Small Flexibility-based Frequency Containment Reserves – Opportunities Analysis and Modeling

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I declare that this document is an original work of my own authorship and that it fulfils all the requirements of the Code of Conduct and Good Practices of the *Universidade de Lisboa*.

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Abstract

Due to an increase of renewables in the electricity mix in Europe in the last years and plans to shut down coal-fired power plants in the future, balancing services being provided by small aggregators is getting increasingly important. The aim of this thesis is to qualitatively analyze and compare different market accesses in Europe for small flexibility based FCR providers. For the analysis, five different countries were chosen, based either on their geographical location, participation in the common FCR market or market potential: Switzerland, Belgium, Germany, Portugal and Spain. For the market access analysis for FCR services of the different countries, the prequalification process of each of these countries was explained and later compared. Out of the five countries compared, the one that appears to have less entry barriers and shows greater possibilities of working in a case-to-case basis is Switzerland, followed by Belgium and then by Germany. In addition to the qualitative analysis, a case study was developed, presenting the pilot project between the German start-up KOENA tec and it partners. In this project, industrial coffee machines are aggregated to provide FCR services to the grid, thanks to KOENA tec's smart plug that can control the power output of the coffee machine. Their goal is to provide 50kW of marketable power in the Swiss grid by aggregating coffee machines. In this sense a simulation of the prequalification test was performed to determine the number of coffee machines that should be used to pass this test. This was done through data analysis of the power profile of a coffee machine. The results show that a minimum of 278 coffee machines need to be aggregated to be able to provide 50kW of balancing services to the grid by using the specified coffee machines.

Keywords

Balancing Market, Aggregator, Frequency Containment Reserve, Small flexibility-based FCR, FCR Cooperation

Resumo

Devido ao aumento de energias renováveis na matrix elétrica na Europa nos últimos anos e aos planos de fechar usinas a carvão no futuro, a inserção de pequenos produtores de energia e/ou resposta da demanda no mercado de balanço se torna cada vez mais crucial. Com isso, o objetivo desta tese é analisar qualitativamente e comparar diferentes acessos de mercado na Europa para pequenos provedores de serviços de balanço primário. Para a análise, foram escolhidos cinco países diferentes, com base em diversos fatores: Suíça, Bélgica, Alemanha, Portugal e Espanha. Para a análise de acesso ao mercado de serviços de FCR dos diferentes países, o processo de pré-qualificação de cada um desses países foi explicado e posteriormente comparado. Dos cinco países comparados, o que parece ter menos barreiras de entrada e mostra maiores possibilidades de analisar cada caso individualmente é a Suíça, seguida pela Bélgica e depois por Alemanha. Além da análise qualitativa, foi desenvolvido um estudo de caso, apresentando o projeto piloto entre a start-up alemã KOENA tec e seus parceiros. Neste projeto, máquinas de café industriais são agregadas para fornecer serviços de balanço primário à rede. O objetio do projeto é fornecer 50kW de energia na rede suíça. Nesse sentido, foi realizada uma simulação do teste de pré-qualificação suíço para determinar o número de máquinas de café que devem ser utilizadas para passar no processo de pré-qualificação. Isso foi feito através da análise de dados do perfil de energia de uma máquina de café. Os resultados mostram que um mínimo de 278 máquinas de café precisam ser agregadas para poder fornecer 50kW de serviços de balanceamento à rede usando as máquinas de café especificadas. Este trabalho mostra que, embora já exista um mercado comum de balanço primário em vigor na Europa, o processo de pré-qualificação para os países participantes pode variar muito. Também mostra como os países da mesma região estão em diferentes estágios de desenvolvimento de um mercado de equilíbrio aberto. Além disso, o estudo de caso confirma a viabilidade técnica do uso de máquinas de café para prestar serviços de balanceamento à rede.

Palavras-chave

Mercado de Balanço de Energia, Pequenos fornecedores de balanço primário, FCR Cooperation, Balanço Primário

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List of Acronyms

aFRR	Automatic Frequency Restoration Reserves

BRO	Balancing Resource Owner
BRP	Balance Responsible Party
BSP	Balancing Service Provider
CE	Continental Europe
CIPU	Coordination of the Injection of Power Units Contract
DSO	Distribution System Operator
E2E	End-to-End
EB GL	Guideline on Electricity Balancing
EIC	Energy Identification Code
ENTSO-E	European Network of Transmission System Operators for Electricity
EU	European Union
FCR	Frequency Containment Reserve
GB	Great Britain
GCT	Gate Closure Time
ICT	Information and Communications Technology
IE/NI	Ireland & Northern Ireland
IoT	Internet of Things
IT	Information & Technology
LFC	Load-Frequency Control
MFR	Mandatory Frequency Response
mFRR	Manual Frequency Restoration Reserves
NE	Northern Europe
PIA	Private Internet Access
PID	Proportional Integral Derivative
RR	Replacement Reserves
RTU	Remote Terminal Unit
SGU	Significant Grid User
SO GL	Guideline on Electricity System Operation
TSO	Transmission System Operator
TU	Technical Unit
VPN	Virtual Private Network

List of Software

R Studio	Environment for R language
Microsoft Office	Standard programs for calculations, graphics and basic programming

Chapter 1

Introduction

This chapter gives a brief overview of the work. First an introduction to the context of the work is made, followed by a brief explanation of KOENA tec's role and their pilot Coffee2Grid project in collaboration with other stakeholders. After that the methodology used for the thesis development is presented. At the end of the chapter, the work structure and motivation are provided.

1.1 Overview

With an increase of renewables in the electricity mix in Europe the last years and a trend for them to gain even more importance [1], comes higher uncertainties in the grid, as renewables sources such as wind and solar are intermittent. In this context, balancing services in the power system are increasingly becoming more challenging. Traditionally, large hydro and fossil-fuel based power plants are the ones responsible for providing ancillary services. However, as many European Union countries have announced their intention to phase out coal-fired power plants by 2030 [2], which in countries like Germany accounts for about 20% of the total installed power capacity, small balancing providers such as prosumers, demand response and small storage units will become more necessary and important.

Aggregators have a vital role in this context, as the balancing markets have a minimum marketable service that can be provided, and therefore aggregating small units lowers their entry barriers in the markets. Aggregators are still a new concept within the balancing market context, and its function is to combine multiple consumer loads or/and small generators' electricity for sale, purchase or auction in the electricity market. Independent aggregators can participate in the balancing market in different configurations, and it is up to each Member State of the EU to choose the most appropriate model and procedure to administer independent aggregators [3]. Given the increasing importance of aggregators, it was stated in the Clean Energy for All Europeans Package that Member States should allow and encourage the participation of demand response through aggregation.

However, entities responsible for organizing the European balancing markets in their area of operation, the Transmission System Operators (TSOs) [4], do not have harmonized rules for the balancing market throughout the whole European Union yet, as decisions about it are set out to be determined by each TSO in their area. With this in mind this master thesis aims to research and analyze the market access for small aggregators in the balancing market in selected countries in the European Union, comparing their policies and prequalification process, as well as researching what are the unified rules for these countries. The objective is to identify opportunities and barriers for small aggregators in providing Frequency Containment Reserve (FCR) services to the grid.

This research is done in collaboration with KOENA tec, a German start-up that provides data analysis and energy efficiency tools for consumers through its smart plug, focused on the gastronomy sector. It is currently developing a pilot project with Gruppo Cimbali, a traditional espresso machines manufacturer, BKW AG, a power generation and distribution utility company, and Vassalli AG, the only distributor of Cimbali machines in Switzerland, to offer FCR services to the grid through industrial espresso machines in Switzerland. The pilot project goal is to successfully provide data-driven energy efficiency advice for operators of espresso machines, as well as to prove it is economically feasible to aggregate these espresso machines as small flexible power assets in order to provide ancillary services to the grid through BKW's virtual power plant, a type of small power plants aggregation.

1.2 Motivation

As small flexibility for FCR services is still a novelty, there are not many up-to-date studies related to market access in the European balancing markets for this type of provider. With that in mind, this thesis was developed aiming at analysing the different balancing markets in the European Union and their access requirements for providers with limited installed capacity. This analysis will incentive small flexibility providers to enter in these markets and to know which one would be a better option for them, based on the opportunities and barriers imposed in each country.

In the case study developed in this master thesis a quantitative analysis of the prequalification test required to provide FCR services in Switzerland is made. The main objective of the quantitative analysis is to determine the minimum number of coffee machines that need to be aggregated in order to pass in the prequalification process to provide 50 kW of flexible power to the swiss grid.

1.3 Methodology

The thesis is composed of four main parts, each one following a different methodology approach. When providing an overview of balancing market structures and their different model organizations, the use-case methodology was chosen. A methodology comprised of describing a system's objectives, its actors, how they related to each other and the system's boundaries, giving a comprehensive knowledge about a structure.

For the unified rules for market access in the European balancing market, since the development of a unified market access in the European Union is still a novelty, not many research papers could be used for this research. Instead, a focus on regulations published by the European Union was given, and extensive reading and analysis of these publications were performed, and this chapter was divided according to the main aspects related to the balancing market access.

A similar methodology was preferred when researching the market access for selected countries: since prequalification of small flexibility FCR providers are still under development in many countries and constantly being updated, there were no applicable research papers with on this subject. Thus, for the market access analysis of selected countries, first a research on the balancing service provision of each country was made, in order to determine if the balancing market exists in that country or if it is a mandatory service by generators connected in the transmission system. In case a balancing market exists in the country, the prequalification process of each country was studied, by visiting the official website of the TSO (or TSOs) present in the country and looking for the most updated documentation published by them that could be relevant. These publications from the TSOs regarding their requirements on market access regulations were then researched and thoroughly analysed, dividing their requirements in different categories and subcategories to facilitate the comparison between the different market access for each country. For the division of the categories, the prequalification process of Germany was used as the standard.

The case study can be divided in two parts: the description of the pilot project between KOENA tec, Gruppo Cimbali, BKW AG and Vassalli AG, in which the use-case methodology was used, and the quantitative analysis of the prequalification test, in which the data analysis methodology was picked, given 61 days of accessible data from the heating cycle of a coffee machine was provided by KOENA tec.

1.4 Document Organization

This master thesis consists of six chapters in total. In this first chapter, an introduction to the subject, the motivation for the thesis development and the methodology used were presented. After that, in chapter 2, an overview of the balancing markets structure is given, explaining its products, main actors and the structure. Chapter 3 lays out the common market access regulations for providing FCR services in the European Union and their efforts to implement a common balancing market for FCR services. In chapter 4, the prequalification processes for small units of FCR providers in selected European countries are described, in order to compare the market access in these countries. Chapter 5 is the case study, presenting and analysing the pilot project developed between the start-up KOENA tec and its partners and doing a quantitative analysis of the prequalification test to provide FCR services in Switzerland. Finally, in chapter 6 an overview of the main results of the thesis and its conclusions are made, and future work opportunities are presented.

Chapter 2

Balancing Markets

This chapter provides an overview of the balancing markets structure through the use-case methodology. First the definition and goal of the balancing market is laid out, explaining their different products. After that, the actors and their role in the balancing market is explained, and finally the system and the different model configurations is described.

2.1 Definition and goal

In a power system, production and consumption of electricity always need to be equal. The system frequency must be as close to its nominal value as possible, otherwise, generators will have to apply more force to bring the frequency back to its nominal value (50Hz in Europe). This can cause the generators to stop working to prevent any damages, starting a cascade effect which can lead to an even higher frequency deviation and thus, an unstable system. If not corrected, this instability can cause a collapse in the system and consequently a blackout. In this context, in order to maintain the nominal frequency of the system it is established a market to exchange capacity and energy to balance the system, the balancing market. In the EU, there are currently four electricity market categories: forward markets, day-ahead markets, intraday markets and balancing markets. Balancing markets are the institutional, commercial and operational arrangements that establish market-based management of balancing [5]. In this market, the Transmission System Operator (TSO) of an area can settle any deviation in the system after the closure of the intraday electricity market. In some countries, such as the United Kingdom, part of the balancing services are not in the market. Larger power plants are obliged to provide balancing services to the grid, what is called Mandatory Frequency Response (MFR) [6].

There are currently two types of services provided in the balancing market: the balancing capacity and the balancing energy. The exchange of balancing capacity happens from one year up to one day before real-time (when electricity is supposed to be delivered). The time occurrence of balancing market for capacity depends on the regulation of each country. In that, generators or demand-side are contracted in advance to be available to deliver balancing services in real-time. Balancing capacity is defined as a volume of capacity the Balancing Service Provider (BSP) has agreed to hold to and to submit bids for a corresponding volume of balancing energy to the TSO while the contract is valid [5]. The second product is the balancing energy, in which the TSOs activate the contracts made in the balancing market for capacity and the participating generators or demand-side that have these contracts specify their prices to increase or decrease their energy injection in real-time.

Different products can be acquired in the balancing markets. Their main differences are in the time of activation and the duration of activation. The four reserve products defined by the Guideline on Electricity Transmission System Operation (SO GL) are Frequency Containment Reserves (FCR), Automatic Frequency Restoration Reserves (aFRR), Manual Frequency Restoration Reserves (mFRR) and Replacement Reserves (RR) [4]. They can also be dimensioned at Load-Frequency Control area (LFC Area) level or at synchronous area level. Synchronous area is defined as an area in which TSOs with the same system frequency are interconnected. In Europe there are, for example, Continental Europe (CE), Great Britain (GB) and Northern Europe (NE). LFC Area is a part of a synchronous area or can be a whole synchronous area and is operated by one or more TSO responsible for the load-frequency control of that area. FCR process is operated at synchronous area level, while FRR and RR processes are operated at LFC area level. The reserve activation structure of each product can be better seen in

Figure 1.

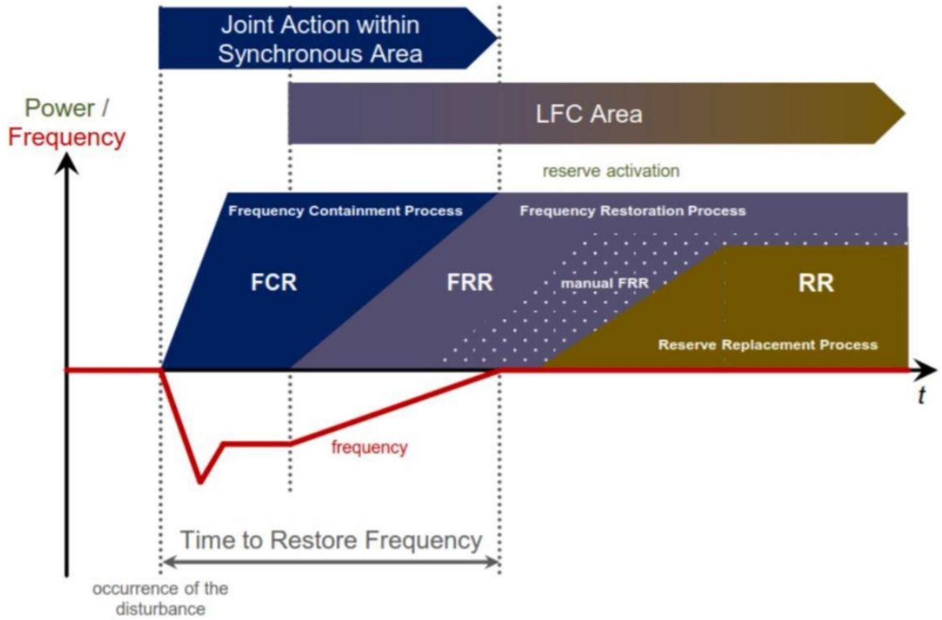

Figure 1: Activation structure of balancing services in relation to time and frequency deviation (extracted from [7]).

