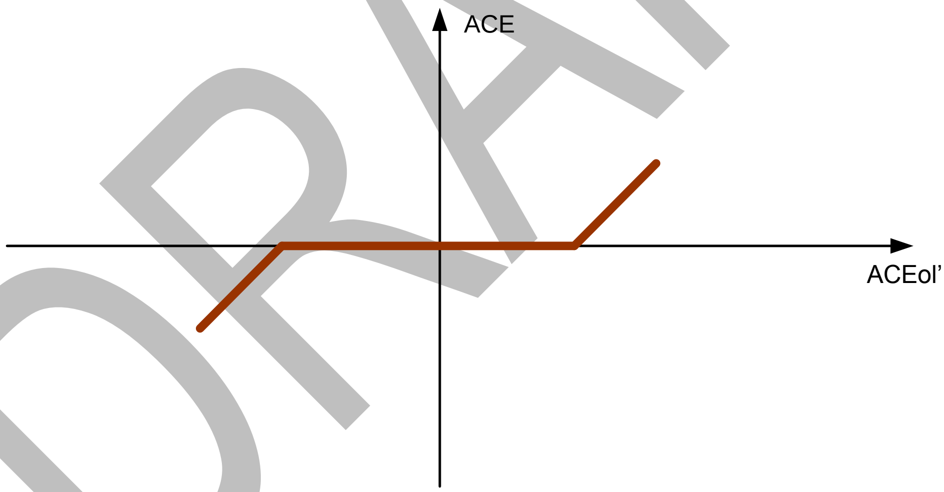


Figure 26: Limited speed of control

In the real world however, due to the reactive nature of the control loop and the limited speed of control a certain part of the ACE always stays imbalanced as depicted in the following diagram.

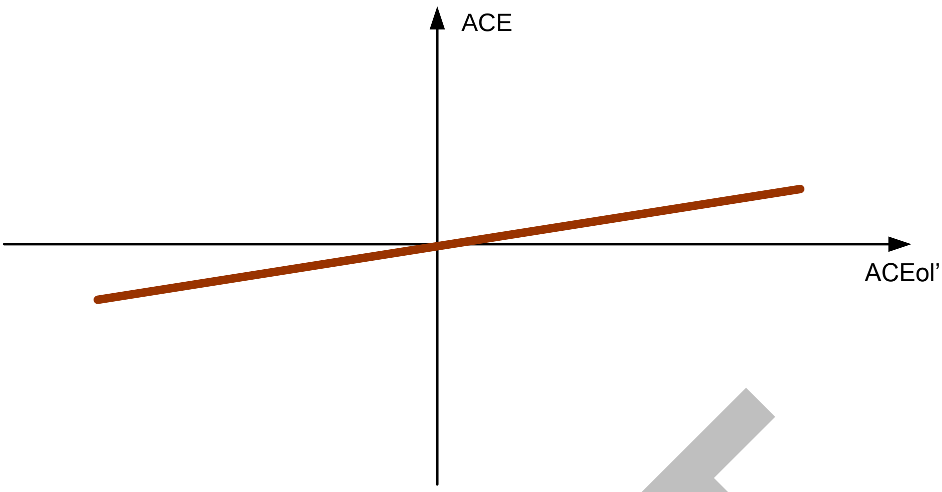


Figure 27: Normal control

5.5 Replacement Reserves

Replacement Reserves are reserves for which activation lead time may be longer than the Time to Restore Frequency, they shall be used to restore activated FRR or anticipate an imbalance and then decrease the use of FRR, to be prepared for further imbalance.

The need for such reserves depends on the market design, and the time during which BRPs may not be able to restore the imbalances. If this neutralization Time is longer than Time to Restore Frequency, a TSO is responsible not only for balancing the system, but also for restoring sufficient level of FRR to be prepared for further imbalances, until BRPs can take actions to do so.

The need for Replacement Reserves may then lead to reduce the need for FRR. So, dimensioning of RR shall take into account at least the following requirements:

- FRR shall at least cover the LFC Block Dimensioning Incident

- the total of FRR + RR shall cover the imbalances of the LFC Block according to the Frequency Restoration Error Quality Target.

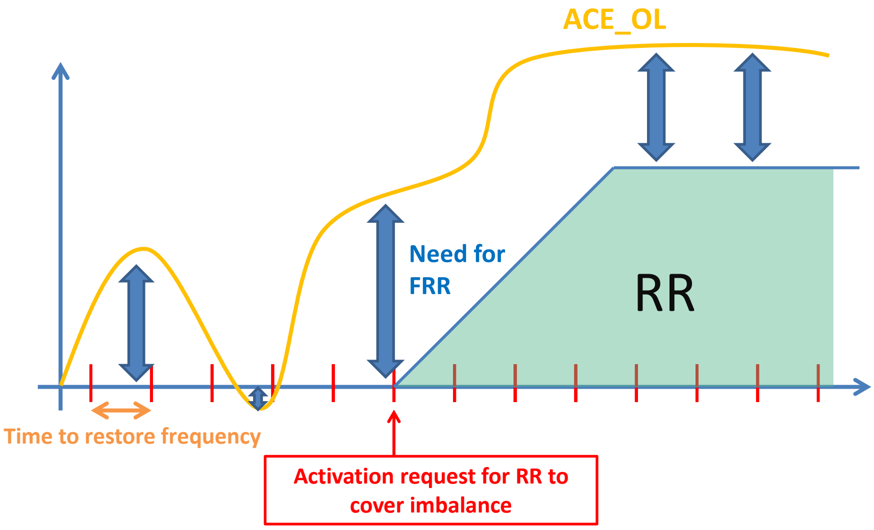


Figure 28: A possible RR activation approach

5.5.1 RR Dimensioning

According to the need for restoration reserves of a LFC Block, each TSO of the LFC Block will define a rule to dimension its RR, and submit it to TSO Decision Process.
The rules for dimensioning will be determined per LFC Block, however, they need to respect at least the mentioned points. If the RR Capacity is taken into account to dimension the FRR Capacity, then RR Capacity will need to ensure that :

- FRR is always available, that is why RR Capacity shall be sufficient to restore the Activated FRR, so that FRR Capacity can always cover at least The Dimensioning incident oft he LFC Block
- RR Capacity along with FRR Capacity shall allow a TSO to respect its Frequency Restoration Error Quality Target.
- for distribution of RR Capacity among TSOs of a LFC Block, it is mandatory to perform a study on the availability of transmission capacity on tie-lines between TSOs at any time.

RR Capacity, along with FRR Capacity shall cover the System Imbalances of a Control Block. However, RR shall be dimensioned so that FRR can cover the Dimensioning Incident of the Control Block. Indeed, FRR reacts faster than RR, and the Imbalances caused by an Incident shall be restored within time to restore Frequency. Whereas RR will have an Activation Time longer than Time to Restore Frequency. It can be used in a proactive manner to prevent activation of FRR, in case an imbalance is forecasted long enough in advance.

5.5.2 RR Minimum Technical Requirements

Since RR are part of the reserves needed to ensure the safety of the system, RR providers shall submit to a prequalification phase, answering minimum technical requirements and other requirements defined by relevant Connecting TSO.
On their side, relevant TSO shall be able to monitor the providers.

As being part of the reserves needed to respect Frequency Restoration Error Quality Target, each RR Providing unit shall be always available, and respect the requirement for availability and information defined by TSOs.

5.6 EXCHANGE AND SHARING OF RESERVES

5.6.1 Scope

The chapter on the exchange and sharing of reserves sets the technical framework allowing the development of a sustainable and efficient cooperation between TSOs of the same and/or different Synchronous Areas in performing Load-Frequency Control and ensuring the provision of reserves. The aim is to improve the economic efficiency in performing LFC within the pan-European electricity system thereby maintaining the high standards for Operational Security set forth in the Operational Network Codes.

The NC LFC&R identifies four main types of cooperation, being:

- Exchange of reserves
- Sharing of reserves
- Cross-border activation process of FRR and RR for optimization purposes
- Imbalance Netting Process

The paragraphs below explain the different kinds of cross-border co-operations:

<u>Exchange and sharing of reserves:</u>

The exchange and sharing of reserves aim to optimize the provision of the required amount of reserves capacity (in [MW]) resulting from the reserves dimensioning processes.

- The exchange of reserves allows the TSO(s) of Area A to place part of their reserves (FCR, FRR or RR) within the Area B of other TSO(s) in order to ensure the provision of the required amount of reserves resulting from the reserve dimensioning process. The exchange of reserves changes the geographical distribution of reserves without changing the total amount of reserves in the system.

  Figure 29 illustrates the exchange of 100 MW of FRR from Area B to Area A. Suppose that the FRR Dimensioning rules for Area A and Area B result in the need of 500 MW FRR for Area A and 600 MW for Area B. Without the exchange of reserves the TSOs of Area A and Area B have to ensure the provision of 500 MW and 600 MW of FRR within their respective Areas.

  As a result of the exchange of 100 MW of FRR from Area B to Area A, 100 MW of FRR of Area B is now located within Area A, whereas Area A still ensures in addition the provision of its full FRR in Area A. Although the geographical distribution of the FRR changed, the total amount of FRR within Area A and B is still 1100 MW, which is the same as before the exchange.

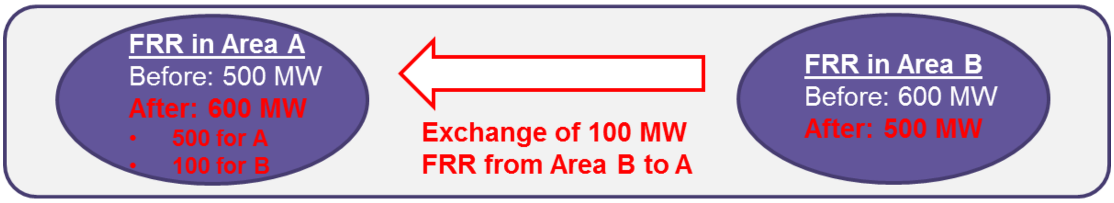


Figure 29: Exchange of 100 MW of FRR from Area A to Area B.

- The sharing of reserves allows the TSO(s) of an Area A and the TSOs of an Area B to rely on the same reserves (FCR, FRR and RR) in order to ensure the provision of the required amount of reserves resulting from the reserve dimensioning process. The sharing of reserves changes the total amount of reserves in the system, thereby also impacting the geographical distribution.

  Figure 30 illustrates the sharing of 100 MW of FRR between the TSOs of Area A and the TSOs of Area B. Suppose that the FRR Dimensioning rules for Area A and Area B result in the need of 500 MW FRR for Area A and 600 MW for Area B. Without the exchange of reserves the TSOs of Area A and Area B have to ensure the provision of 500 MW and 600 MW of FRR within their respective Areas.

  However, as in some cases it might be very unlikely that both TSOs need to activate the full amount of FRR at the same time, the TSOs of Area A and Area B can 'share' part of their FRR. In practice this means that the TSOs of Area B can make use of e.g. 100 MW of FRR of the TSOs in Area A and vice versa. As a result the TSOs of Area A and Area B now need to ensure the provision of 400 MW and 500 MW of FRR in their respective Areas. The TSOs of both Areas now make 100 MW of their own FRR also available to the TSOs of Area B. The total amount of FRR within the system is now 900 MW, whereas it was 1100 MW without the sharing agreement.

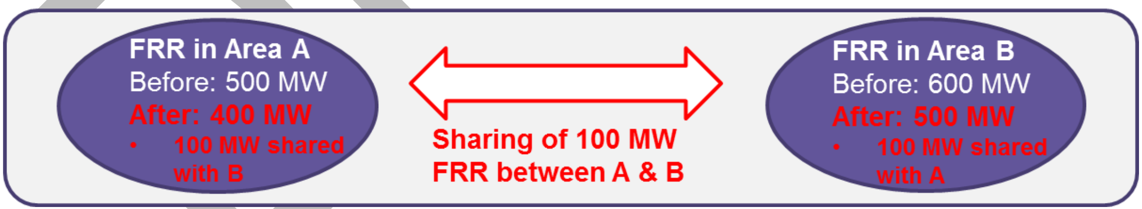


Figure 30: Sharing of 100 MW of FRR between Area A and Area B

A geographically even distribution of reserves and a sufficient amount of reserve capacity ([MW]) in the system are key requisites for ensuring Operational Security. As the exchange of reserves impacts the geographical distribution of the reserves and the sharing of reserves impacts the reserve capacity within the system, it is important that the NC LFC&R sets technical limits for the exchange and sharing of reserves to secure Operational Security. These are treated further on in this supporting document.

<u>Imbalance Netting Process and Cross-Border Activation Process of FRR and RR for Optimization purposes:</u>

The cross-border activation process of FRR and RR for optimization purposes and the imbalance netting process aim to optimize the activation of reserves (energy in [MWh]) without impacting the provision of reserves (capacity in [MW])[2].

- The Imbalance Netting Process aims to avoid the counteracting activation of FRR within different LFC Areas thereby reducing the activated control energy (in MWh). As the Imbalance Netting Process is already discussed in the chapter on the Load-Frequency Control Structure and is not considered in this chapter.

- The Cross-Border Activation Process of FRR and RR For Optimization Purposes is introduced in order to allow the TSOs to activate the most efficient reserve resources in the system, regardless of their geographical location and subject to available transmission capacity to accommodate the resulting fluxes. This process is also referred to as a Common Merit Order list for the activation of reserves. As this process deals with the activation of reserves [MWh] only, it is not related to the exchange or sharing of reserves which are related to reserve capacity [MW].

  Figure 31 gives an example of the cross-border activation of FRR for optimization purposes. Suppose that the FRR Dimensioning rules for Area A and Area B result in the need of 500 MW FRR for Area A and 600 MW for Area B. Area A and Area B therefore have to ensure the provision of 500 MW and 600 MW of FRR within their respective Areas. The TSOs of Area B now have to activate 100 MW of FRR in response to an imbalance of 100 MW within their Area. The cost for activating 100 MW of FRR within Area B is 90 €/MWh, whereas the cost of activating 100 MW of FRR in Area A would be only 60 €/MWh.