Frequency Containment Reserves (FCR) refers to the operating reserves necessary for constant containment of frequency deviations in the synchronously interconnected system. The EU SO GL defines it as "*the active power reserves available to contain system frequency after the occurrence of an imbalance*" [4]. It is the first reserve activated when there is a frequency deviation, with activation time up to 30 seconds, and being activated automatically and locally. The settlement of balancing energy for this type of reserve is optional in the Guideline on Electricity Balancing (EB GL) due to the small volumes of capacity and activated energy, and generally the activation of FCR is not remunerated, only the availability of capacity is paid. Instead, the capacity for FCR is either remunerated or in some markets required for some generators [5].

Frequency Restoration Reserves (FRR) refers to the active power reserves available to restore system frequency to its nominal value. It has an activation time between 30 seconds up to 15 minutes in the European Union Balancing Market, depending on the specifications of the synchronous area. FRR can be divided in two types: automatic Frequency Restoration Reserve (aFRR) and manual Frequency Restoration Reserve (mFRR). aFRR is activated automatically by a control device, replacing FCR if the deviation lasts longer than 30 seconds. mFRR, as the name suggests, is activated manually and it is used to relieve the aFRR when an imbalance continues for a long period. For the activation of balancing energy for FRR the volume necessary is calculated and settled by the TSO, and the imbalance settlement price might be positive or negative, depending whether the grid need electricity injection or storage. If a BSP injects electricity into the grid when there is a surplus of electricity in it, for example, it might be penalized.

The last balancing service activated is the Replacement Reserve (RR). It comprises the active power reserves used to restore the required level of frequency containment reserve or frequency restoration reserve, to assure their availability in case there is another system imbalance. Its activation time varies from 15 minutes up to hours, depending on the LFC area. This service is not present in all areas of the EU. Similar to the settlement of FRR, it is the TSO's obligation to calculate and settle the activated volume of balancing energy for restoration reserve, and the payment can be made to or from the TSO from or to the balancing service provider, depending on the balancing energy service participation and balancing energy price direction.

Within these different balancing products, different service types can be performed: symmetrical, asymmetrical up and asymmetrical down. In the symmetrical service type, the service provider needs to act whenever there is a frequency deviation in the range of, for example, 49.8Hz≤f≤50.2Hz if it claims to provide symmetric 200mHz service type, meaning that both upward and downward services are procured simultaneously. For the asymmetric service types, the services for upward and downward balancing are procured separately, and the service provider can provide one of these types. Upward offer is activated when there is a power shortage in the grid, and downward offer is activated when there is an energy surplus in the system [11].

2.2 Actors and roles

2.2.1 Transmission System Operator (TSO)

The Transmission System Operator (TSO) has different roles in the system in the European Union. It is the entity responsible for operating and ensuring the system security of a given area and, where suitable, of its interconnections with other systems, with a high level of reliability and quality. It is also responsible for providing and operating high and extra-high voltage networks for long-distance transmission of electricity, guaranteeing the electricity supply in its system area in the long term by the developing the transmission system [8]. Apart from that, TSOs are also responsible for developing tools and solutions for the prevention and correction of disturbances in the system, and also developing and operating network operation tools for its control area related to real-time operation and operational planning [4].

TSOs are also responsible for maintaining the frequency stability and, as part of this task, they are accountable for the organization of European balancing markets. In order to do that, they need to develop a qualification process for those interested in providing balancing energy or balancing capacity to the grid in their synchronous areas, as well as determining the reserve capacity required and the dimensioning rules. In the balancing markets, they are responsible for activating or procuring balancing services to the balancing service providers (BSP) and the balance responsible parties (BRP).

The EB GL states that transmission system operators should also aim for their integration for a more efficient system balance [5]. In that sense, the European Network of Transmission System Operators for Electricity (ENTSO-E) was established by the EU's Third Legislative Package for the Internal Energy

Market in 2009 [9]. ENTSO-E aims at setting up an internal energy market in Europe and maintaining its functioning, while supporting Europe's energy and climate agenda. This association currently represents 42 TSOs from 35 countries around Europe in policy positions, as well as promoting technical cooperation between the TSOs and coordinating R&D plans and innovation activities. It also publishes codes and guidelines for managing electricity networks in Europe and coordinates their implementation. This includes standards and standard structures for how balancing markets should be operated and organized.

2.2.2 Balance Responsible Party (BRP)

Balance Responsible Parties (BRP) in the electricity market are the actors financially responsible for the imbalances to be settled with the connecting TSOs. They have their individual supply and demand and they are obliged to keep they balanced in real time [5]. A BRP can be a market participant, such as a producer or a supplier, or a representative chosen by it to be responsible for its imbalances in the electricity market. The EB GL determines that each balancing energy bid from a BSP needs to be assigned to one or more BRP for the calculation of the imbalance adjustment [5].

In more technical terms, BRPs are accountable for keeping their position (sum of their injections, withdrawals and trades) balanced over a period of time. Their position can be either negative or positive imbalances, also defined as short and long energy positions in real time, respectively. If the BRP has a short position, it means that the difference between the value contracted and the metered position resulted in a deficit of electricity flowing in the system. If the BRP has a long position, however, this difference resulted in a surplus of electricity flowing in the system. An imbalance charge can be placed to the BRP depending on its imbalance and the state of the system, where the BRP can either have to pay or receive a payment. This imbalance charge is a crucial element of the balancing market and it is called imbalance settlement.

Also, in the EB GL it is determined that TSOs have to develop the terms and conditions for BRPs. In these terms and conditions, the requirements for becoming a BRP need to be defined, as well as the definition of balance responsibility for each connection. Other conditions are delimited, such as requirements on data and information to be given to the TSOs, the rules for the settlement of the BRPs, and the rules for the BRPs to change their schedules before and after the intraday energy gate closure time [5].

2.2.3 Balancing Service Provider (BSP)

A Balancing Service Provider (BSP) is a market participant providing balancing services to its Connecting TSO (TSO that operates the scheduling area where BSPs and Balance Responsible Parties have obligations related to balancing) in the TSO-TSO model or to its Contracting TSO in case of the TSO-BSP Model (when a TSO has a contract for balancing services with a BSP in another scheduling area). They can provide either or both balancing capacity and balancing energy by lowering or increasing their energy injection to the grid. Possible actors that can become BSPs are owners of power generating facilities (either from conventional or renewable energy sources), third parties, demand facility owners, and also energy storage units' owners.

In order to provide bids in the balancing market, a BSP needs to pass a prequalification process coordinated by the TSO in its scheduling area. The BSP shall comply with the minimum technical requirements set out in the EU SO GL, as well as the availability and connection requirements [4]. After being accepted as BSP, they need to submit their service proposals before the procurement gate closure time. Once their proposal is qualified in the market for balancing capacity, they have to submit their services for volumes and time period that they have been chosen for. To submit a bid for balancing energy, a BSP does not need to have been contracted for balancing capacity.

2.2.4 Third-Party Aggregator

The aggregator is still a new concept and a challenge to define in the balancing market framework. With the development of legislation in Europe allowing decentralized, small electricity production and the development of demand response, there was an increase of potential balancing service providers. However, since their balancing capacity is limited, these small producers faced several market barriers. In this context, the role of the third-party aggregator was formed, and its function is to combine multiple consumer loads or/and small generators' electricity for sale, purchase or auction in the electricity market [3]. The aggregator, then, enables resource owners that would be too small to participate on their own to nonetheless participate in the electricity market. In Figure 2 it can be seen a diagram to better understand the role of the aggregator not only for flexibility markets but also for grid operation.

Figure 2: The role of the aggregator between the balancing resource owner and the market [10].

Unlike traditional BSPs, third-party aggregators do not necessarily own their assets, which means they are not always affiliated with the customer's supplier. They are intermediaries between Balancing Resource Owners (BROs) and the market, being able to sell their services to a BSP or directly entering the market. Independent aggregators can participate in the balancing market in different configurations, and it is stated by the European Parliament and the Council of the EU that each Member State can choose the most appropriate model and procedure to administer independent aggregators, as long as the principles set out in the Directive 944/2019 is are respected [3].

The Directive mentioned above was introduced as part of the Clean Energy for All Europeans Package, and it states, among other things, that Member States should allow and encourage the participation of demand response through aggregation. Besides that, it obliges aggregators to be financially responsible for the imbalances they cause in the electricity system, which means they are either also Balance Responsible Parties or that they delegate their balancing responsibility.

2.3 The balancing market system

The balancing market system consists of three main phases: balance service provision, balance planning and balance settlement. It also consists traditionally of three main actors, already mentioned in the previous subsection: Balance Responsible Party (BRP), Balancing Service Provider (BSP) and the Transmission System Operator (TSO). During the balancing service provision, BSPs can submit balancing capacity bids in the balancing capacity market to the TSO, and the TSO does the procurement of balancing capacity to the BSPs in merit order, which is based on the lowest marginal costs of power plants (cost of producing one more MWh in their current state). Balancing energy offers can be submitted by BSPs in upward and/or downward direction.

The balance planning phase happens one day before delivery of the balancing service. In this phase the BRPs submit energy schedules to the TSO, presenting their planned energy consumption and generation for the next day. In this same phase, the BSPs submit their balancing energy bids in the balancing energy market to the TSO.

Finally, the balance settlement phase occurs after the time of delivery of balancing services. In this phase, the energy imbalances of the BRPs and the activated balancing energy are settled. BSPs who provided upward balancing receive the upward price, while BSPs that provided downward balancing pay to the TSO the profits they gain from generating less energy, which makes them avoid variable generating costs or consume the energy they had not previously paid for [11]. Regarding the BRP, whether it has to pay or receive a price depends on two variables: the state of the system and the position of the BRP. In Figure 3 is presented a structure of the balancing market for better understanding can be seen.

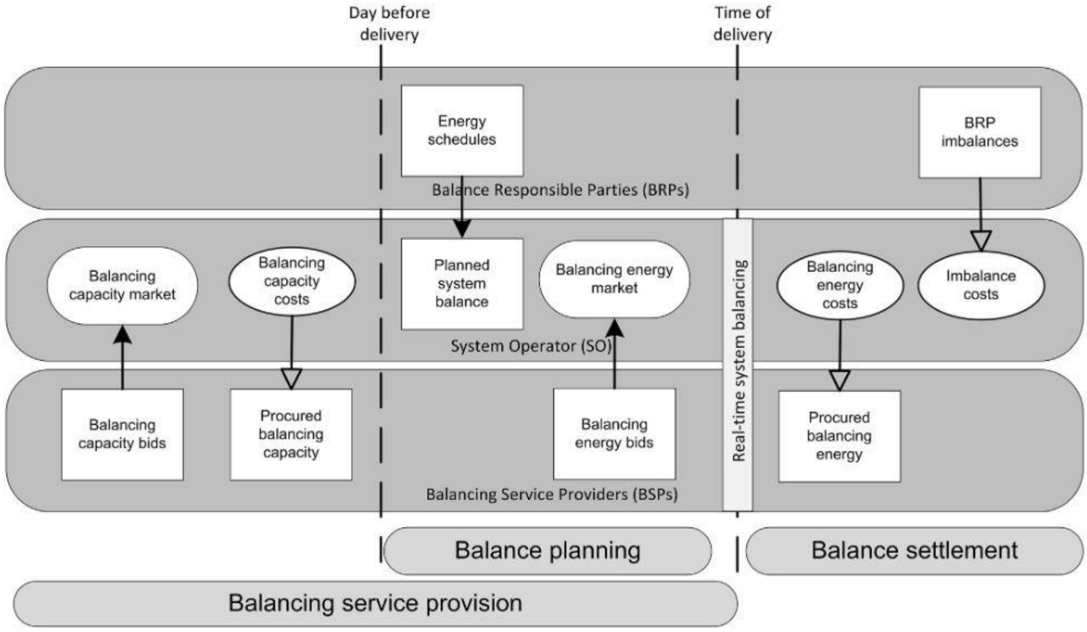

Figure 3: Structure schematic of the balancing market, where time is in the horizontal axis and actors in the vertical axis [12].

With the aggregator enabling the participation of small producers and demand response in the balancing market, new balancing market models are possible. There are currently four models in discussion by specialized entities and TSOs in Europe, and this is discussed in length by the Nordic TSOs [13]. A review and summary of this discussion is done in the following:

The first model is the integrated model. In it, an existing BRP/electricity supplier takes the part of the aggregator, providing aggregation services to the customers. It is also possible that they have a contract with an aggregator, and they act like one firm. Therefore, with this configuration one player is responsible for the aggregation, financial responsibility and balancing services to the TSOs. As an advantage, this model can be implemented more easily, but also limit the number of players in the balancing market, as the BRP role is required for all BSPs. Figure 4 shows a schematic of this model.

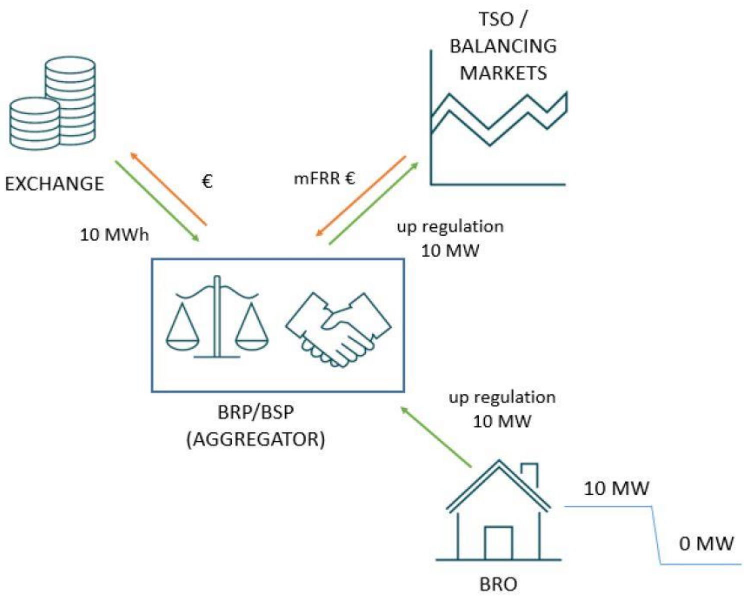

Figure 4: Integrated model scheme [13].

The second model is the dual supply model. In this model, the aggregator is responsible for frequency stabilization and does not necessarily provide electricity supply to the customer. It allows the Balance Resource Owner (BRO) to have two electricity suppliers: one for the appliances used for flexibility and another for the rest. This can be done by adding a sub-metering to the appliances used for providing balancing services. This model is particularly beneficial for aggregators to offer their services as they can supply electricity and trade the flexibility as one actor and even for customers that are not currently having their electricity demand being supplied by BKW. As an advantage, it allows the aggregator to manage an entire portfolio of flexibility through one BRP/Supplier, but it is a more costly model since it requires a new metering system and may discourage customers, as it adds complexity like having two electricity bills. This model schematic can be better understood in Figure 5.