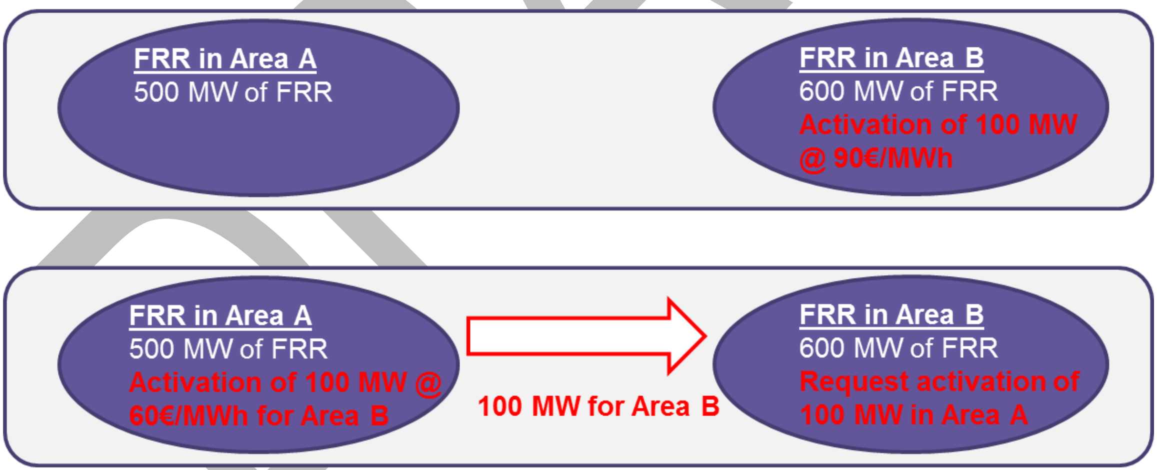


Figure 31: Cross-border activation of 100 MW of FRR for optimization purposes

[2] As the dimensioning of FRR and RR are based on historical imbalances of the LFC Block, the imbalance netting between different LFC Areas of the LFC Blocks is taken implicitly into account in the FRR and RR Dimensioning Process and therefore impacts the required amount of FRR and RR. The imbalance netting between different LFC Blocks however does not impact the required amount of reserves within the involved LFC Blocks.

The NC LFC&R sets technical limits for the Imbalance Netting Process and the Cross-Border Activation Process of FRR and RR for Optimization Purposes as to ensure Operational Security. It is however in the scope of the Network Code on Electricity Balancing to define the market arrangements to develop these processes within the technical limits set by the NC LFC&R.

Cross-border transmission capacity:

It is important to note that sufficient cross-border transmission capacity must be available to accommodate the cross-border flows resulting from the activation of reserves in case of a cross-border cooperation (exchange and sharing of reserves, imbalance netting, …). The NC LFC&R sets forth the technical requirements for cross-border transmission capacity (e.g. amount of capacity required, its availability etc.), whereas the Network Code on Electricity Balancing shall deal with the market aspects (e.g. reservation of capacity, …).

The next paragraphs give further details on the requirements and limits for the exchange and sharing of reserves and on the cross-border activation process of FRR and RR for optimization purposes.

5.6.2 Exchange of reserves

The Network Code LFC&R lays down provisions for the amount of FCR, FRR and RR required to ensure Operational Security and to respect the frequency quality targets.

In order to ensure the provision of this required amount of reserves, TSOs can also rely on reserve providers located within the Area of another TSO. This is called the exchange of reserves. The reason for this can be either

- technical, e.g. in case of insufficient reserves within the Area of a TSO ;
- economical, e.g. in case that the provision of reserves within the Area of another TSO is economically more efficient.

An even distribution of reserves, both within and between the Synchronous Areas, is critical for ensuring operational security and to enable TSOs to perform their tasks according to the requirements set forth in this Network Code. The even distribution of reserves ensures that reserves are more or less located near the location where imbalances originate and therefore

- makes the system more robust in case of network splitting;
- avoids issues of rotor angle stability (even distribution of FCR);
- ensures that the different Areas of a Synchronous Area and different Synchronous Areas can operate up to a certain extent more or less independent of each other;
- minimizes the risk in case that transmission capacity is unavailable, e.g. due to congestions.

The NC LFC&R sets forth technical limits for the redistribution of reserves within and between Synchronous Areas by the exchange of reserves in order to ensure operational security.

The roles and responsibilities of TSOs and Reserve Providers involved in the exchange of reserves, as well as the technical requirements for the exchange of reserves are covered in the NC LFC&R.

Exchange of FCR within a Synchronous Area:

The Initial FCR Distribution ensures the even distribution of FCR within the Synchronous Area. Furthermore the FCR chapter provides limits for the maximum amount of FCR located on a single unit or electrical node, thereby ensuring an even distribution of FCR within the area of the TSO.

The redistribution of FCR by the exchange of FCR Obligation has to be limited as to ensure that:

- the flows arising from the activation of exchanged FCR can be managed;
- that sufficient FCR is available in the different grid areas in case of network splitting;
- issues of rotor angle stability shall not occur upon activation of the FCR.

The different nature of the Synchronous Areas, in terms of geographical and electrical size, the organization of the Synchronous Area in Monitoring Areas, LFC Areas and LFC Blocks, network topology and the total amount of FCR, requires that limits for the re-distribution of FCR are set on different types of areas, constituting the Synchronous Area:

- For the Synchronous Area of Continental Europe: the limits are set on the level of LFC Areas and LFC Blocks; and
- For the Synchronous Areas of Nordics: limits for the internal distribution are fixed in a multi-party agreement

As the other Synchronous Areas only consist of a single TSO, there is no exchange of FCR Obligation within the Synchronous Area. The requirements and limits for the exchange of FCR Obligation between Synchronous Areas are explained further in this document.

The exchange of FCR Obligation is limited to adjacent LFC Blocks (SA CE) and subject to a multi-party agreement in the Nordics in order to ensure that the exchanged FCR remains locally available and to avoid the large scale shift of FCR from one side of the Synchronous Area to the other side which can cause issues of rotor angle stability or issues in case of network splitting.

The amount of FCR Obligation that the TSOs of an LFC Block (SA CE) can fulfil for neighbouring LFC Blocks is limited to 30% of the Initial FCR Obligation of the LFC Block. This avoids local concentration of FCR in a single LFC Block, which would be problematic in case of network splitting and might cause issues of rotor angle stability. As to enable small LFC Blocks to participate in the exchange of FCR, each LFC Block is allowed to fulfil at least 100 MW of FCR Obligation for its neighbouring LFC Blocks.

Each LFC Block (SA CE) must keep 30% of its Initial FCR Obligation located within its own Area as to ensure the availability of a minimum amount of FCR within the LFC Block in case of network splitting. This rule is only applicable for the SA CE due to its large size.

Figure 32 gives an example for the application of the limits for the exchange of FCR within the Synchronous Area. Simulations show that these limits for the exchange of FCR obligation ensure the even distribution of FCR throughout the Synchronous Area.

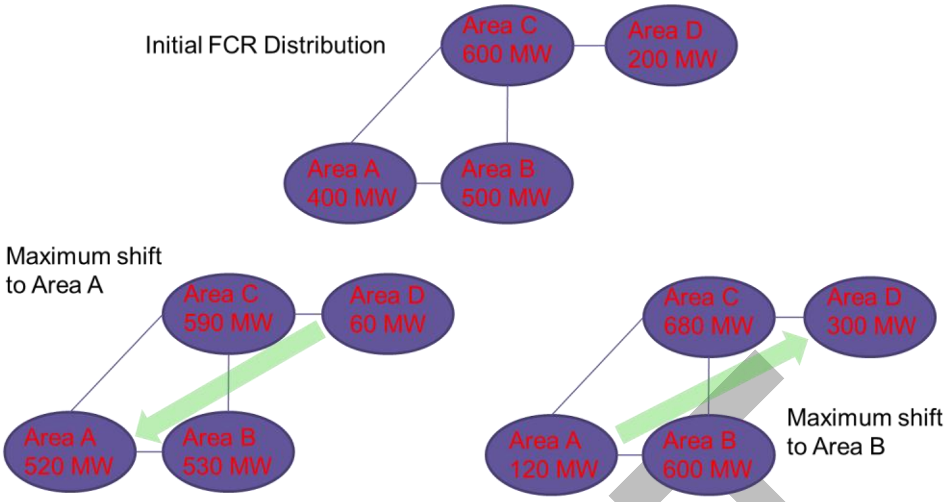


Figure 32: Exchange of FCR within the Synchronous Area (Continental Europe)

The Real-Time Reliability Margin accommodates the flows resulting from the activation of FCR throughout the Synchronous Area. FCR is activated simultaneously within the entire Synchronous Area and flows towards the physical location where the imbalance originated. The re-distribution of FCR therefore changes the flows resulting from its activation throughout the entire Synchronous Area and therefore impacts the Real-Time Reliability Margin. Depending on the new distribution of the FCR, the Real-Time Reliability Margin of some Areas can increase or decrease. The NC LFC&R sets requirements for the TSOs to adjust the RT RM, if required, in case of the exchange of FCR Obligation.

As Frequency Containment is the joint responsibility of all TSOs of the Synchronous Area, each TSO is responsible for its own FCR Obligation towards the Synchronous Area. The exchange of FCR has to be seen as the exchange of the part of the FCR Obligation from the Reserve Receiving TSO to the Reserve Connecting TSO. As such the Reserve Connecting TSO becomes technically responsible for the activation and the monitoring of the exchanged FCR. Therefore the exchange of FCR is always performed according to the technical TSO – TSO model.

The market arrangement can be either TSO – BSP or TSO – TSO as this depends on whether:

- the Reserve Receiving TSO has an arrangement with the Reserve Connecting TSO for the exchanged FCR Obligation and the Reserve Connecting TSO ensures the provision of the exchanged FCR Obligation; or
- the Reserve Receiving TSO has an arrangement with the Reserve Connecting TSO for the exchange of FCR Obligation but ensures the provision of the exchanged FCR Obligation within the area of the Reserve Connecting TSO by itself.

In both cases the Reserve Connecting TSO becomes however technically responsible for the exchanged FCR (technical TSO-TSO model). A TSO is therefore technically responsible for all the FCR Providing Units and FCR Providing Groups physically located within its area. Furthermore an FCR Providing Unit or FCR Providing Groups can only have a responsibility for the activation of FCR with the TSO responsible for the area where it is located.

<u>Exchange of FCR between Synchronous Areas:</u>

TSOs of a Synchronous Area may receive part of the FCR required for their Synchronous Area from another Synchronous Area. In such case the Reserve Connecting TSO(s) of the other Synchronous

Area are then responsible for the provision of this exchanged FCR Obligation, in addition to their own FCR Obligation within their Synchronous Area. An example of such an exchange is shown in Figure 33.

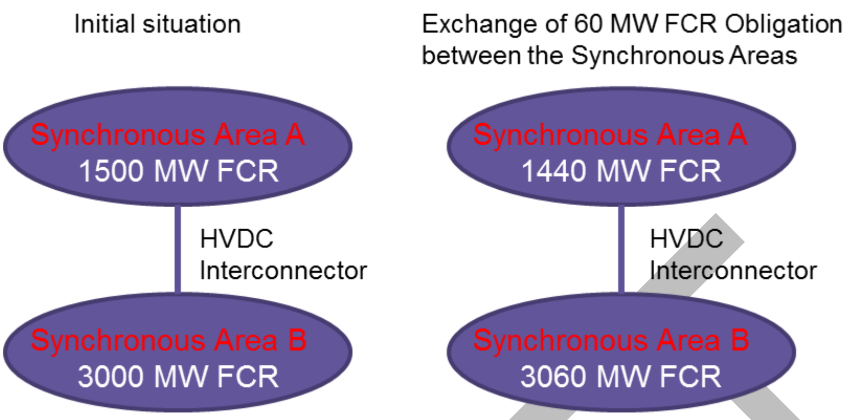


Figure 33: example of the exchange of 60 MW of FCR Obligation between Synchronous Areas A and B

FCR is activated by the FCR Providing Units or FCR Providing Groups based on the Frequency Deviation of the Synchronous Area. This introduces some complexity in the exchange of FCR Obligation between Synchronous Area as the exchanged FCR Obligation shall now only be activated in case of a Frequency Deviation in the Reserve Connecting Synchronous Area and not in case of a Frequency Deviation in the Reserve Receiving Synchronous Area.

The HVDC Operator therefore has to operate the HVDC Interconnector based on the Frequency Deviation of the Reserve Receiving Synchronous Area. In this way the HVDC Interconnector ensures that the HVDC Interconnector injects the amount of required FCR to the Reserve Receiving Synchronous Area by subtracting this power from the Reserve Connecting Synchronous Area.

As the HVDC Interconnector subtracts power from the Reserve Connecting Synchronous Area in case of a Frequency Deviation in the Reserve Receiving Synchronous Area, it introduces an imbalance in the Reserve Connecting Synchronous Area, which results in a Frequency Deviation in this Area. As a result FCR shall be activated by all the TSOs of the Reserve Connecting Synchronous Area as to contain the Frequency Deviation in their Area.

The exchange of FCR between Synchronous Areas impacts the frequency quality of the Reserve Connecting Synchronous Area in case of FCR activation required by the Reserve Receiving Synchronous Area. Therefore all the TSOs of the Synchronous Area shall agree in a multi-party agreement on a set of rules and minimum requirements for the exchange of FCR Obligation between Synchronous Areas.

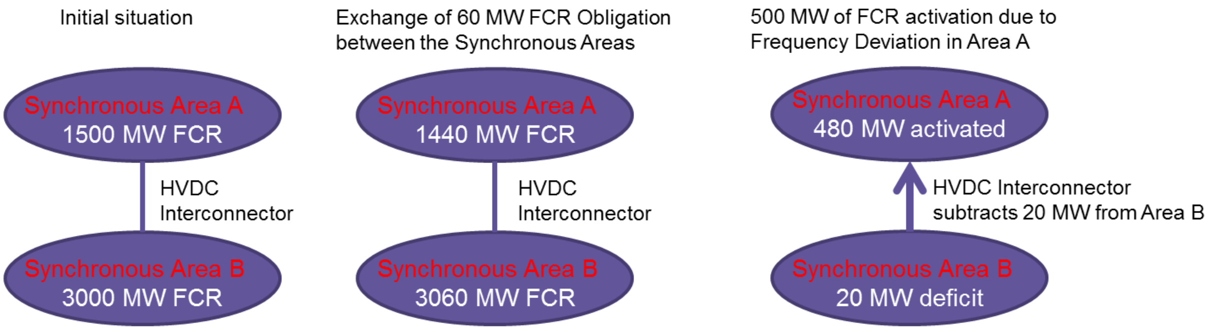


Figure 34: FCR activation in case of the exchange of FCR Obligation between Synchronous Areas

Figure 34 gives an example for the exchange of 60 MW of FCR Obligation between Synchronous Area A and B as indicated in Figure 33. Suppose that there occurs a sudden Frequency Deviation of -50 mHz in the Synchronous Area A requiring the activation of 500 MW of FCR (1/3 of the total FCR of Synchronous Area A) and no Frequency Deviation in Synchronous Area B. Due to the exchange of 60 MW of FCR Obligation, 480 MW of FCR shall be activated within Synchronous Area A, while the HVDC Interconnector shall inject the additional 20 MW to Synchronous Area A by subtracting it from Synchronous Area B. The introduced deficit of 20 MW in Synchronous Area B shall cause a Frequency Deviation which will then be contained by the activation of 20 MW of FCR within Synchronous Area B.

Furthermore such an exchange shall impact the Frequency Restoration Control Error of the LFC Block in the Reserve Connecting Synchronous Area to which the HVDC Interconnector is connected. The injection or subtraction of power by the HVDC Interconnector to deliver the required amount of FCR to the Reserve Receiving Synchronous Area is seen as an imbalance within this LFC Block. The FRP of the LFC Block shall then restore the Frequency Deviation of Synchronous Area B to zero.

The Reserve Receiving TSOs shall furthermore verify that the amount of exchanged FCR Obligation delivered per HVDC Bi-pole shall not exceed the maximum amount of FCR delivered by a single FCR Providing Unit or electrical node as agreed within the Synchronous Area.