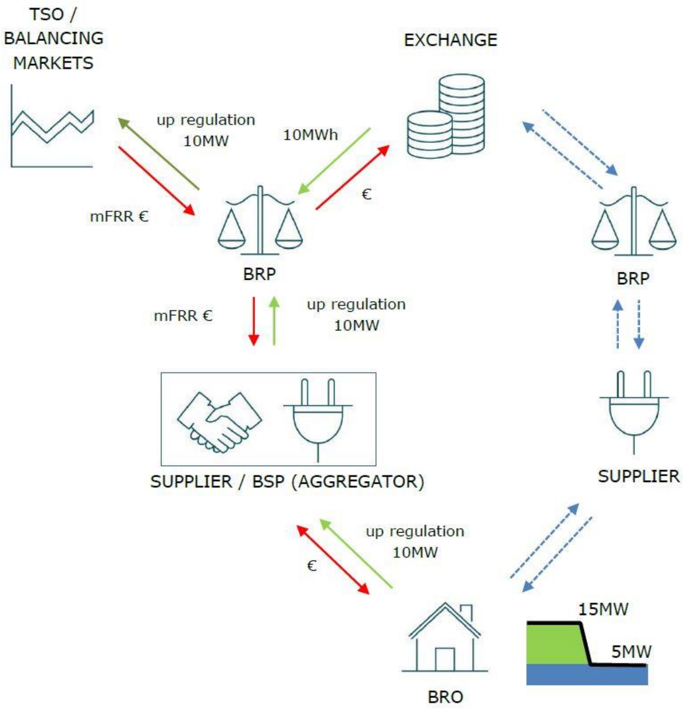

Figure 5: Dual Supply Model scheme [13].

The third model is called the uncorrected model with third-party aggregator access and multi-BRP aggregation. In this model, the BRP's balance is not corrected when reserve is activated. It is only used for frequency reserves with short and few activations, resulting in a low amount of energy activation [13]. Compensation for balancing services is done from TSO to BSP, while there is a bilateral contract between BRO and BSP. This model lowers the entry barriers for third party aggregators to participate in the balancing market and it is an easy model to implement, but there is the risk of not being profitable for BRPs. In Figure 6 the scheme for this model can be seen.

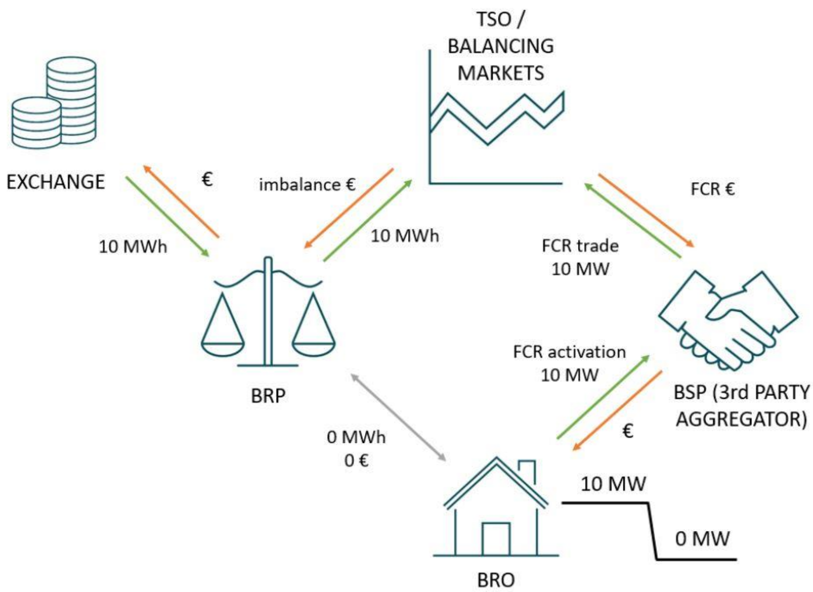

Figure 6: Uncorrected model with third-party aggregator access and multi-BRP aggregation [13].

The fourth and last model is the reimbursement model with third-party aggregator access and multi-BRP aggregation. In this model, BRPs are reimbursed by the TSO for the activated energy, while there is also a compensation for balancing service from TSO to BSP. This model promotes impartial conditions for all actors while allowing third-party aggregation and thus, more flexibility to the balancing market. As a downside, it is a more complex model, needing larger changes to IT systems [13]. Figure 7 shows the flow scheme of this model.

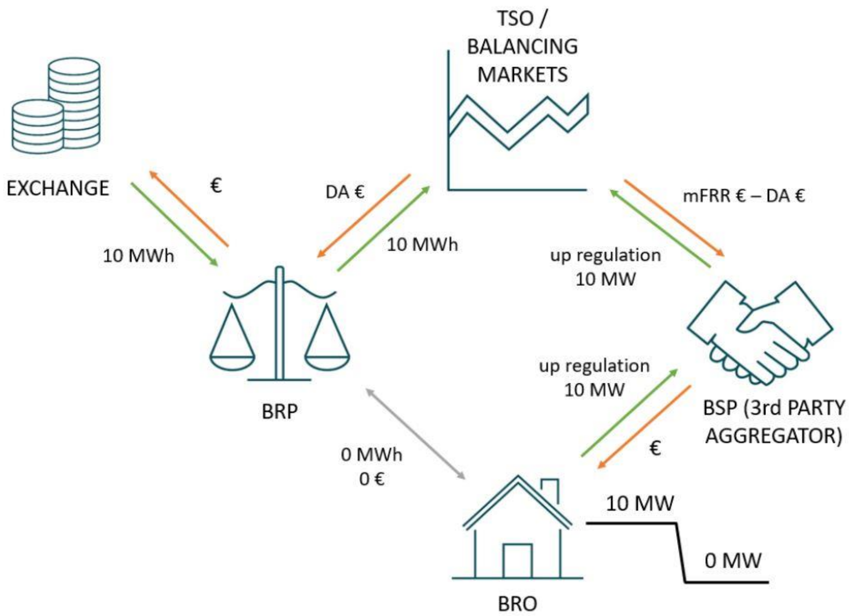

Figure 7: Reimbursement model with third-party aggregator access and multi-BRP aggregation [13].

Chapter 3

Unified Market Access Regulation for FCR service provider in the EU

When analyzing and comparing the different market accesses for small units in FCR services across different countries in Europe, it is important to first investigate the possible common rules set out for the whole European Union. The purpose of this chapter is to understand and layout what the unified rules regarding market access for FCR service providers in the European Union are, as well as define what is left for each TSO of an LFC area to decide when it comes to the minimum requirements for market access. The current regulation on common market access for FCR service providers will be presented, following the outcome of this regulation, with the implementation of a common balancing market for FCR services in the European Union.

3.1 Unified rules for market access in the European Union

The main regulation that established common guidelines for market access procedures in the European Union is the System Operation Guideline (SO GL), released in 2017. It sets harmonized rules on system operation for TSOs, Distribution System Operators (DSOs) and significant grid users (SGUs) in order to ensure system security, enhance efficient use of the network and increase competition in the system [4]. It sets out harmonized requirements for the provision of load-frequency control (LFC) and reserves for the efficient operation of the internal electricity market, providing the technical structure for the development of cross-border balancing markets.

In the following subsubsections, common rules for the dimensioning, technical minimum requirements, prequalification process and the provision of FCR services in the European Union are introduced, as well as the requirements that are left for the TSOs to define. Often these requirements are different depending on the synchronous area, an area covered by interconnected TSOs with the same system frequency in the steady-state [14]. In the EU there are currently five different synchronous areas: Continental Europe (CE), Ireland & Northern Ireland (IE/NI), Great Britain (GB), the Nordic countries (Nordic) and the Baltic countries (Baltic).

3.1.1 Dimensioning

Article 153 of the SO GL determines that, at least annually, all TSOs of a synchronous area need to establish the reserve capacity for FCR required and the initial FCR obligation of each TSO in that synchronous area. The dimensioning rules of the synchronous area specify that the reserve capacity for FCR required need to cover at least the reference incident and the results of the probabilistic dimensioning approach for FCR, that considers the load, generation and inertia pattern of the synchronous area. As for the incident reference, the guideline also determines a value of 3000 MW in positive direction and 3000 MW in negative direction for Continental Europe, while in Great Britain, Ireland, Northern Ireland and Nordic synchronous areas it is the largest imbalance occurred from an instantaneous change of active power.

The initial FCR obligation of each TSO in a synchronous area is based on the sum of the net generation and consumption of its control area divided by the total sum of net generation and consumption of the synchronous area in one year.

3.1.2 Technical Minimum Requirements

The technical minimum requirements for FCR service providers are set out in the SO GL. Despite laying out minimum properties for FCR, it declares that TSOs of a synchronous area can specify additional requirements for FCR if needed to ensure operational security. The reserve connecting TSO can also set additional requirements for its FCR providing groups. The properties required for FCR in each synchronous area can be seen in Table 1 below. A providing unit is defined as is a single or multiple aggregated power generation plants and/or consumption units with a common grid connection point, while a providing group is aggregated power generation plants and/or consumption units and/or reserve units with different network connection points [4].

FCR properties in the different synchronous areas		
Minimum accuracy of frequency measurement	CE, GB, IE/NI and Nordic	10 mHz or the industrial standard if better
Maximum combined effect of inherent frequency response insensitivity and possible intentional frequency response dead band of the governor of the FCR providing units or FCR providing groups.	CE	10 mHz
	GB	15 mHz
	IE/NI	15 mHz
	Nordic	10 mHz
FCR full activation time	CE	30s
	GB	10s
	IE/NI	15s
	Nordic	30s if system frequency is outside standard frequency range
FCR full activation frequency deviation	CE	±200 mHz
	GB	±500 mHz
	IE/NI	Dynamic FCR ±500 mHz
		Static FCR ±1000 mHz
	Nordic	±500 mHz

Table 1: FCR properties in the different synchronous areas [4].

The correct operation of FCR of an LFC area shall be ensured by each TSO in continental Europe. They need to guarantee that the FCR activation is not artificially delayed and begins as soon as there is a frequency deviation. If the frequency deviation is equal to or larger than 200 mHz, at least 50% of full FCR capacity should be delivered at the latest after 15 seconds, and full FCR capacity should be delivered at the latest after 30 seconds of the frequency deviation. This activation has to rise at least linearly between seconds 15 and 30. In case the frequency deviation is smaller than 200 mHz, the FCR capacity activation should be at least proportional to the same time behavior mentioned for frequency deviations equal or higher than 200 mHz [4].

The FCR provider shall deliver to its connecting TSO relevant information regarding its FCR providing units and FCR providing groups, such as time-stamped status (*on* or *off*) and time-stamped active power data. This data can be aggregated by the FCR provider for more than one FCR providing unit if the maximum power of the units is lower than 1.5 MW and if a clear verification of activation of FCR is viable. The connecting TSO can request this information to be available in real-time, with a time resolution of at least 10 seconds.

3.1.3 Prequalification process

The FCR prequalification process is set and defined by each TSO in its connecting area. In this process, the FCR provider should prove it satisfies the technical and additional requirements set out in the system operation guideline. Despite this process being developed by the TSOs, the guideline determines the deadline periods for this process. The FCR provider submits its application to the reserve connecting TSO, alongside the required information of potential FCR providing units or FCR providing groups, and the connecting TSO has 8 weeks to confirm if the application is complete. If the application is considered incomplete, the potential FCR provider has 4 weeks from the date of the request of additional information to submit them. If the potential FCR provider does not submit this additional information before the deadline, the application will be considered withdrawn. After the confirmation of complete application, the reserve connecting TSO has 3 months to evaluate the information provided and rule whether the potential FCR provider and its products and services comply with the criteria set for the FCR prequalification.

It is determined by the SO GL that the qualification of FCR providing units or groups is re-evaluated at least every 5 years or given a modification of the technical or availability requirements of the equipment or its modernization.

3.1.4 Provision

It is the TSO obligation to guarantee the availability of its FCR obligations agreed among the other TSOs of the same synchronous area, and the FCR provider needs to secure the continuous availability of FCR, except in the event of a forced outage of an FCR providing unit. The FCR provider should inform its connecting TSO about any changes in the availability of its FCR providing unit or FCR providing group if they are relevant for the results of prequalification.

Many FCR providing units and/or groups loss can threat the system’s security. In order to avoid that, the SO GL determines a limitation of the share of the FCR provided per FCR providing units to 5% of the reserve capacity of FCR required for each synchronous area, for the Continental Europe and Nordic areas. In Great Britain, Ireland and Northern Ireland and the Nordic synchronous areas, the FCR provided by the unit defining the reference incident in the dimensioning process is excluded. In all synchronous areas, the unavailable FCR can also be replaced as soon as technically possible.

Regarding the duration availability, an FCR providing unit or group with no capability limit shall activate its FCR for as long as the frequency deviation remains for all synchronous areas, except for Great Britain and Ireland and Northern Ireland, where FCR needs to be activated until the activation of FRR. If an FCR providing unit or group has a limited energy reservoir, the FCR shall be activated for as long as the frequency deviation persists or until its energy reservoir is drained.

For activation period, the SO GL establishes that TSOs are responsible for setting a minimum activation time for FCR for those with limited energy reservoir. This period, however, should be between 30 and 15 minutes, inclusive. That means an FCR providing unit or group should continuously provide FCR for at least 15 to 30 minutes. The determination of this value by the TSO should be made considering after conducting a methodology for cost-benefit analysis. If an FCR provider has some FCR providing units or FCR providing groups with energy reservoir limitations, this should be specified in the prequalification process.

Concerning the recovery of energy reservoir of FCR providing units or groups that have limitations, the guideline determines the FCR provider shall ensure the energy reservoir recovery as soon as possible, and sets the maximum time for it to be 2 hours after the end of the alert state (period in which there is significant frequency deviation) in Continental Europe and Nordic synchronous areas. For Great Britain and Ireland and Northern Ireland synchronous areas, the methodology stated in the synchronous area operational agreement should be used by the FCR provider.

3.2 FCR Cooperation

The Guideline on Electricity Balancing (EB GL) established that, if two or more TSOs in the European Union would like to (or already do) exchange balancing capacity, development of a proposal with harmonized rules and processes for the exchange and procurement of balancing capacity need to be made by them [5]. The TSOs from Austria, Belgium, Netherlands, France, Germany and Switzerland had created the FCR Cooperation for the development of a common FCR market in 2016 and, in that sense, released the draft of Proposal for the establishment of common and harmonized rules and processes for the exchange and procurement of FCR [15]. The FCR Cooperation is a common market which plans to integrate the FCR balancing market in the European Union in order to increase competitiveness, efficiency and security of supply, while creating incentives for new BSPs and different technologies to provide FCR services. Currently, West Denmark and Slovenia are expected to join and start procuring FCR services in the common market in the first quarter of 2021 [16].

3.2.1 Product definition

In the draft proposal, the baseline for the product in the FCR market is established. First, regarding the bid size, the minimum bid size is set for 1 MW, divisible with the bid resolution of 1MW, and indivisible bids' maximum size is 25MW, enabling the participation of smaller BSPs. It is also established that the product needs to be symmetric, meaning that the procurement of upward and downward FCR is done together. Concerning the auction frequency, it is designed to occur on a daily basis, ideally having its closure time as close as possible to the delivery day, targeting it to be at 8:00 CET in D-1 (one day before delivery). This was planned to happen in three stages: first, it was implemented with the gate closure time (GCT) at 15:00 CET in D-2 during working days only, then GCT at 15:00 CET in D-2 all days, including holidays and weekends, and the final milestone was achieved recently in June 2020, with the daily auctions with GCT at 08:00 CET in D-1 and publication of the winning bidders thirty minutes after the GCT [16]. Having the GCT as close as possible to the delivery of the service allows alternative flexibility resources that are harder to forecast, such as renewable energy sources and demand-side response, to bid in the market with higher reliability. Moreover, it is also proposed that the product duration is 4 hours and symmetrical, instead of the initial one week (from Monday 0h until Sunday 24h) symmetrical, increasing the flexibility and allowing the integration of renewable energy and decentralized sources.