Exchange of FRR and/or RR within a Synchronous Area:

The dimensioning of FRR and RR are performed at the level of the LFC Block and the TSOs of the LFC Block are responsible for the provision of this amount of FRR and RR and to perform the FRP and Replacement Process for their LFC Block.

An even distribution of FRR/RR in the Synchronous Area is crucial to ensure Operational Security as it ensures that:

- A sufficient amount of FRR/RR to be available to all TSOs in case of Network Splitting; and
- Allows the LFC Blocks of the Synchronous Area to operate more or less in an independent way (in case of communication or IT-issues,…); and
- Reduces the risk of having insufficient FRR/RR available in case of sudden issues of congestions in the network.

The initial dimensioning of FRR/RR on the level of the LFC Blocks ensures a more or less even distribution of FRR/RR within the Synchronous Area. The exchange of FRR/RR between LFC Blocks of a Synchronous Area allows a further optimization of the provision of the required FRR/RR for the LFC Blocks but has an impact on the distribution of FRR/RR within the Synchronous Area and must therefore be limited.

The exchange of FRR/RR within a Synchronous Area only applies to the Synchronous Area of Continental Europe as it is the only Synchronous Area consisting of more than one LFC Block. The dimensioning rules for FRR/RR ensure the even distribution of FRR/RR within the LFC Blocks.

In order to ensure the even distribution of FRR/RR within the Synchronous Area the TSOs of an LFC Block have to keep a minimum of 50% of the FRR/RR of the LFC Block physically located within their own LFC Block. This amount of FRR/RR would allow the TSOs of the LFC Blocks to operate their LFC Block independently from other LFC Blocks for more than 90% - 95% of the time, reducing the risks in case of communication issues etc., while still allowing a significant potential for the optimization of the provision of FRR/RR by exchanging with other LFC Blocks.

The TSOs of the LFC Areas of the LFC Block have the right to set limits to the amount of FRR/RR that can be located outside of their LFC Area for technical reasons such as e.g. internal congestions in the LFC Block.

As for the exchange of FCR, the exchange of FRR/RR is also subject to a notification procedure and approval by the Affected TSOs.

Both a technical TSO – TSO as a TSO – BSP model are allowed for the exchange of FRR/RR between LFC Blocks of the Synchronous Area. This means that either the Reserve Connecting or Reserve Receiving TSO can be responsible for the activation (imperfections) and monitoring of the exchanged FRR.

In case of a common merit order list for FRR and/or RR, the technical TSO – TSO model is considered to be superior to the technical TSO – BSP model. In anticipation of the implementation of such a single common merit order list and in order not to forbid currently implemented technical TSO – BSP arrangements throughout Europe, the technical TSO – BSP model is also allowed. Furthermore the TSO – BSP model facilitates the cross-border cooperation between TSOs with a different market design or reserve products.

The FRR/RR Providing Units or Groups can only have obligations for the activation of FRR/RR with one and only one TSO. This is required to allow the unambiguous monitoring of the performance of the FRR/RR Providers.

The exchange of FRR requires that transmission capacity is available to transport the energy resulting from activation of the exchanged FRR to the area of the Reserve Receiving TSO. The Reserve Connecting and Reserve Receiving TSO have to agree on who is responsible for securing and ensuring before real-time that sufficient transmission capacity is available for the exchange of FRR/RR.

Exchange of FRR and/or RR between Synchronous Areas:

The rules and limits for the exchange of FRR and/or RR between LFC Blocks of different Synchronous Areas are identical to the rules of exchange of FRR and/or RR between LFC Blocks of the same Synchronous Area.

The operators of the HVDC Interconnectors shall operate the HVDC Interconnector in such a way that the activated FRR and/or RR are transported from the Reserve Connecting TSO to the Reserve Receiving TSO.

5.6.3 Sharing of reserves

The dimensioning procedures for FCR/FRR/RR result in a certain amount of FCR/FRR/RR capacity to be provided by each TSO. However, as demonstrated in paragraph 5.6.1, in some cases it is very unlikely that a couple of TSOs would need to activate their full amount of either FCR/FRR/RR at the same time, which results in a potential to reduce the amount of FCR/FRR/RR to be provided by these TSOs and to make common use of part of the reserves. This is called the 'sharing' of reserves.

The sharing of reserves allows for a reduction of the total reserves within the system without performing a common dimensioning for these reserves. Sharing therefore introduces a risk in the system in case the involved TSOs would need to have access at the reserves made available for common use. Limits for the sharing of reserves are therefore required to ensure Operational Security.

In case of sharing of reserves it is always the Reserve Connecting TSO that has priority access to the reserves made available for common use. This is because the Reserve Connecting TSO ensured the provision of this amount of reserves. In case the Reserve Receiving TSO wouldn't have access to the reserves made available for common use, he shall have to take other measures in order to fulfil its responsibilities in terms of the FCP/FRP/RP towards the other TSOs of the Synchronous Areas.

The sharing of reserves is always according to a technical and economical TSO – TSO model as TSOs make available part of their own reserves to other TSOs.

This chapter focuses further on the roles and responsibilities of the TSOs involved in the sharing of FRR and lays down the technical requirements for the sharing of FRR.

Sharing of FCR within a Synchronous Area:

Frequency Containment is a joint responsibility of all TSOs of the Synchronous Area, meaning that, in case of an incident/imbalance in the Synchronous Area, FCR is activated simultaneously by all TSOs of the Synchronous Area in order to stabilize the frequency. As a result all FCR is shared -implicitly- amongst the TSOs of the Synchronous Area. Therefore no further sharing of FCR within the Synchronous Area can be considered, as this would lead to a total amount of FCR being less than the required amount of FCR for the Synchronous Area.

Sharing of FCR between Synchronous Areas:

The FCR Dimensioning Process is performed at the level of the Synchronous Area. The resulting amount of FCR ensures that the Frequency can be contained in case of the occurrence of the Reference Incident and ensures that the risk of having insufficient FCR available is limited to an agreed upon value.

The sharing of FCR between TSOs of different Synchronous Areas, and the resulting reduction of FCR within the total system, is not allowed since it would introduce a dependency between the Synchronous Areas in terms of Frequency Containment.

The sharing of FCR between Synchronous Areas is only allowed between the Synchronous Areas of Great Britain and Ireland due to the specific situation of a nearby small and relatively large Synchronous Area.

The sharing of FCR between different Synchronous Areas might however be further considered in the future, but will be linked most likely with a common FCR Dimensioning.

Sharing of FRR within a Synchronous Area:

The sharing of FRR within a Synchronous Area allows small LFC Blocks, needing a relatively high amount of FRR to cover their Dimensioning Incident compared to the FRR required to cover other imbalances, to reduce their FRR capacity by cooperation with other LFC Blocks. This enhances the economic efficiency as it reduces the amount of FRR in the LFC Blocks required for a rather unlikely event (Dimensioning Incident).

The limits for the sharing of FRR within a Synchronous Area set forth in the FRR Dimensioning Rules are conceived in a way that limits the risk that more than one TSO would need to access the reserves made available for common use at the same time as there is no common dimensioning performed. This is achieved in the following way:

- The TSOs of an LFC Block have to ensure at least the provision of 99% of their required FRR resulting from the FRR Dimensioning Process. This ensures that in 99% of the time the TSOs of the LFC Block have sufficient FRR available without having to access the FRR made available for common use; and
- Only TSOs of an LFC Block for which the FRR required to cover the Dimensioning Incident (positive and negative) exceeds the amount of FRR required to cover 99% of the historical (positive and negative) imbalances are allowed to reduce their FRR capacity. This means that, in case these TSOs would need to access the common reserves, it is most likely due to the occurrence of the Dimensioning Incident in their LFC Block. This event is considered to be uncorrelated with the imbalances of other LFC Blocks, thereby reducing the risk that more than one TSO needs to access the common reserves at the same time; and
- The maximum FRR reduction for an LFC Block is limited to 30% of its Dimensioning Incident. This limits the size of the risk in case the sharing wouldn't work out.

Figure 35 and Figure 36 give an example of the application of the sharing rules for two different LFC Blocks.

- In Figure 35 the LFC Block needs 1000 MW of FRR to cover the Dimensioning Incident while it would only need 800 MW of FRR to cover 99% of the other imbalances in the LFC Block. According to the limits for the sharing of FRR, this LFC Block can reduce its FRR capacity, resulting from the FRR Dimensioning Process with 200 MW by concluding sharing agreements with other LFC Blocks.
- In Figure 36 the LFC Block cannot reduce its FRR by concluding sharing agreements with other TSOs. This is due to the fact that the TSOs of this LFC Block need an amount of FRR, exceeding the Dimensioning Incident, to cover random imbalances in their LFC Block. As it is not clear whether these imbalances are correlated with the imbalances in other LFC Blocks, a reduction of FRR by sharing is excluded. However, in case of a common FRR Dimensioning with another LFC Area or LFC Block of the Synchronous Area, such an LFC Block can further optimize the total amount of FRR required.

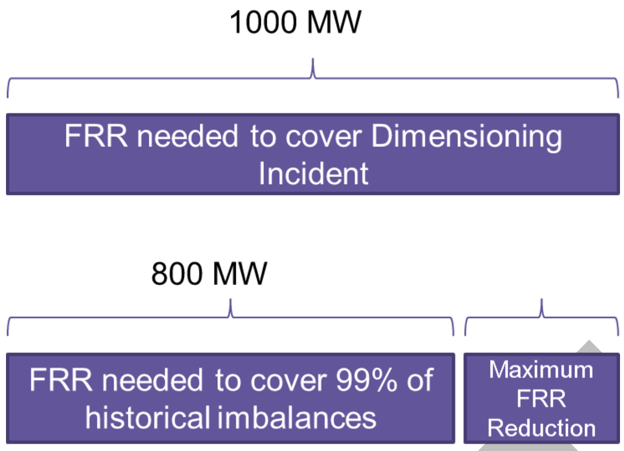


Figure 35: Calculation of maximum FRR reduction by the sharing of FRR within a Synchronous Area

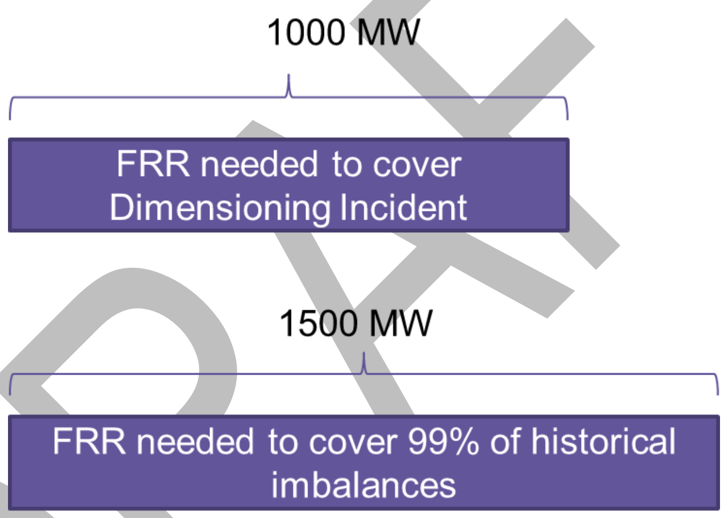


Figure 36: Calculation of maximum FRR reduction by the sharing of FRR within a Synchronous Area

The Reserve Receiving TSO shall only activate the ‘shared’ FRR in other LFC Blocks in case sufficient transmission capacity is available.

In case two LFC Areas of a Synchronous Area would like to further optimize their total amount of FRR they can perform a common FRR Dimensioning by forming a LFC Block. The common dimensioning of FRR ensures that there is no risk to have insufficient FRR, which cannot be guaranteed in case of simple sharing of FRR without common dimensioning.

Sharing of FRR between Synchronous Areas:

The limits and requirements set for the sharing of FRR between LFC Blocks of different Synchronous Areas are identical to the limits and requirements for the sharing of FRR between LFC Blocks within a Synchronous Area.

Sharing of RR within a Synchronous Area:

The limits for the sharing of RR are less strict that those for the sharing of FRR as the longer activation delay of RR compared to FRR gives more reaction time to the TSOs to elaborate alternative solutions in case the sharing wouldn't work out.

The TSOs of different LFC Blocks of the same Synchronous Area are allowed to share part of their RR in case they are able to verify that the risk of needing simultaneous access to the common RR is very unlikely.

Sharing of RR between Synchronous Areas:

The limits and requirements set for the sharing of FRR between LFC Blocks of different Synchronous Areas are identical to the limits and requirements for the sharing of FRR between LFC Blocks within a Synchronous Area.

5.6.4 Cross-border activation of reserves for optimization purposes

In addition to the provision of reserves, TSOs are allowed to cooperate in order to optimize the efficiency of the activation of FRR and RR (cost for activated energy [€/MWh]). This chapter lays down the technical limits and requirements for this process in order to ensure operational security and to enable the TSOs to perform their tasks according to the requirements within this Network Code. The market arrangements shall be further elaborated by the Network Code on Electricity Balancing (principles for the development of a common merit order list for the activation of FRR/RR).

5.7 Time Control Process

At the Synchronous Area level, the electrical system operation is based on active power control in aim to maintaining continuously the equilibrium between consume and generation. In this process, the global parameter controlled is the system frequency meaning the number of times that the repeated event (voltage wave cycle) occurs per unit time [1 second]. Whatever is the adopted control process structure, for the repeated phenomena (frequency or time of voltage wave cycle), the performance for long term period is the deviation from the time etalon. In this sense, the final evaluation and control refers at the same values: time as integration of period of voltage wave and time etalon as Universal Time Control (UTC). The integration of frequency / voltage time period is considered the electrical time or the synchronous time (the electrical time of the Synchronous Area)

If the nominal frequency is 50Hz, the voltage time period represents 1 / 50 = 0.02s = 20ms.

A long term integration of nominal frequency is absolute interval of astronomical time, while that same time integration of real voltage time period (frequency) has a different value. This difference serves in the majorities of Synchronous Area as a performance indicator for the real time operating of the structure of control and maintaining the system power equilibrium. The TSO members of same Synchronous Area endeavour to maintain this difference between agreed limits.

5.7.1 Causes of electrical time deviation

During the normal operation, the average system frequency usually deviates from its nominal value. These deviations can be the consequences of different events which occur in system operation and typically controlled by cascaded integral processes (FCR, FRR). Even in normal operation, the total process of active power has an integral character which requires be controlled and adjusted for long time period. Causes of frequency deviations are: tripping of units /consumers , electricity market rules using step schedules and larger time frame schedules (usually hourly frame), load behaviour (load is a continuous process and generation has a step scheduling), real time load – frequency control based on different units ramp rates.

That is why the instantaneous system frequency has to be modified appropriately, to bring the average system frequency and thus the electrical time, back to its nominal value.

5.7.2 Necessity of time control

The electrical time control is both a final frequency control process as long-term frequency stability and a service given by the TSO (Synchronous Area) to users which have internal process based on electrical time.

In this last category are devices which dependent on electrical time:

- meters of electrical energy which calculate different tariff periods in a precise time measurement based on frequency as the input value have,
- power plants control energy;
- power quality devices;
- old industries process;
- customers in textile industries and
- synchronous motors.