3.2.2 Technical principle

Each country in the FCR Cooperation has a limit on imports and exports of FCR services. There are a minimum and maximum amount of volume of FCR that needs to be procured from the BSPs within the LFC area in which the TSO is located. In the procurement process, each TSO needs to procure FCR services separately. After gate closure time, the Central Clearing System of the FCR Cooperation gathers all the bids of all the participating countries and calculates the optimal combination of bids to be awarded, considering the constraints related to minimum and maximum local shares of each LFC area. The results of the awarded bids are published one hour after the gate closure time [17].

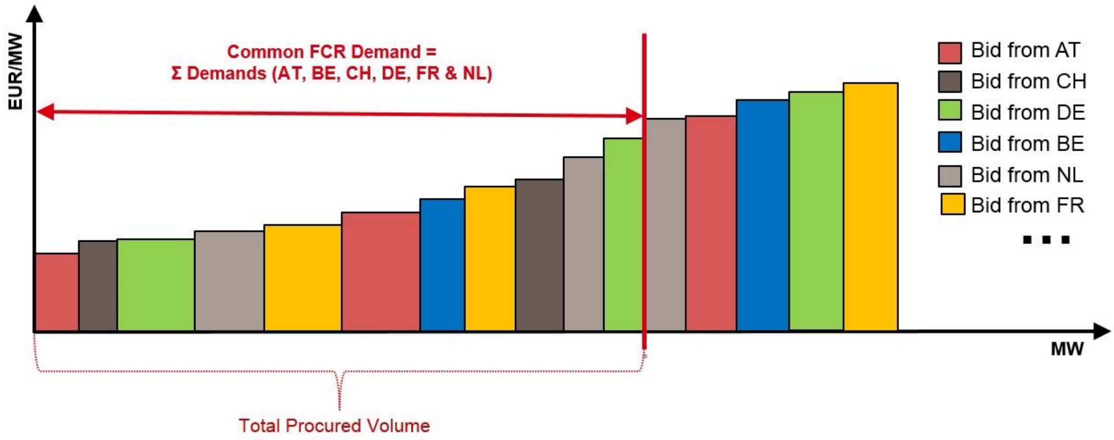

Figure 8: Common merit order list in the FCR Cooperation [17].

Regarding the prequalification process, in order to participate in the FCR Cooperation, the BSP needs to pass through the prequalification procedure and sign a general framework agreement with its connecting TSO.

3.2.3 Procurement and Settlement Processes

The procurement of FCR in the FCR Cooperation is arranged with the TSO-TSO model, in which the BSP contacts its connecting TSO for the provision of balancing services, which then provides the balancing services to the requesting TSO. The draft proposal also establishes that the TSO-BSP Settlement is based on marginal pricing (or pay-as-cleared), which means the price of the bid is the marginal price (maximum price of the accepted offers). The reason for choosing pay-as-cleared instead of pay-as-bid is to increase economic efficiency and optimal resource allocation, saving small or new BSPs money and time by allowing them to bid the marginal price, instead of running expensive analysis on past price developments. As for the TSO-TSO settlement, if the import or export limits of a country are not reached, its target costs is its demand in the common auction multiplied by the cross border marginal price, while if the import and/or export limits are reached, the importing country has to pay for all its procured volume (both local and cross border) the local marginal price, which is higher than the cross border marginal price in this case. This is done in order to benefit both importing and exporting countries in a situation where an import or export limit is reached.

Chapter 4

Market Access for FCR Services in Selected Countries

In order to compare the market access between the chosen countries for small flexibility FCR providers, comprehension and analysis of the prequalification process of each one of them are crucial. Understanding the tests to be performed, the requirements that need to be fulfilled in case of limited energy storage and how to become a BSP in each country is important to evaluate in which country entering in the balancing market would be facilitated. With that in mind, in this chapter, the prequalification processes for Switzerland, Belgium, Germany, Portugal and Spain are laid out, and an overview of them and their comparison will be made, with the aid of a table listing their main requirements.

The countries selected for the study were chosen for different reasons. Germany was chosen for being the country where KOENA tec is located, while Switzerland was chosen since KOENA tec's pilot project is located in this country. Moreover, these two countries and Belgium were selected as they are one of the countries that participate in the FCR Cooperation project. Portugal and Spain were selected due to their tradition in coffee consumption and their high beverages servings establishments ratio in relation to their population [18]. Some other countries were considered for the study, however, due to scarcity of space in this thesis to analyse them all, they could not be researched.

When applying for a prequalification process, a BSP can apply at least one providing unit or providing group. A providing unit is single or an aggregation of power generating modules and/or demand units connected to a common connection point, while a providing group is an aggregation of power generating modules, demand units and/or reserve providing units connected to more than one connection point. One power generating module or demand unit is defined as a Technical Unit (TU).

The requirements set for the prequalification process can be divided into two different categories: Operational & Control and Security & Software. In the Operational & Control category, the operational tests and requirements regarding availability, detection and elimination of faults and requirements in case of limited energy storage will be explained, while in the Security & Software requirements regarding the control system connection of the BSP and IT requirements will be described.

4.1 Prequalification Process in Switzerland

The prequalification process in Switzerland is developed and organized by the only TSO present in the country, Swissgrid. In the process, the potential BSP needs to fill out a form for the specific service it wishes to provide (either primary, secondary, tertiary control or voluntary voltage support) and send it together with a list of all the providing units and Technical Units intended to provide the service. In this list, it needs to contain several specifications, such as the type of providing unit (either conventional or virtual), apparent and rated power and location. A conventional providing unit is defined as a system of a power plant, such as a generation set, a large industrial user, an emergency generator or similar, while a virtual providing unit consists of a number of substations, such as heat pumps, gathered together into individual feed-in/feed-out nodes in terms of operational planning, control and monitoring. The bundling of consumers and consumer groups fits into this category [19]. When submitting a virtual providing unit to the prequalification process, a list of all substations that compose a virtual providing unit must also be provided, along with the system type, nominal rated power, metering point ID and other information.

After sending the form and the list of the providing units, Swissgrid needs to confirm them and assign them their corresponding Energy Identification Code (EIC) codes. Only after this confirmation should the prequalification documents proving the suitability of the providing units in providing balancing services be sent to Swissgrid. Besides that, the TSO might also request some additional tests and requirements to the potential BSP, besides the ones explained in the subsections below. Swissgrid can take up to 25 working days to decide after the BSP sends all the necessary documents.

The main documents containing the requirements and explanation of the prequalification process in Switzerland are “Prequalification documents – ancillary service provider” [20], “Prequalification documents – primary control” [21], “Test for primary control capability” [22], “Requirements for the list of generating units” [19], “Requirements for schedule data and electronic data Exchange” [23], “Monitoring data requirements” [24] and “Framework Agreement for the Supply of Primary Control Power” [25].

4.1.1 Operational & Control

The requirements under the heading “Operational & Control” are the following: Operational Test, Additional Requirements in Case of Limited Energy Storage, Availability, Delivery Behaviour, Detection and Elimination of Faults, Frequency measurement, FCR Trial Under Operational Conditions and Process Control Test.

- Operational Test

The most important test developed for the prequalification process for FCR services in Switzerland is the capability test [23]. This test aims to verify if a providing unit that wants to provide primary control services to the Swiss electricity market meets the necessary technical conditions. The main method of this test is the activation of test signals on the turbine controller (or respective flexible asset controller in case it is not a turbine). However, if for some reason this test cannot be implemented, alternative simplified tests can be used, if it is in accordance with the TSO Swissgrid. Since the offers for FCR in the Swiss balancing market must be symmetrical, tests in both directions (upward and downward) need to be performed.

In the activation of test signals, the nominal speed or grid frequency is reduced or increased from 50 Hz to either 49.8 or 50.2 Hz within 10 seconds, and the power deviations of the providing unit/group are recorded after 30 seconds. Each TU of a providing unit is tested separately in case of a conventional TU, but identical and similarly calibrated generators do not need to be tested if agreed by Swissgrid and the BSP. The BSP is the responsible for implementing the test, with occasional support from the manufacturer or experts of the grid operator being allowed and encouraged.

In this test, the FCR service must be fully activated within 30 seconds of the frequency deviation, and it must be provided for at least 15 minutes. These requirements are in accordance with what is established by the SO GL for Continental Europe.

As for the metering requirements of this test, the metering time period is 100 ms and the nominal frequency should be smaller than 5 mHz. Besides that, the recording period should not last more than 30 minutes. All measurements made during the test must be given with at least one-time stamp for all parameters in a csv file. A graph with the ideal test signal can be seen in Figure 9.

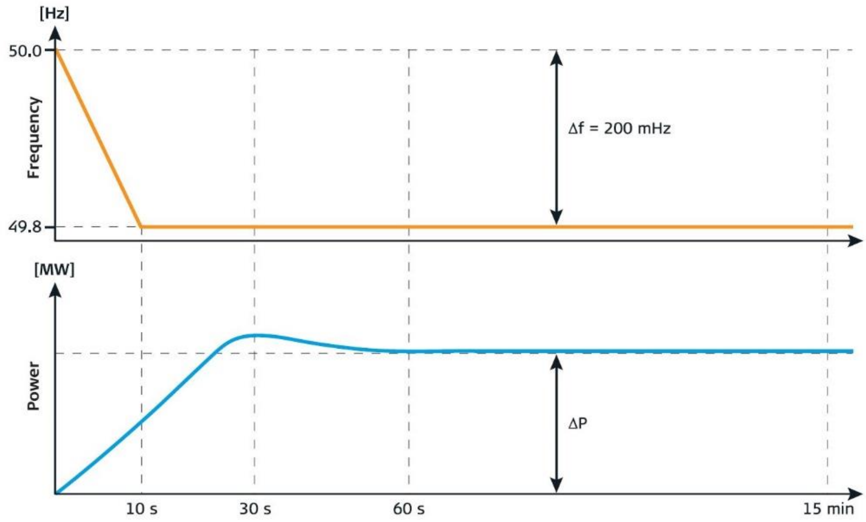

Figure 9: Ideal test signal for FCR capability [23].

The test must be carried out in a way that there is no risk of damaging any of the components of the providing unit and no protection and control mechanisms trigger shutdowns during the test, while not removing any of the protection devices for the purpose of the test.

The gain and droop times are also determined in the capability test and are represented as s in the equation below:

$$s = \frac{\Delta f / f_n}{\Delta P / P_n}$$

Where Δf is the frequency deviation, f_n is the nominal frequency, ΔP is the power deviation and P_n is the nominal power of the TU.

One important determination during this test is the dead band determination. It is carried out with the help of a hysteresis (in simple terms, a lag between the input and the output), corresponding to Δf of the total and Δf/2 of the semi-dead band. In the test, the input signal is adjusted in order to determine the point where a change can be detected in the output. The tolerance band of the dead band is required to be Δf ≤ 20 mHz or Δf/2 ≤ 10 mHz, and the stepwise frequency increase lower than 5 mHz.

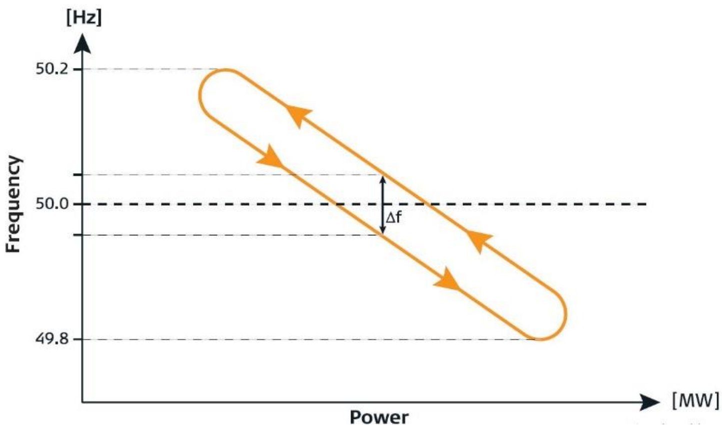

Figure 10: Dead band determination [23].

Additional requirements for the test, such as maximum permissible power deviation, are also set. One of the requirements is that the power measured accuracy needs to be 5% of the nominal value. The minimum and maximum threshold when reaching full activation is 10% of the difference between power before activation and power when service is fully activated. These requirements can be better understood in Figure 11. The difference between power before activation and full activated power is required to be:

$$\Delta P = \frac{\frac{0.2}{50}}{s} P_n$$

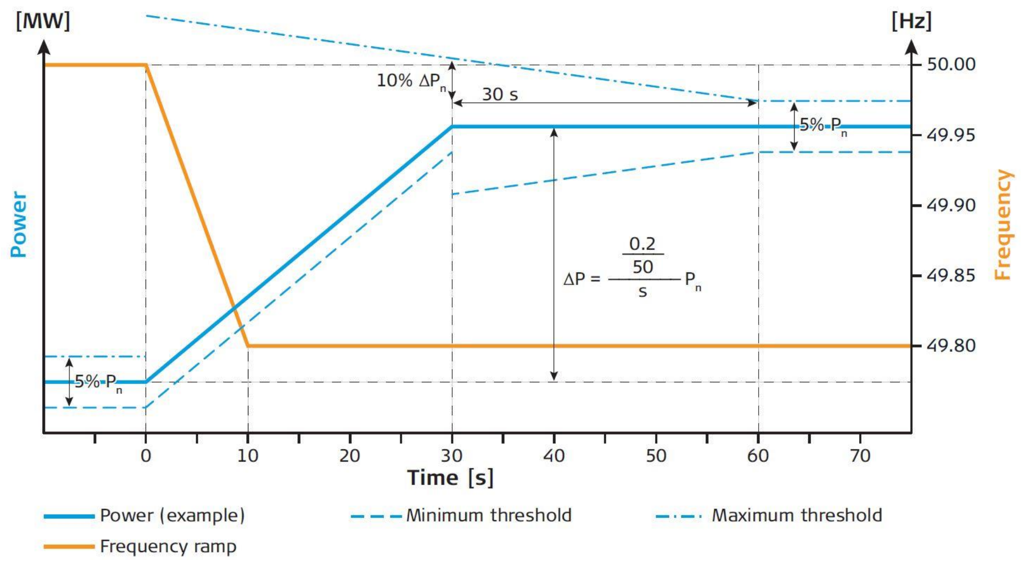

Figure 11: Tolerance bands and performance characteristics of capability test [23].

- Additional requirements in case of limited energy storage

There are no additional tests in case the providing unit or providing group has limited energy storage.

- Availability

Swissgrid determines that the remunerated control power must be available 100% of the time. If a providing unit fails, a contract penalty needs to be paid by the BSP, corresponding to the product of a penalty factor and the remuneration for the FCR service contracted excluding the volume of unavailable control power during the tender period. If the failure of the providing unit is not the BSP's fault and the availability during the tender period is at least 99.9%, no penalty needs to be paid. The BSP must provide suitable documentation, such as operating logs, to prove the failure was not its fault. In the case of operating availability between 100% and 99.9% or below 99.9% when the fault is proven not to be the BSP's fault, the penalty factor is 3. In all other cases, the penalty factor is 10. In case of a force majeure and in cases of official orders, the BSP is released from its obligations according to the situation (nature and duration of impairment). In these cases, no penalty will be charged from the non-availability of the FCR service [25].