However, this service is often called into question. Cost and advantage are still reappraised.

5.7.3 Practice of electrical time control

Till 1926, after the invention of the electric clock driven by a synchronous motor, in largest Synchronous Areas is starting the implementation of system frequency control for long time period, keeping electrical time accuracy. The network operators control the daily average frequency and endeavour that electrical clocks deviations stay within a few seconds. In practice, for long time correction of system frequency average errors from nominal, the operators raise or lower the nominal frequency by a specific percentage to maintain synchronization of electrical time to UTC.

Taking in consideration the Synchronous Area size and the value of nominal frequency, there are different values regarding the electric time control:

- The accuracy of frequency adjustment:
    - ±0.02% for system with 50Hz as nominal frequency = 0,01Hz (Continental Europe)

  - ±0.033% for system with 60Hz as nominal frequency = 0,02Hz (NERC)

- Correction duration:
  - 1 day - Continental Europe
  - 1/4h – GB, NERC
- Allowed range:
  - [-30s;+30s] - Continental Europe, NE
  - [-10s;+10s] – GB, East NA
  - [-2s;+2s] - West NA
  - [-3s;+3s] - West NA
- Range of started correction actions:
  - [-20s;+20s] - Continental Europe
  - [-15s;+15s] – NE

In the synchronous area of Continental Europe, the deviation between electrical time and UTC (based on International Atomic Time) is calculated at 08:00 each day in a control centre in Switzerland (Laufenburg).

The target frequency (in the FRR process) is then adjusted by up to ±0.01 Hz (±0.02%) from 50 Hz as needed, to ensure a long-term frequency average of exactly 50 Hz × 60 sec × 60 min × 24 hours = 4,320,000 voltage cycles per day.

The time error corrected by a frequency offset of 0.01Hz during 1 day is:

0.01 Hz / 50 Hz *24*60*60s = 17.28 seconds

That put in evidence the adopted range of 20 seconds as range of start the corrective actions inside the Continental Europe. The value of 0.01 Hz adopted for frequency correction is coherent with the insensitivity of governors.

In North America, whenever the electrical time error exceeds 10 seconds for the east, 3 seconds for Texas, or 2 seconds for the west, a correction of ±0.02 Hz (0.033%) is applied. Time error corrections start and end either on the hour or on the half hour. The correction is provided also in the FRR process.

The time error corrected by a frequency offset of 0.02Hz during 1/2 hour is:

0.02 Hz / 60 Hz *30*60s = 0.6 seconds

5.7.4 Current approach in Continental Europe

The active power control in the interconnected networks is progressively controlled in four steps, the FCR control, the FRR control, the RR control and the electrical time control. The objective of the last one is to monitor and to limit discrepancies observed between the synchronous time and the Universal Coordinated Time (UTC) within the synchronous area of the Continental Europe.

The hierarchy of frequency control structure, including electrical time control is present in following figure:

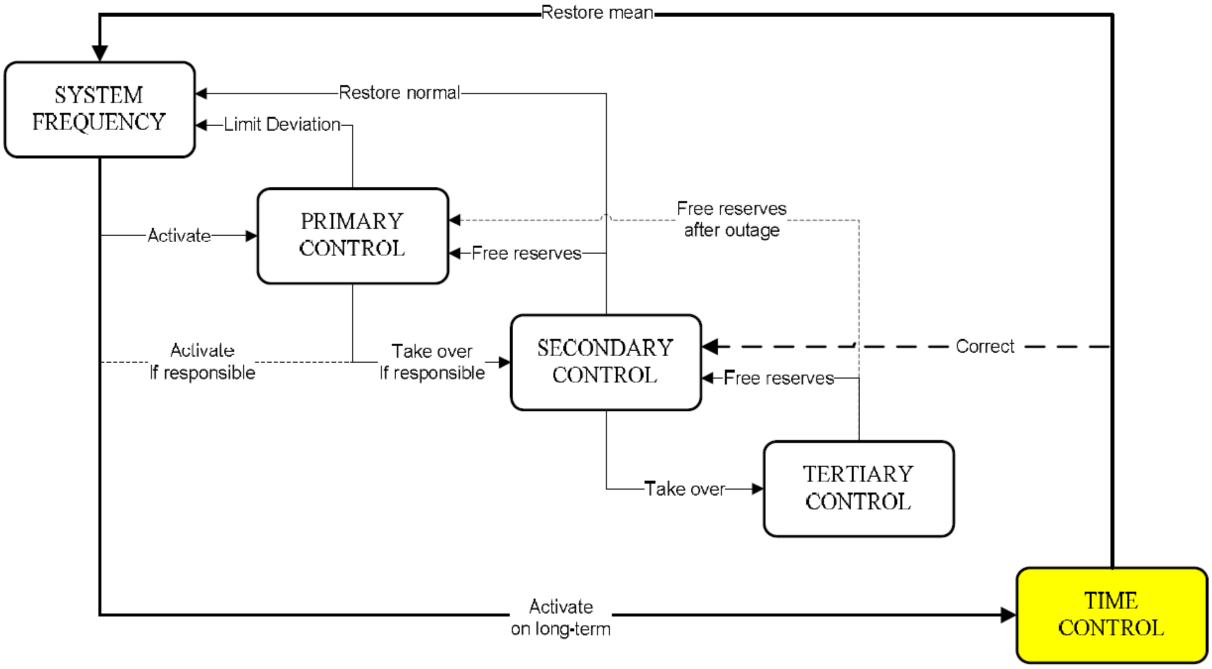


Figure 37: Control Processes from the UCTE Operation Handbook

The Operational Handbook defines three levels of electrical time deviation from UTC (Discrepancy):

Tolerated Range of Discrepancy: a range of ±20 seconds within is no need for time control actions.

Target Range of Discrepancy: a range of ±30 seconds under normal conditions in case of trouble-free operation of the interconnected network.

Exceptional Range of Discrepancy defined under exceptional conditions in case of trouble-free operation of the interconnected network the discrepancy between electrical time and UTC is within a range of ±60 seconds.

The electrical time control in Continental Europe consists on the adjustment the set-point frequency for FRR controller. The time monitor must ensure that the mean value of the system frequency is close to the nominal frequency value of 50 Hz and the electrical time deviation within the target range.

The time deviation between synchronous time and UCT is calculated for 8 a.m. each day by the time monitor – a central instance that monitors continuously the deviation. If the time deviation is within tolerated range, the frequency offset for time correction has to be set to zero. If the deviation is out of tolerated range and electrical time is behind UTC, the frequency offset has to be set to +10 mHz. If the deviation is out of tolerated range and electrical time is ahead of UTC, the frequency offset has to be set to –10 mHz. This offset is determined by the time monitor.

The frequency offset will be sum of the nominal frequency 50 Hz in all FRR controllers of the Synchronous Area (Continental Europe) and the time correction is valid for all hours of the next day, starting at 0 a.m.

The information for the time correction has to be forwarded towards all LFC areas / Blocks of the Synchronous Area every day at 10 a.m. by the time monitor. The LFC areas / Blocks themselves forward this information towards their underlying LFC areas without delay.

The quality of system frequency can be evaluated as deviation of electrical time from UTC during a time interval. In Continental Europe the Operational Handbook specifies that the frequency control is satisfactory over a one month period where the number of days' operation at a set point frequency of 49.99 Hz or 50.01 Hz does not exceed eight days per month respectively (to be confirmed by experience).

5.7.5 Current approach in Grid Codes of NE, GB, Ireland

The Nordic Grid Code specifies that the time deviation is used as a tool for ensuring that the average value of the frequency is 50.00 Hz.