The BSP must inform Swissgrid promptly if it is unable to meet its contractual obligations entirely. If a fail in availability happens and it was caused as a result of gross negligence, such as failure to take account of average outages typical of providing units, or intentional outage, Swissgrid can take the liberty to ban the BSP from any future tender invitations by explaining the reasons of this exclusion in writing.

- Delivery behavior

The delivery behavior of FCR providing units and groups in Switzerland follows the requirement defined by the SO GL of at least linear provision, which means at least 50% of the service must be provided within 15 seconds and 100% after 30 seconds. No additional requirements regarding the delivery behavior are set by the swiss TSO, besides the requirement to start the activation after 3 seconds of the frequency deviation.

- Detection and elimination of faults

In case of a fault that affects the delivery of FCR services, either partially or completely, the BSP needs to immediately inform Swissgrid through the communication channel established between them. In case the BSP fails to inform about any faults repeatedly, Swissgrid reserves the right to exclude the BSP from future tenders.

- Frequency measurement

Swissgrid states that the accuracy of frequency measurement tolerance must be below 10 mHz for FCR services, either positive or negative. This is in accordance with what is imposed in the SO GL for Continental Europe.

- Test under operational conditions

In the documents provided, no tests under operational conditions are specified.

- Communication Test

After submitting the Terms & Conditions signed for the providing units or providing groups the BSP wishes to prequalify and Swissgrid accepts the documents, the BSP needs to install the RTU (Remote Terminal Unit) for data monitoring, and the providing units/groups are then connected to both the network controller and the monitoring center. After that, and before starting the prequalification test for capability, a monitoring test is performed in close cooperation with the TSO, in which the communication system between the providing groups and/or providing units and the TSO is tested.

4.1.2 Security & Software

The requirements under the heading “Security & Software” are the following: Reserve provider control system, reserve provider control system connection to TSO, closed user group, TU connection and bundling, additional requirements, and external IT service providers.

- Reserve provider control system connection to TSO

The control system of the BSP is connected to the TSO Swissgrid through a Swisscom LAN interconnected network available for real-time monitoring. The BSP has to bear the costs of its connection to the Swisscom LAN interconnect, while the costs of the communication connection of the Swissgrid location is paid by the TSO. The data availability to the TSO is requested to be, at minimum, 99.5%. The online monitoring data needs to be updated at a maximum resolution of 10 seconds.

The connection between the TSO's control centre and the reserve provider's control system must be based on a point-to-point control technology. The transmission protocol supported by Swissgrid is the IEC 60870-5-104 for the transmission of monitoring data via the Swisscom LAN Interconnect Service. A BSP is also allowed to transmit monitoring data via Private Internet Access (PIA), in which Swissgrid only supports the transmission protocol «IEC 60870-6-104» (TASE.2). In Figure 12 the communication connection solution recommended by Swissgrid can be seen [24].

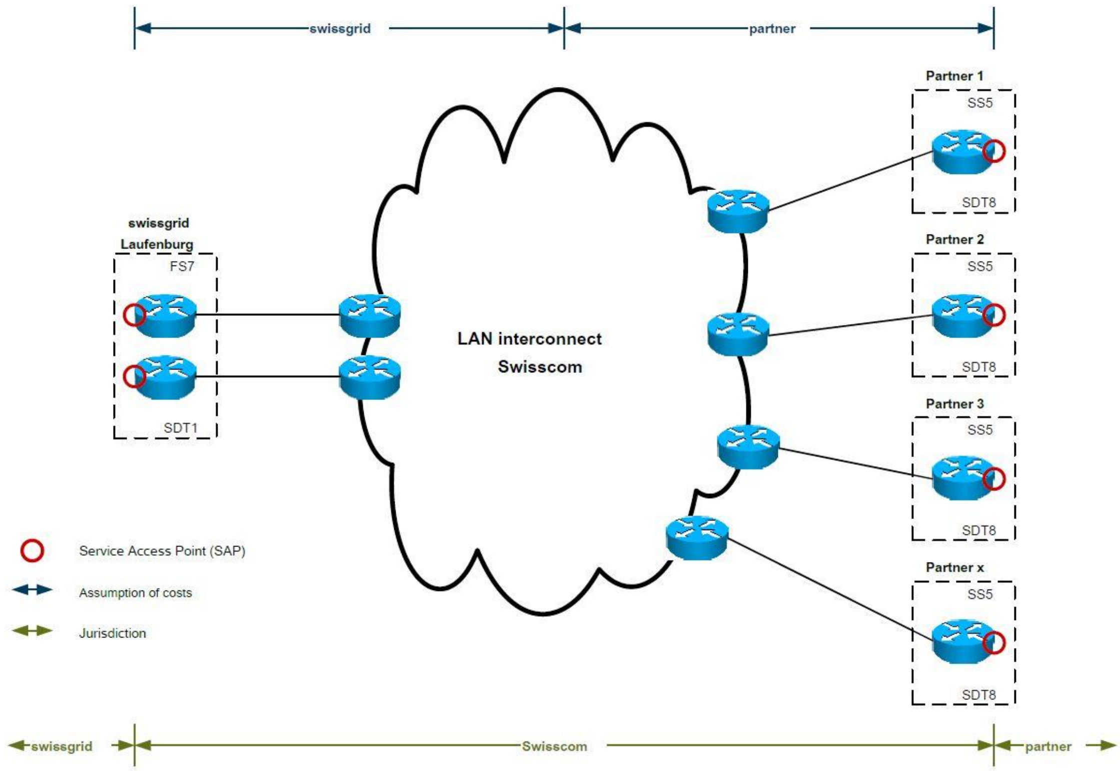

Figure 12: Overview of communication connection between the TSO and BSP [24].

- Reserve provider control system

No specific requirements regarding the security and software of the BSP's control system are set by the Swiss TSO besides the ones mentioned in the above bullet point.

- Closed user group

The communication between the BSP and the TSO must be protected from other networks by using closed user groups. The potential BSP is the responsible for the costs and for applying to a connection with the closed user group with the telecommunications provider Swisscom. The communication is done through the LAN Interconnect Service, a communication infrastructure for site networking.

- TU connection and bundling

No additional requirements are made for the TUs' connection by the Swiss TSO.

- Additional requirements

No additional requirements are made regarding Security & Software of BSPs' systems.

- External IT service providers

The TSO Swissgrid does not mention the use of external IT service providers for FCR service providers.

4.2 Prequalification Process in Belgium

For providing FCR services in Belgium, different requirements are set by Elia, the Belgian TSO, that need to be met by the BSP and its providing group(s). In order to provide FCR services to the Belgian grid, after qualifying as a BSP, its providing groups need to meet certain requirements and pass some tests specified below. These requirements and tests differ whether the Technical Units are under the Coordination of the Injection of Power Units Contract (CIPU Contract) or not (Non-CIPU). Generators with an installed capacity of more than 25MW connected to Elia's grid need to have a CIPU contract, while smaller generating units or virtual power plants are considered Non-CIPU Technical Units. Since the objective of this thesis is to analyse the market access for small flexibility-based FCR, this section will focus on the prequalification procedure for Non-CIPU Units.

When applying a new providing group for supplying FCR services, the BSP needs to hand in the Energy Management Strategy, a detailed document in which it proves the compliance of this providing group with the requirements for the provision of FCR. Among other things, in this document, the BSP informs if the providing group has limited energy storage or not and also needs to prove its Energy Management Strategy does not impact third-party entities. The BSP must also submit a list of the providing units that are technically capable of providing FCR services to the grid, including their organization into providing groups.

After delivering the Energy Management Strategy, Elia requests that two prequalification tests are performed by the BSP: The System Frequency Profile Test and the Real-Time Frequency Test. They need to be carried out by each providing group that wishes to provide FCR services and they will determine the maximum quantity of FCR power a providing group can offer in auctions (FCR_{max_PG}). In order for the tests to be carried out, the BSP must inform Elia and the DSO (if needed) about its plans to perform the prequalification tests of a certain FCR providing group. Then, the two or three parties must agree on a time to perform these tests within ten working days of the tests' requests to the TSO by the BSP. At the time agreed on, the BSP starts the synthetic frequency profile test and, after the end of this test, the BSP has 24 hours to start the real-time frequency test, which lasts for a period of 4 hours. The BSP is responsible for all the costs arising from these tests. The specifics of each one of these tests for each service type (symmetrical or asymmetrical) are in the following subsubsection, along with the other requirements of the prequalification process.

The main documents regarding the FCR prequalification process in Belgium for Non-CIPU TUs are the “General Framework for Frequency Containment Reserve Service by Non-CIPU Technical Units” [26], the “Terms and Conditions for the Frequency Containment Reserve Service by Non-CIPU Technical Units” [27] and the “FCR – Communication Requirements” [28].

4.2.1 Operational & Control

The requirements under the heading “Operational & Control” are the following: Operational Test, Additional Requirements in Case of Limited Energy Storage, Availability, Delivery Behaviour, Detection and Elimination of Faults, Frequency measurement, FCR Trial Under Operational Conditions and Process Control Test.

- Operational Test

The operational test to be performed in the Belgian prequalification procedure is the Synthetic Frequency Profile test. For this test, Elia receives the measurements via the real-time connection of each delivery point of a providing group, except for virtual delivery points, where the aggregated data is considered. The test consists of steps of frequency deviation of 50mHz in each step, in which the number of steps varies depending on the service type.

For this test, Elia will calculate the prequalified power supplied $P_{\sup\_prequal}(t)$ value as follows:

$$P_{sup\_prequal}(t) \; = P_{ref\_prequal} - P_{measured}(t)$$

Where $P_{ref\_prequal}$ is the average power measured in the 20 seconds before the beginning of the test.

For the calculation of the maximum FCR power in the test of a providing group $FCR_{\max\_PG\_SFP}$, Elia calculates 10 seconds average values of $P_{sup\_prequal}(t)$ resulting in $Av\_P_{sup\_prequal}(t)$. Each value is in reality calculated during 15 seconds to take into account the 5 seconds tolerance at the beginning of each step, and after that Elia selects for each one of the steps the lowest or highest (if upwards or downward direction, respectively) value among one average value of $P_{sup\_prequal}(t)$ over the first 15 seconds of the step after the 5 seconds tolerance and also the remaining number of average values of $P_{sup\_prequal}(t)$ over 10 seconds for each step.

The providing group must have a certain power profile depending on the service type (either symmetric 200mHz, symmetric 100mHz, asymmetric up or asymmetric down). For 200mHz, the following profile must be obtained by the providing group in the test:

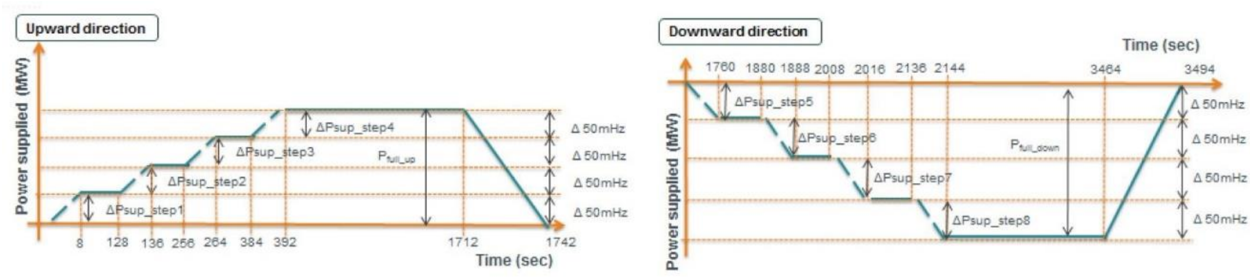

Figure 13: Power supplied profile during synthetic frequency profile test for service type 200mHz [26].

In the test, the providing group must, in a maximum of 13 seconds, reach the volume of each step of 50mHz, and must keep the power supplied for 2 minutes before going to the next 50mHz step. After achieving the maximum power it can supply, the providing group must provide this power for 22 minutes. For symmetrical FCR, the providing group is prequalified for each direction (upward and downward), which means two tests in each direction is performed with a maximum time difference between them of 24 hours.

After receiving the data from these tests, Elia will calculate a value P_{step_min}, which corresponds to four times the minimum increment of power supplied $\Delta P_{\sup\_step\_i}$ between all steps (absolute values). $\Delta P_{\sup\_step\_i}$ is the difference between the lowest or highest (if upwards or downward direction, respectively) $Av\_P_{sup\_prequal}(t)$ value during the step i-1 and the lowest or highest (if upwards or downward direction, respectively) $Av\_P_{sup\_prequal}(t)$ value the step i.

The value P_{step_min} is compared to minimum power supplied (P_{full_up}; P_{full_down}) as seen in the graphs. P_{full_up} is calculated as the lowest $Av\_P_{sup\_prequal}(t)$ value during the full power step in the upward direction, and P_{full_down} is the highest $Av\_P_{sup\_prequal}(t)$ value during the full power step in the downward direction.

In the end, for the determination of the maximum FCR power in the test of a providing group $FCR_{\max\_PG\_SFP}$ for 200mHz service type, this rule applies: if $P_{step\_min} \geq 0.9 * min(P_{full_{up}};\ -P_{full\_down})$, then $FCR_{\max\_PG\_SFP}= min(P_{full_{up}};\ -P_{full\_down})$; if not, $FCR_{\max\_PG\_SFP} = P_{step\_min}$.

For providing the 100mHz service type, the power supplied profiles during the tests for upward and downward direction are in Figure 14.

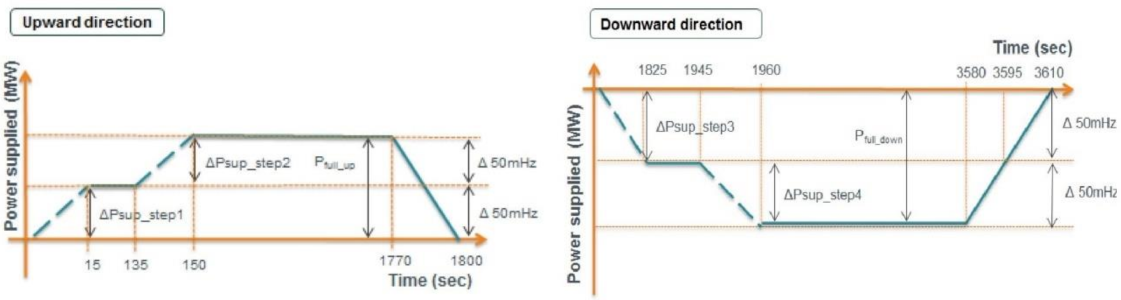

Figure 14: Power supplied profile during synthetic frequency profile test for service type 100mHz [26].

In this test, the providing group must deliver the volume of each 50mHz step in a maximum of 20 seconds and maintain this volume for 2 minutes before going to the next 50mHz step. Once the maximum supplied power is achieved, it needs to be maintained for 27 minutes. Like the test for 200mHz service type, the test for the opposite direction needs to be performed within 24 hours of the first test.

The calculation of P_{step_min} is similar than for the 200mHz service type, being the minimum of each step 2 times $\Delta P_{\sup\_step\_i}$ instead of 4. The definitions of (P_{full_up}; P_{full_down}) are also similar and for the determination of $FCR_{\max\_PG\_SFP}$ the same rule applies.

For the asymmetric up service type, the supplied power profile in Figure 15 must be obtained by the providing group doing the prequalification test.

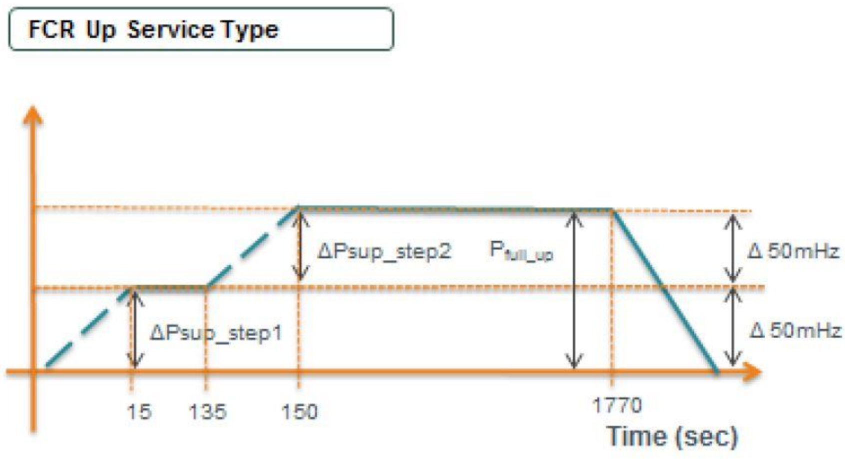

Figure 15: Power supplied profile during synthetic frequency profile test for service type asymmetric up [26].

The profile of this test is the same as for 100mHz upward direction service type: The providing group must deliver the volume of each 50mHz step in the maximum 20 seconds and maintain this volume for 2 minutes before going to the next 50mHz step. Once the maximum supplied power is achieved, it needs to be maintained for 27 minutes.

The calculation of P_{step_min} is also the same as for the 100mHz service type test, considering it the minimum value of $2 * \Delta P_{\sup\ \_step\_i}$ between the two steps. The value obtained for P_{step_min} will then be compared to P_{full_up}, and if $P_{step\_min} \geq 0.9 * P_{full_{up}}$, $FCR_{\max\ \_PG\_SFP} = P_{full_{up}}$; if not, $FCR_{\max\ \_PG\_SFP} = P_{step\_min}$.

If the providing group had already had a prequalification test for 100mHz service type, the $FCR_{\max\ \_PG\_SFP}$ obtained in it is considered a minimum also for the Up service type. The determination of $FCR_{\max\ \_PG\_SFP}$ for the Up service type will then be as follows:

If:

$$P_{step\_min} \geq 0.9 * P_{full_{up}}$$

Then

$$FCR_{\max\ \_PG\_SFP} = \max\left[FCR_{\max\ \_PG\_SFP}\ for\ the\ 100mHz\ test;\ P_{full_{up}}\right]$$

If not:

$$FCR_{\max\ \_PG\_SFP} = \max\left[FCR_{\max\ \_PG\_SFP}\ for\ the\ 100mHz\ test;\ P_{step\_min}\right]$$

As for providing asymmetric down FCR services to the grid, the providing group needs to have the following power supplied profile during the Synthetic Frequency Profile Test:

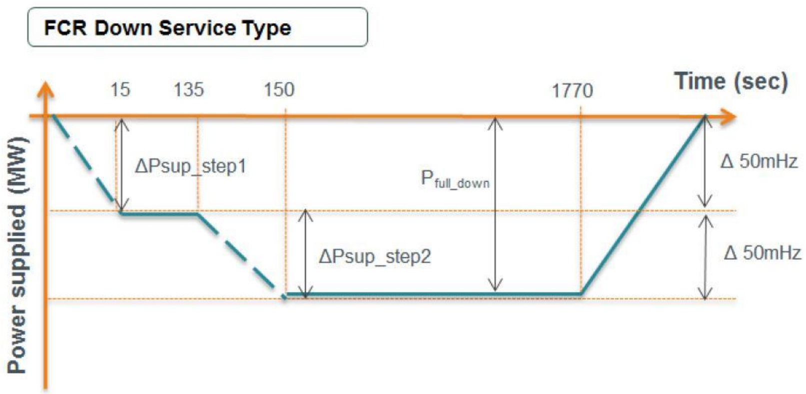

Figure 16: Power supplied profile during synthetic frequency profile test for service type asymmetric down [26].

The profile of this test is the same as for 100mHz upward direction and asymmetric up service types: The Providing group must deliver the volume of each 50mHz step in the maximum 20 seconds and maintain this volume for 2 minutes before going to the next 50mHz step. Once the maximum supplied power is achieved, it needs to be maintained for 27 minutes.

The calculation of P_{step_min} is also the same as for the 100mHz and the asymmetric up service types tests, considering it the minimum value of $-2 * \Delta P_{\sup\_step\_i}$ between the two steps. The value obtained for P_{step_min} will then be compared to P_{full_down}, and if $P_{step\_min} \geq 0.9 * P_{full\_down}$, $FCR_{\max\_PG\_SFP} = P_{full\_down}$; if not, $FCR_{\max\_PG\_SFP} = P_{step\_min}$.

Just like for the asymmetric up service type, if the Providing group had already done a prequalification test for 100mHz service type, the $FCR_{\max\_PG\_SFP}$ obtained in it is considered a minimum also for the Down service type. The determination of $FCR_{\max\_PG\_SFP}$ for the Down service type will then be as follows:

If:

$$P_{step\_min} \geq 0.9 * P_{full\_down}$$

Then

$$FCR_{\max\_PG\_SFP} = \max\left[FCR_{\max\_PG\_SFP}\ for\ the\ 100mHz\ test;\ -P_{full\_down}\right]$$

If not:

$$FCR_{\max\_PG\_SFP} = \max\left[FCR_{\max\_PG\_SFP}\ for\ the\ 100mHz\ test;\ P_{step\_min}\right]$$

- Additional requirements in case of limited energy storage

Elia does not determine any additional requirements for the Providing groups with limited energy storage.

- Availability

Elia requests that all BSPs are available at all times while providing FCR services. In case of a fault or forced outage, the BSP needs to still provide the contracted power by transferring part or all of the contracted power to a Counterpart BSP.

In order to prove the availability of the providing group during the delivery of the service, two different tests can be performed: The Capacity Availability and the Energy Availability. The Capacity Availability is aimed at verifying that the BSP can deliver the entire nominated FCR Power on one or more Providing groups, and it can be requested by Elia maximum 2 times per delivery period, Providing group and Service Type, being able to request it more times in case of a negative result. In the Energy Availability Test it is certified that the energy requirements such as the delivery behavior, the avoidance of artificial delay and the continuity of the service are fulfilled during the whole delivery time, and it can be requested either 3 times per year (in case of limited energy storage) or 1 time per year (in case the Providing group has no limited energy storage). If a Providing group fails in one of the tests, Elia will reduce the BSP's remuneration accordingly.

- Delivery behavior

The delivery behavior of FCR Providing Units and Groups is also subject to the requirement of at least linear provision as stated in the SO GL, which means at least 50% of the service must be provided within 15 seconds and 100% after 30 seconds. It cannot be artificially delayed and needs to begin, at the latest, 2 seconds after the frequency deviation starts. It is also required that providing groups continuously provide their services for as long as the frequency deviation occurs, except for when the Providing group has limited energy storage, in which case it needs to be active for at least 25 minutes continuously. After these 25 minutes, the Providing group has 2 hours maximum to regenerate its energy reserve.

- Detection and elimination of faults

In case of a fault that hinders partially or completely the delivery of FCR services, the BSP needs to immediately notify Elia about it. After one hour maximum of the forced outage, the BSP has to communicate to Elia about the quantity of FCR power available lost, stating the start date and hour of the fault, the providing group(s) involved and the amount of MW and service type that was not available. The BSP will not be remunerated for the FCR power lost due to the forced outage.

The BSP must ensure correct provision on the first possible quarter-hour after the occurrence of the fault, and Elia gives the BSP 6 hours to find a backup solution. If the BSP cannot find a solution within these 6 hours, Elia can request another Availability Test in the Providing group(s) affected. If there is an occurrence of more than one forced outage per Providing group providing a certain service type over a period of 3 months, the TSO will lower the BSP's prequalified volume for this service type accordingly until the BSP can prove it has found and implemented a permanent solution to avoid the occurrences of forced outages.

- Frequency measurement

The Belgian TSO Elia determines that each TU installed in a providing unit must have its own measurement equipment, except in the case of a Virtual Providing Unit. In this case, a frequency measurement equipment must be installed for the entire Virtual Providing Unit at the Providing Unit where the Providing group is delivering the service. The accuracy of frequency measurement tolerance must be below 10 mHz, and the setpoint of frequency is 50Hz.

- Test under operational conditions

Besides the operational test, a providing group that wishes to provide FCR services to the grid needs to provide a trial run under operational conditions for a continuous period of four hours. The BSP can select the most suitable time for them to perform the test and inform Elia about it before starting it. If during this test there is one or more frequency deviation larger than 40mHz, Elia will verify if the BSP has responded accordingly to the highest frequency deviation that occurred. If there is a positive difference between the FCR power required P_{req_act} and the FCR power supplied P_{sup_act}, the factor $\Delta FCR_{\max\_PG\_FRF}$ is calculated as follows:

$$\Delta FCR_{\max\_PG\_FRF} = min\left(\frac{P_{sup\_act}}{P_{req\_act}}; 1\right)$$

For the calculation of P_{sup_act}, two values are compared: the average value of the power measurement of the providing group 20 seconds before the beginning of the frequency deviation $P_{\sup\_before}$ and the lowest power value measured in a period of 30 seconds after the frequency deviation reaches its maximum value P_{sup_after}. If the BSP is providing asymmetric upward service, $P_{\sup\_before}$ is the value measured before the frequency becomes smaller than 49.9Hz for the first time in a period of 300s, and for asymmetric downward service, it is the measured value before the frequency becomes higher than 50.1Hz for the first time in a period of 300s. The equation of P_{sup_act} then depends if the service is being provided in the upward or the downward direction and it goes as follows:

For upward direction:

$$P_{sup\_act} = \max\left(P_{\sup\_before} - P_{sup\_after}; 0\right)$$

For downward direction:

$$P_{sup\_act} = \max\left(P_{\sup\_after} - P_{sup\_before}; 0\right)$$

As for the calculation of P_{req_act}, it is defined as the absolute difference between P_{req_before} and P_{req_after}. The determination of these two values depends on the type of service being provided. In the three tables set below, the equations for these parameters can be seen. The equations fit for both P_{req_before} and P_{req_after}, only changing the value of the frequency. f_{before} is the average value of the frequency during a period of 20 seconds before the frequency variation starts for Symmetric Service Types, 49.9Hz for the Upward Asymmetrical Service Type and 50.1Hz for the Downward Asymmetrical Service Type. f_{after} is the average value of the frequency during a period of 5 seconds for Asym. Service and 20 seconds for Sym. Service from the time that the frequency variation reaches its maximum value.

Sym. 200mHz	Sym. 100mHz
$\boldsymbol{P_{req} = -\lambda_0 * P_{Period} * \Delta f}$	$\boldsymbol{P_{req} = -\lambda_{Elia} * P_{Period} * \Delta f}$
$\lambda_0 = power/frequency\ characteristic\ of$	$\lambda_{Elia} = 2 * \lambda_0;\ \lambda_0\ same\ as\ for\ Sym. 200mHz$

ENTSO-E, equal to 5 [1/Hz].	
$P_{Period} = Power\ Nominated\ for\ the\ period$	$P_{Period} = Power\ Nominated\ for\ the\ period$
$\Delta f = (f_{before}\ or\ f_{after}) - 50Hz$	$\Delta f = [\min((f_{before}\ or\ f_{after}) - 50Hz; +/-0.1Hz)]$

Table 2: Calculations done for Test Under Operational Conditions for the Belgian market, Symmetric service type.

Asym. Down	
$(f_{before}\ or\ f_{after}) < 50Hz$	$\boldsymbol{P_{req} = 0MW}$
$50{,}1Hz \leq (f_{before}\ or\ f_{after}) \leq 50.2Hz$	$\boldsymbol{P_{req} = -(\lambda_0 * 2 * P_{Period} * (\Delta f - 0.1Hz))}$
$(f_{before}\ or\ f_{after}) \geq 50.2Hz$	$\boldsymbol{P_{req} = -P_{Period}}$
λ_0 =*power/frequency characteristic of ENTSO-E, equal to 5 [1/Hz].*	
$P_{Period} = Power\ Nominated\ for\ the\ period$	
$\Delta f = (f_{before}\ or\ f_{after}) - 50Hz$	

Table 3: Calculations done for Test Under Operational Conditions for Belgian market, Asymmetric Down service type.

Asym. Up	
$(f_{before}\ or\ f_{after}) > 49{,}9Hz$	$\boldsymbol{P_{req} = 0MW}$
$49{,}8Hz \leq (f_{before}\ or\ f_{after}) \leq 49{,}9Hz$	$\boldsymbol{P_{req} = -(\lambda_0 * 2 * P_{Period} * (\Delta f + 0{,}1Hz))}$
$(f_{before}\ or\ f_{after}) \geq 50{,}2Hz$	$\boldsymbol{P_{req} = -P_{Period}}$
λ_0 =*power/frequency characteristic of ENTSO-E, equal to 5 [1/Hz].*	
$P_{Period} = Power\ Nominated\ for\ the\ period$	
$\Delta f = (f_{before}\ or\ f_{after}) - 50Hz$	

Table 4: Calculations done for Test Under Operational Conditions for the Belgian market, Asymmetric Down service type.

After calculating the $\Delta FCR_{\max\_PG\_FRF}$, Elia can determine the maximum FCR Power the Providing group can offer in auctions $FCR_{\max\_PG}$. The equation for providing 200mHz Symmetric service type is:

$$FCR_{\max\_PG} = \min[FCR_{\mathrm{ref\_200}\_PG}; FCR_{\max\_PG\_SFP} * \Delta FCR_{\max\_PG\_FRF}] * E_{max}$$

While for all other service types the following equation is used:

$$FCR_{\max\_PG} = \min[\sum_{i}^{n} FCR_{\mathrm{ref\_i}}; FCR_{\max\_PG\_SFP} * \Delta FCR_{\max\_PG\_FRF}] * E_{max}$$

Where:

- $FCR_{\mathrm{ref\_200}\_PG} = 2 * \min[\sum FCR_{\mathrm{ref\_synth\_up}} ; \sum FCR_{\mathrm{ref\_synth\_down}} ; \sum FCR_{\mathrm{ref\_synth\_100}}] + \sum FCR_{\mathrm{ref\_200}\_standalone}$; The sums are referred to the fact that within a Providing group providing 200mHz certain Providing Units might also provide asymmetric up, down or symmetric 100mHz. These are the sum of their FCR power for these services.
- $FCR_{\mathrm{ref\_i}}$: FCR_{ref} declared by the BSP for Providing Unit I in the list of Providing Units previously provided;
- n: number of Providing Units in the Providing group;
- E_{max}: a factor defined as the difference between the worst measuring precision among all Providing Units and 1%.

Finally, the FCR_{max} a BSP can offer to Elia for a service type can be determined by summing the $FCR_{\mathrm{max}\ \_PG}$ of the service type all Providing groups.