The time deviation shall be held within the time range of - 30 to + 30 seconds. At ΔT = 15 seconds, Statnett and Svenska Kraftnat shall contact each other in order to plan further action.

The frequency target has a higher priority than the time deviation and the costs of frequency regulation. The time deviation shall be corrected during quiet periods with high frequency response and with a moderate frequency deviation.

The GB Grid Code specifies that the TSO will endeavour (in so far as it is able) to control electric clock time to within plus or minus 10 seconds by specifying changes to Target Frequency, by accepting bids and offers in the Balancing Mechanism. Errors greater than plus or minus 10 seconds may be temporarily accepted at NGET's reasonable discretion. For SA GB there is no statutory requirement to monitor and control clock error. The SONI Grid Code (Northern Ireland) specifies that the TSO will endeavour (in so far as it is able) to control the electric time to UTC within plus or minus 10 seconds by specifying changes to target System Frequency. Errors greater than plus or minus 10 seconds may be temporarily accepted at the TSO's reasonable discretion. The TSO will give 15 minutes' notice to each Generator of variation in target System Frequency.

5.8 Co-operation with DSO

The basic concept for the co-operation with DSO is the "Reserve Connecting DSO", which is defined as "the DSO responsible for the grid to which a Reserve Providing Unit or Reserve Providing Group is connected to providing reserves to a TSO".

The Reserve Connecting DSO has the right to check, if the provision of reserves is admissible from the point of view of system security in the DSO grid. For this purpose the Reserve Provider has to ask the Reserve Connecting DSO for permission before offering reserves to the TSO. The Reserve Connecting DSO has the right to object or to limit the reserve provision if necessary from a system security point of view. The idea is that the DSO gives a general permission for the reserve provision. Thus the DSO shall check different operational scenarios for the permission. Since this general permission can obviously not be given for an unlimited period of time the DSO has the right to reassess the permission on an annual basis. This is an important opportunity to take into account grid developments.

The TSO is by purpose not involved in the relationship between the DSO and the Reserve Provider. The idea is that the Reserve Provider receives a kind of permission document from the Reserve

Connecting DSO and sends it to the TSO as a prerequisite to provide Reserves. It is the full DSO responsibility to give the permission for the reserve provision. In case a DSO objects or limits the reserve provision the NRAs may be involved for the sake of dispute resolution between the Reserve Provider and the Reserve Connecting DSO.

For the activation of reserves there will be no interference between the TSO and the Reserve Connecting DSO; the reserves are activated directly by the TSO. For this reason it is very important for the Reserve Connecting DSO to perform the security checks mentioned above carefully before the permission of reserve provision. Additionally the Reserve Connecting DSO has the right to request information from the Reserve Provider needed to perform a proper system operation planning and system operation of the DSO grid.

In critical situations the Reserve Connection DSO may – as any System Operator – apply remedial actions and eventually stop reserve provision if needed. Such cases will be taken into account in the reserve provision contracts and are not part of the NC.

6 ADDED VALUE OF THE LFC&R NC

While deciding on the objectives and major topics to be included in the LFC&R NC, a constant screening process with the objectives defined by the FG SO [1] has been carried out. The analytic approach taken for drafting the LFC&R NC resulted in the current code structure. Reaching this point and by recognising that the added values of the code are inherently linked to its Objectives of the LFC&R NC, the following benefits are to be expected by implementing the operational principles defined in the LFC&R NC:

- Apply EU wide harmonised control processes as a basis for load-frequency control: the control processes “frequency containment reserve”, “frequency restoration reserve” and “replacement reserve” set a basis for an efficient and effective load-frequency control in the EU.;
- Deliver harmonised definition for a common control structure inside a synchronous area: the set up of a proper control structure sets a basis for an efficient and effective load-frequency control in each synchronous area. This control structure design sets clear rules for TSO responsibilities offering valuable incentives to co-operate on LFC Block or synchronous area level. The control structure chosen by each synchronous area depends on the number of TSO involved and the complexity of the system in terms of congestion management;
- Provide a harmonised approach for a common frequency quality target inside a synchronous area: this includes frequency target values as well as frequency evaluation criteria;
- Provide a harmonised approach for a frequency restoration quality target for each LFC Block: this includes the amount of reserves needed per LFC Block. The individual quality target values for the frequency restoration are defined per LFC Block and derived from the common frequency quality target of the synchronous area;
- Provide a framework to determine the amount of reserve needed: the NC delivers the basis to determine the amount of reserves needed per control process “frequency containment reserve”, “frequency restoration reserve” and “replacement reserve” in order to deliver the required quality;
- Provide an EU wide harmonised framework for border crossing exchange to enhance efficiency and as a basis to the market: The efficiency of the load-frequency control is enhanced by border-crossing exchange of reserves. This exchange relates to the control processes “frequency containment reserve”, “frequency restoration reserve” and “replacement reserve” as well as to imbalance netting. The border-crossing exchange is treated inside a
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synchronous area as well as cross synchronous areas. The NC sets restrictions to the border-crossing exchange where needed from a technical point of view;

- Provides a basis for the new processes required from the BAL NC such as "Imbalance Netting" and "Common Merit Order".

7 RESPONSES AND NEXT STEPS

7.1 OVERVIEW

This chapter provides information on how to respond to the consultation on the OPS NC and provides an overview of the processes which ENTSO-E intends to follow in developing a final version of the OPS NC for submission to ACER.

7.2 SUBMISSION OF RESPONSES

Responses to the public consultation on the LFC&R NC are requested by 31 March 2013. All responses should be submitted electronically via the ENTSO-E consultation tool, explained at https://www.entsoe.eu/resources/consultations/ .

We appreciate that many stakeholders and involved parties may wish to discuss issues raised in this document. For this reason ENTSO-E has scheduled a workshop for 12th March 2013 at the ENTSO-E premises. We will structure the workshop in a way which enables parties with an opportunity to provide their views. Should you wish to attend, please contact Pilar.Munoz-Elena@entsoe.eu.

Stakeholders are explicitly ask to submit their opinion on the necessity of the further continuation of the time control process in the different Synchronous Areas.

7.3 RESPONDING TO COMMENTS

ENTSO-E will endeavour to respond to comments raised by stakeholders, indicating how a comment has been taken into account or indicating the reasons for not doing so, via the consultation tool. This document seeks to answer some of the questions which we have been repeatedly asked during the process of developing the code up to date.

7.4 NEXT STEPS

As a consequence of the 12 month timescale, this is the only formal consultation by ENTSO-E on the LFC&R NC. We should urge parties to provide comments and views. Following the closure of the consultation ENTSO-E will begin the process of considering comments and reflecting them in text. It will be the responsibility of the LFC&R NC drafting team, which contributed to the development of this code to process comments, provide feedback and make changes as necessary. An updated code will be subject to internal approval and will be sent to ACER ahead deadline. As indicated above, parties will see answers to their individual comments via the consultation tool as soon as we are able to provide them.

As mentioned in section 2.3. of this document, in the public workshop for the LFC&R NC at the mid of May 2013, as the result of public consultation, the major comments received and the therefore amendments made in the Code will be presented.

8 LITERATURE & LINKS

[1] "Framework Guidelines on System Operation" (FG SO), ACER, 2 December 2011. (http://acernet.acer.europa.eu/)

[2] "Initial Impact Assessment", ACER, June 2011.

[3] ENTSO-E Ad-hoc Team Operational Reserves Report (https://www.entsoe.eu/fileadmin/user_upload/_library/resources/LCFR/2012-06-14_SOC-AhT-OR_Report_final_V9-3.pdf)

[4] ENTSO-E RG CE Operation Handbook Policy 1 Annex 1 (https://www.entsoe.eu/publications/system-operations-reports/operation-handbook/)