- Communication Test

Before starting the prequalification tests (the System Frequency Profile Test and the Real-Time Frequency Test), the BSP needs to show its connection to the TSO's control system works correctly and that it has the ability to exchange data with Elia. This is done through the Communication Test, in which both the nomination communication and real-time communication are tested. On the nomination side, it has to be proven the correct exchange of nomination files to the TSO through an online platform developed by Elia (files regarding the information on its FCR Power obligation, for each Providing group and each service type), while as for the real-time communication, the BSP must show the correct recording and transmitting of the real-time values required, such as real-time data regarding the availability tests, the energy content and the measured power. If the BSP fails in this test, Elia and the BSP will work together to find the source of the problem and the BSP should be able to fix this problem on its own. All the costs relative to this test are paid by the BSP.

4.2.2 Security & Software

The requirements under the heading "Security & Software" are the following: Reserve provider control system, Reserve provider control system connection to TSO, Closed user group, TU connection and bundling, Additional requirements, External IT service providers.

- Reserve provider control system connection to TSO

The TSO Elia requires a redundant communication channel between the BSP and Elia, with the communication protocol being determined by the TSO. If Elia decides to improve certain procedures or real-time exchanges, the BSP commits to apply these changes in a reasonable time. The BSP's communication system must be available at least 95% of the time monthly for real-time data transfer.

For the correct data transmission between the BSP and the TSO, a bidirectional link in the software TASE2/ICCP is strongly recommended by Elia, as opposed to 2 unidirectional links.

- Reserve provider control system

The first IT requirement set by Elia for potential BSPs is the obligation of the BSP to have its entire real-time communication system and its processes redundant. The BSP control system must, then, have two physical communication links and two different Uninterruptible Power Supplies (UPS) with a minimum of 8 hours of autonomy per physical link.

The physical connection must be set up on a leased line and a secured VPN. Regarding the software to be used, the TASE2/ICCP software of the BSP must be in conformity with the IEC 60870-6 TASE2 standard, and the software version must be of 2000. If the BSP's system does not support this software, a protocol converter must be installed. Any changes to the protocol must be agreed between Elia and the BSP.

- Closed user group

The TSO Elia does not mention the use of closed user groups for FCR service providers.

- TU connection and bundling

No additional requirements are made for the TUs' connection by the Belgian TSO.

- Additional requirements

No additional requirements are made regarding Security & Software of BSPs' systems.

- External IT service providers

The TSO Elia does not mention the use of external IT service providers for FCR service providers.

4.3 Prequalification Process in Germany

There are different minimum requirements to provide FCR services in Germany, and these requirements should be proven to be met in the prequalification process developed by the four TSOs operating in Germany: TransnetBW, TenneT, Amprion and 50Hertz Transmission. In this prequalification process, a potential balancing service provider needs to submit certain documents concerning its providing units or providing groups to meet the minimum requirements to provide balancing services to the grid. They have to be part of a pool, which consists of a single or multiple aggregated providing units and/or providing groups. The power plants or consumption units that compose a providing unit or group are called Technical Units (TUs), and in order to pass the prequalification process at least one performance measurement must be carried out for each TU.

The main documents regarding the prequalification process in Germany are the "Prequalification procedure for reserve providers (FCR, aFRR, mFRR) in Germany" [29] and the "Minimum requirements for the reserve provider's information technology" [30].

4.3.1 Operational & Control

The requirements under the heading “Operational & Control” are the following: Operational Test, Additional Requirements in Case of Limited Energy Storage, Availability, Delivery Behaviour, Detection and Elimination of Faults, Frequency measurement, FCR Trial Under Operational Conditions and Process Control Test.

- Operational Test

Every potential balancing service provider for FCR in Germany needs to run some tests to prove it meets minimum requirements in different categories, such as operation, availability and control. An important test within the prequalification procedure is the operational test. The operational test is a practical test based on standardized criteria, in which the BSP proves the technical suitability of its providing units or/and groups. The data collected in the test for both the providing unit/group that is being prequalified and the TUs that compose it are documented in an operating protocol, in which the BSP must submit with the application documents. This test is usually carried out by the BSP alone, but coordination with the connecting TSO is requested in case the providing unit or providing group capacity is superior to 100 MW.

The operational test is required if a providing unit/group is being prequalified for the first time, a TU or providing unit/group changes the BSP, the validity of the prequalification expires after 5 years. The use of data collected in regular operation is not an option in order to demonstrate continued compliance with the requirements, if the technical requirements or the availability requirements or the equipment have changed or if there are significant changes in the composition of a providing unit or providing group.

In this test, at least for the initial prequalification, the interaction of all providing units and providing groups of a pool must be demonstrated, thus all TUs of all providing unit/group must complete the first operational test simultaneously. When renewing the prequalification certificate upon its expiration, on-demand data from regular operation can be submitted if the requirements checked in an operational test continue to be met. The operational test for prequalification in the negative direction can be combined with the operational test for prequalification in the positive direction, so that proof can be provided for both directions.

During the operational test, the BSP must record the following data for transmission to the prequalification portal: measured power, operating point and setpoint of the relevant TU and providing unit/group. Setpoint is the control reserve provided by the BSP. The control power measured value is derived from this data and consists of the difference between the measured power and the operating point. This data, when put in a graph, needs to result in a "double hump curve", consisting of three retention phases and two delivery phases. The duration of each phase for provision of FCR is a fifteen-minute schedule interval, and the providing unit/group reaches the specified setpoint within 30 seconds.

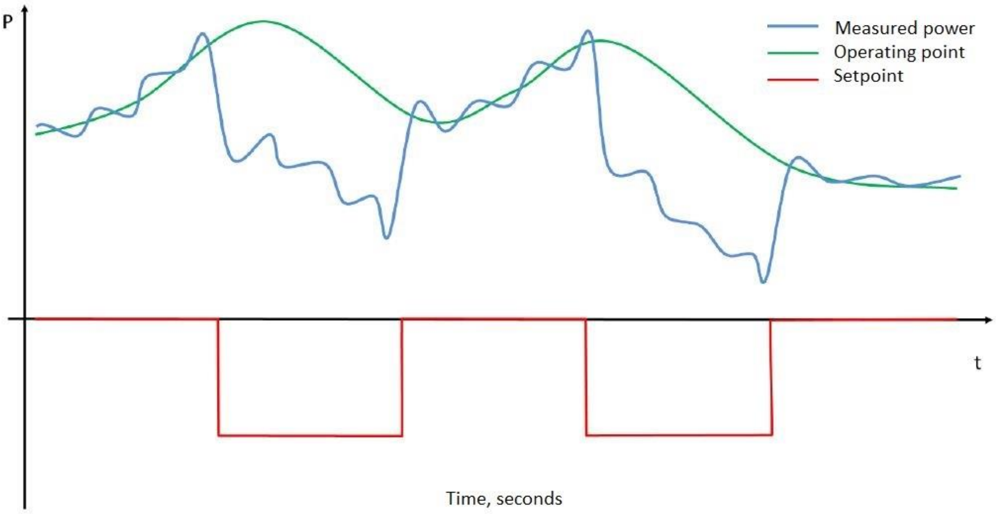

Figure 17: Data recorded during operational test (based on image from [29]).

An operational test for FCR provision has 3 different time ranges: Service Change Range (SCR), Transient Area (TA) and Stationary Area (SA). The SCR begins with the setpoint jump, usually a frequency deviation of +/- 200 mHz and lasts a maximum of 30 seconds, ending when the setpoint is reached for the first time. The transient area begins at the end of the SCR, at the latest 30 seconds after the setpoint step. It ends 90 seconds after the setpoint jump. The Stationary Area begins 90 seconds after the setpoint jump and lasts at least 13.5 minutes.

The pre-qualifiable performance determination is a necessary step in the operational test. Its value is taken by the mean value of the transient and the stationary area of each retention and delivery phase. The control power measures values, which are assigned to the power change range, are not taken into account when determining the mean values. The starting point for the determination of the pre-qualifiable performance in the positive (negative) direction is the minimum (maximum) mean value of the control power measured value in the delivery phases. From this, the maximum (minimum) mean value of the control reserve measured value is deducted in the retention phases.

Depending on the technology used by the power generation plant or consumption unit, the control power measured value fluctuates more or less around the setpoint. One of the steps of the operational test is to check these fluctuations do not exceed certain limits when providing balancing services. Permitted deviations are expressed as a percentage of the pre-qualifiable service. The deviation relates to the deviation of the control reserve measured value from the mean value of the retention or delivery phase. Control power measured value is tested to see if the deviation of the setpoint lies in the "allowed" fluctuations interval, the "tolerable" fluctuations interval or outside the interval of "tolerable" fluctuations. At least 95% of the control power measured values must be in the interval of the "allowed" fluctuations; A maximum of 5% of the measured values may be in the "tolerable" interval. To best understand these areas and the variations percentage allowed for each interval for FCR services, the graph in Figure 18 can be seen.

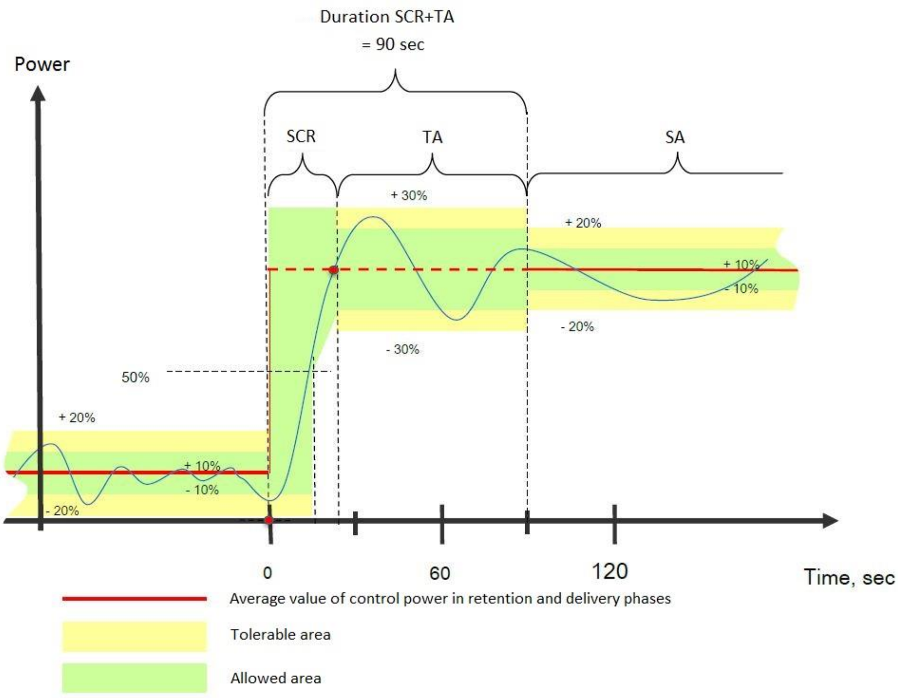

Figure 18: Graphic explanation of the tolerable and allowed areas (based on image from [29]).

- Additional requirements in case of limited energy storage

In case of a providing unit or providing group with limited energy storage (which cannot provide the prequalification service continuously over four hours without additional measures), additional requirements need to be proven to be met in the operational test.

The first requirement is that the working capacity of the energy storage device must reach or exceed two differently defined lower limits. The limits required are different for the prequalified performance and the marketable performance. The marketable service, unlike the prequalified service, takes into account the duration of the service. It is the same as the service, which can be performed continuously over a period of four hours, and the marketable service of a pool is determined by the BSP as the sum of the marketable services of the providing units and providing groups of the pool. For the prequalification performance, this minimum is 15 minutes, while for the marketable performance it is the work capacity required for the alert state plus the maximum of either the work capacity required to take into account a previous call or the work capacity required to account for the delayed effect of storage management measures.

The alert state is defined in the SO GL as "the system state in which the system is within operational security limits, but a contingency from the contingency list has been detected and in case of its occurrence the available remedial actions are not sufficient to keep the normal state" [4]. Accordingly, the alert state exists if, on the one hand, the frequency deviation is ±200 mHz and, on the other hand, either the frequency deviation has previously been ±100 mHz for at least five minutes or more than ±50 mHz for at least 15 minutes. Regarding the delayed effect of storage management measures, it is due to the fact that a shift in the operating point in the context of memory management is always accompanied by a delayed effect (lag) which delays the restoration of the memory content. This lag must be bridged by an additional work capacity, for the consideration of which an FCR call with a frequency deviation of ± 50 mHz is assumed. The lag is defined by the strategy of storage management measures. The product structure and lead times of intraday trading, as well as the system processing times of the reserve providers, must be taken into account when determining the lag, particularly for storage management measures in quarter-hourly intervals.

The second requirement for those with limited energy storage is that the reserve operator must demonstrate that there is a storage management system for providing unit/group that meets the requirements described in the prequalification procedure document developed by the German TSOs. The use of storage management must allow the providing unit/group to ensure that the reserve available is secured over the duration of the reference value of four hours by shifting the working point in conjunction with compensating energy transactions during the normal state for FCR. The performance balance between shifting the working point and loading/unloading must be guaranteed. Any compensation measures used in the context of storage management (trading transactions, compensation measures in one's own balancing group) must be proven in a suitable form at the request of the TSO.

The third requirement for a providing unit/group with limited energy storage is that the usable work capacity must be demonstrated in the operational test. There are two ways to test this requirement: a third delivery phase is added after the last retention phase, and this phase is performed until the minimum necessary work capacity has been demonstrated, or the reserve operator can repeat the delivery and retention phases in the time stipulated previously as often as is needed until the minimum necessary work capacity is proven. Proof of usable work capacity must be provided at least with the desired marketable performance, and the use of storage management measures is not permitted when determining the usable work capacity.

The fourth requirement is that, in order to always have enough work capacity to be able to provide the entire marketable service for at least 30 minutes in an alert state, suitable storage management measures must be taken to ensure that the work capacity is always within a permitted work area. When determining the permitted work area, the ratio of usable storage capacity E_{USC} to marketable performance P_{MP} is used. The upper C_{uL} and lower C_{lL} working area limit are calculated as follows:

$$C_{uL} = \frac{E_{USC} - 0.25h * P_{MP}}{E_{USC}}$$

$$C_{lL} = \frac{0.25h * P_{MP}}{E_{USC}}$$

The reserve operator must demonstrate that he has identified suitable storage management measures, the use of which ensures compliance with these requirements. The proof comes from the fact that the reserve operator shows that - given a historical frequency curve that the TSO specifies - the algorithm that controls the storage management would have kept the charge level within the permitted working range. In addition to a general description of the algorithm and the simulation process by the control reserve provider, this requires a practical test in the sense of a simulation based on the frequency data specified by the TSO.

The fifth and last requirement for providing unit/group with limited energy storage is an adequate dimensioning of the maximum feed-in or maximum power consumption. A continuous provision with a frequency deviation of just below ± 50 mHz requires that compensating energy transactions of a quarter of the marketable performance must be possible without affecting the FCR activation when fully loaded. The maximum feed-in or the maximum power consumption must therefore exceed the marketable power by at least a quarter, so that despite simultaneous storage management measures, the FCR can be provided in full. Through a higher dimensioning of the maximum feed or of the maximum power consumption, the memory management performance can be increased accordingly.

- Availability

As explained in subsection 3.1.4 of chapter 3, the FCR provider needs to secure the continuous availability of FCR, except in case of a forced outage of a TU. The German TSOs determine that if a fault occurs that leads to unavailability of FCR units or groups, appropriate security must be activated immediately, no later than two seconds after a frequency deviation. If the activation does not take place within these two seconds, the BSP can prove to the TSO this is technically justified.

The failed service must be completely replaced no later than 15 minutes after the end of the quarter of an hour in which the collateralization event occurred. Additionally, each providing unit/group must demonstrate that it is able to continuously activate the entire marketable service over a period of four hours. In the case of providing unit/group with limited energy storage, the use of additional measures as part of the verification is permitted. In the case of providing unit/group with no limited energy storage, a confirmation from the control reserve provider is sufficient.

- Delivery behavior

In order to avoid an artificial delay, the delivery behavior of FCR units and groups is also subject to the requirement of at least linear provision as stated in the SO GL. A (at least) linear provision is defined by the fact that the FCR measured power $P(t)_{FCR}$ at any time after the frequency deviation Δf does not fall below a certain value, which is described by a series of inequalities. The providing units or groups must be activated no later than two seconds after the frequency deviation. Generally, the frequency deviation is between 0 and 200 mHz. Given a response time of the providing unit/group of T_{RT} seconds is the minimum $P(t)_{FCR}$ performance at the time t seconds after the frequency deviation:

$$P(t)_{FCR} = 0 \; for \; t \; in \; the \; period \; 0 \leq t \leq T_{RT}$$

$$P(t)_{FCR} = P_{PQ}.\frac{\Delta f}{200mHz}.\frac{t - T_{RT}}{2.(15s - T_{RT})} \; for \; t \; in \; the \; period \; T_{RT} \leq t \leq 15s$$

$$P(t)_{FCR} = P_{PQ}.\frac{\Delta f}{200mHz}.\frac{t}{30s} \; for \; t \; in \; the \; period \; 15s \leq t \leq 30s$$

$$P(t)_{FCR} = P_{PQ}.\frac{\Delta f}{200mHz} \; for \; t \; in \; the \; period \; t > 30s$$

There is also a requirement for delivery behavior in terms of robustness against frequency deviations.

Specifically, this means that providing units or providing groups must be able to activate FCR in the frequency range from 47.5 Hz to 49.0 Hz for at least 30 minutes, 49.0 Hz from 51.0 Hz for an unlimited time and 51.0 Hz and 51.5 Hz for at least 30 minutes, regardless of the frequency deviation. Each providing unit and group must deliver FCR for the maximum period for which it is able to do this within the respective frequency ranges. The period is therefore determined by the technical capabilities of the providing unit/group.

For the providing unit or providing group that can only provide the service in a certain frequency range, it is required that they prove their service profile is like the ones shown in Figure 19 and Figure 20, either in a positive or negative direction.

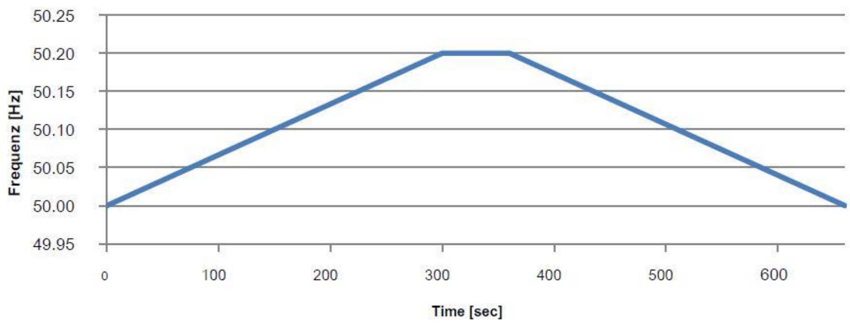

Figure 19: Additional performance profile for non-proportional performing FCR units/groups; positive control direction [29].

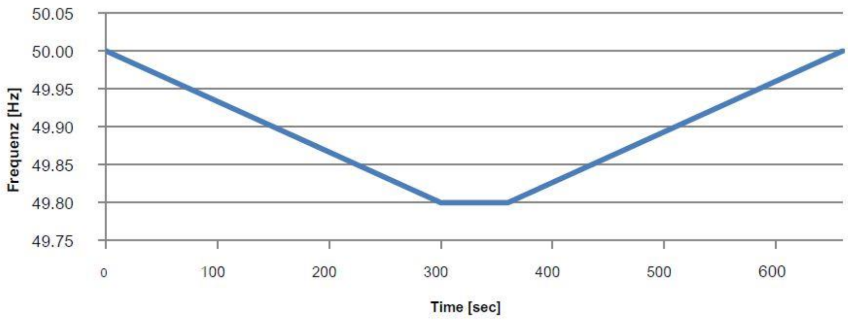

Figure 20: Additional performance profile for non-proportional performing FCR units / groups; negative control direction [29].

- Detection and elimination of faults

The control reserve provider must take appropriate measures to ensure that disruptions in provision are recognized and rectified immediately. Correct provision must be ensured again no later than 15 minutes after the end of the quarter of an hour in which the fault occurred. Disruptions are to be documented in a suitable manner and explained to the connecting TSO on request.

- Frequency measurement

In addition to what was established in the SO GL regarding technical minimum requirements for frequency measurement, the German TSOs determine that the frequency measurement must always be carried out decentralized so that providing unit and providing group can autonomously provide FCR.

They also determine that for each network connection point, at least one frequency measurement must be carried out at any location between a TU and the network connection point. If a TU has several network connection points or if several TUs have a common network connection point, a frequency measurement is sufficient. If several TUs have several network connection points and the TUs are part of one or more closed distribution networks, at least one frequency measurement within the closed distribution network is required.

- Test under operational conditions

Besides the operational test, a providing unit or providing group that wishes to become part of an FCR pool needs to provide a trial run under operational conditions for a continuous period of eight hours. If a TU is added to or removed from a providing unit/group, it is usually not necessary to perform a new test, unless its composition changes significantly overall. In this case, the TSOs reserve the right to request another test.

The FCR trial is carried out by the control reserve provider, who provides the TSO with the recorded data via the prequalification portal. As part of the FCR trial, the data points measured feed-in, measured frequency, setpoint, and operating point must be recorded and transmitted. Besides these points, if a providing unit/group has limited energy storage, the BSP must also measure the work capacity (in both positive and negative directions). Together with the data, the control reserve provider must submit a description that shows how he determines the corresponding setpoints of the participating TU from the measured frequency.

As part of the FCR trial, a failure of the connection of the providing unit/group to the central control unit (e.g. the control system of the control reserve provider or the central control box of a providing group) is simulated and the correct re-connection is checked. During this trial, the control reserve provider must firstly demonstrate that the FCR is correctly provided even if the communication link fails. It is also checked that the corresponding data is recorded decentralized for the duration of the fault and is correctly supplied after the communication connection has been restored. This ensures that the reserve operator can fulfil his obligation to provide evidence even in the event of a disruption. The assumed duration of the failure depends on the security solution of the provider.

- Communication Test

In order to pass on the prequalification procedure, each pool must pass a control test and demonstrate that it complies with the requirements set out for this test. Unlike the operational test, in this test, the control technology test is carried out in close coordination with the TSO. It can last from one to two hours, depending on what is agreed between the BSP and the TSO. The reserve operator must show that his pool is correctly connected to the TSO's control system. This includes the correct recording and transmission of the measured values required as real-time data (see Annex A for the list of real-time data points to be recorded) and the clear reception or the implementation of setpoint specifications. The reserve operator must also demonstrate the robustness of the pool's provision. This includes a regular function test (setpoint specification) under operational conditions and showing that the pool can also deal with technical and operational challenges such as disruptions. One of the conceivable faults that could be simulated in the control test is, for example, the failure of a TU in the pool. In this part, the smooth functioning of the protection by another TU/providing unit/group in case of a failure or malfunction of a TU/ providing unit/group is also verified.

In this process control test, for those wanting to provide FCR services a test delivery under realistic conditions based on the measured frequency deviations must also be performed. Besides that, a review of product specifications for the FCR is made.

4.3.2 Security & Software

As part of the prequalification process, the BSP must provide proof that it complies with minimum requirements defined for the Information & Technology (IT) aspect of the balancing services. These minimum requirements regarding security and software are divided into eight different categories: Availability, operation, network, closed user group, encryption, verification, Saas, and others.

The requirements under the heading "Security & Software" are the following: Reserve provider control system, Reserve provider control system connection to TSO, Closed user group, TU connection and bundling, Additional requirements, External IT service providers.

For this part of the prequalification procedure the BSP must submit the following documents to confirm the IT requirements are met: a comprehensive IT concept, the IT checklist filled out with the corresponding chapter of the IT concept for each requirement and the classification of the information security of documents submitted by the BSP.

- Reserve provider control system connection to TSO

If the marketable power of an FCR provider is higher than or equal to 90 MW and the central control system is required, the German TSOs require that the control system must have a locally redundant design. In this case, these need to be redundantly connected to the TSO's control system if requested by it. The availability of an individual connection between the TSO's and reserve provider's control system must be set and should be of a value similar to 98.5% (availability required for aFRR providers).

The connection between the TSO's control centre and the reserve provider's control system must be based on a dedicated point-to-point control technology. The solution technology for this connection is up to the reserve provider, which can choose to use the classic fixed-line connections or to use new technologies. Another requirement is that the serial interfaces (V.24/V.28) with IEC protocol 60870-5-101 (TSO-specific) must be used, and X.21 instead of V.24 can be used as the interface format if approved by the connecting TSO.

- Reserve provider control system

The first IT requirement regarding the control system is the obligation of duplicating the reserve provider's central control system. These control systems' security must be ensured by the BSP for control reserve. An automatic switch between these two redundant central control systems must appear in maximum 15 minutes.

Another requirement is that the operating location of the data centers used (including the staff) must fulfil the requirements on the law and comply with acknowledged techniques. The delay on the transmission route E2E (End-to-End – from the data logging by the TU through the BSP control system and the receipt by the TSO) must be of a maximum specified by the BSP but should be around the same time required for aFRR of 5 seconds.

- Closed user group

The term closed user group is used to designate connections in the access network provided by a telecommunications provider which are operated by this provider in a closed system. These may be connections to different transmission networks, and a contract should be developed with the telecommunications provider to set up these closed user groups. In this sense, some requirements are set for the use of these connections.

The BSP is responsible for applying for a connection and a closed user group with the telecommunications provider, selecting only those that promptly inform the BSP about any maintenance work that is planned. The contract regarding the closed user group is done between the BSP and the telecommunications provider.

The communication between the TU and control systems must be protected from other networks by using closed user groups, and the TUs should only communicate with each other via the central gateway to the reserve provider’s control system. To secure that, the reserve provider needs to establish a separate E2E encryption (not by the telecommunications provider). Besides that, only closed user groups are permitted in the access networks for the participant connection, and they should only use private addresses, which cannot be accessed by other networks. The network traffic of the closed user group must not have contact with external networks, such as other networks from the telecommunications provider.

The closed user group can only be used to provide control reserve, and any additional data related to the provision of system services may be allowed in discussion with the connecting TSO. The data transferred between the access routers must be transmitted via an encrypted IPsec-VPN tunnel with AES256 or equivalent technologies.

Regarding the use of Internet technologies, it is only allowed in a closed user group established only for this purpose and it has to be provided by the telecommunications provider.

The access router must be configured in a way that all network traffic is routed to the Virtual Private Network (VPN, it means the connection between two private network segments that is established via a network operated by a third party), and any communication outside this tunnel is not permitted. The router configuration needs to be monitored in an automated and daily or weekly basis, with an integrated alert function in order to prevent any prohibited manipulation of the router. The transmission routes are required by the TSOs to be encrypted.

- TU connection and bundling

Each TU must be connected to the BSP’s control system with an availability of at least 95%, being this availability proven either by contracts, by the system or via statistics. If the control system has a locally redundant design, the TU is connected to each of the two control systems, also with redundancy in this connection. A media break to the Internet Protocol (IP) is also required.

Regarding the bundling of small TU, it is permitted via public Internet with encrypted VPN, and closed user groups are not mandatory. A media break with a serial interface between bundled small TU and the pool provider is mandatory.

The maximum size of a small TU is defined to be 25 kW, while the maximum size for bundling of small TU is 2 MW. The connection of a micro installation is only allowed to a pool. An example of a micro installation of balancing services can be seen in Figure 21.

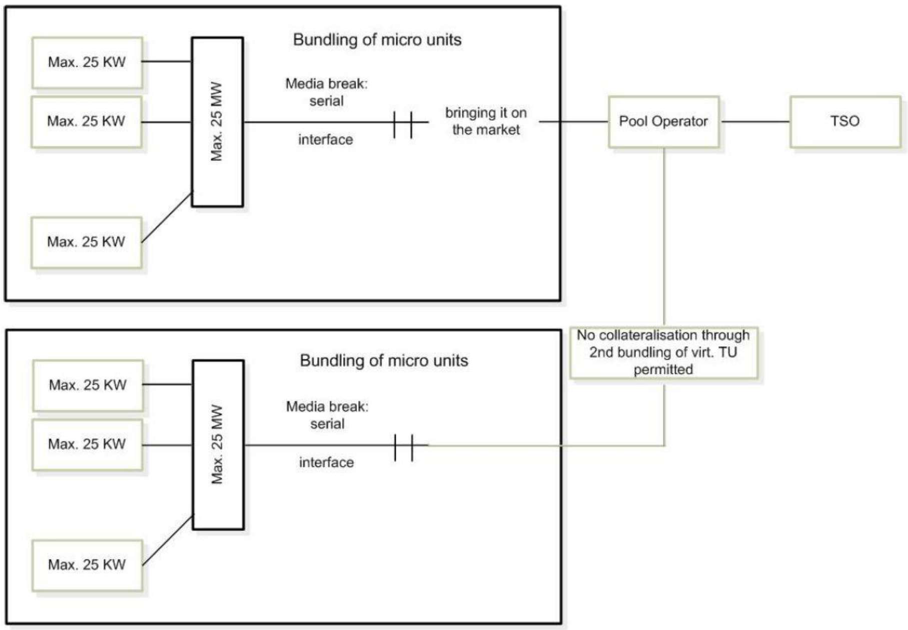

Figure 21: Overview of bundling of micro units [30].

- Additional requirements

Some additional IT requirements that do not fit into the previous categories were also developed by the German TSOs. One of these requirements is that data transfers from and to other networks with a different protection requirement are made through data hubs. They would guarantee that data can be transferred between the network used to provide the control reserve and the other networks with a lower protection requirement without establishing a direct connection between these networks. Besides that, only unidirectional communication from the control system is allowed, and the data hub must have a multi-stage virus protection.

If a fault on parts of the system occurs which does not result in a complete failure, such as compromising the provision of balancing service, the BSP must fix this failure within 24 hours if it happens on a working day. If it does not take place on a working day, the BSP can rectify it on the next working day. The BSP must also ensure the continuous monitoring of the availability of the transmission paths.

Regarding protection, unless it is a micro installation, the BSP must also ensure sufficient protection to the premises, systems and networks required to provide control reserve, while the electrical operating rooms must be locked. The BSP’s devices must also be stored in a sealed safety cabinet secured by an alarm.

The BSP must operate an integrated patch and change management and demonstrate this as part of the prequalification and document the relevant processes. Updates are transferred via the data hub principle independent of the type of system to be updated, whether it is operating system, application or virus signatures, for example. If a technology is endangered, the BSP must notify the TSO, and the BSP must repair it upon request. In the transition period of this repair, alternative technologies should be implemented with the TSO.

- External IT service providers

Special regulations are set for the BSPs that seek services from external IT service providers that offer their services to several BSPs. The first requirement is that the procurement of these services must expressly be disclosed as part of the prequalification and approved by the TSO. In addition to it, BSPs that procure these services are treated as BSPs with the highest protection requirements (that means that requirements applied only to services provided that are higher than a certain marketable power are also applied to these BSPs, even if they do not provide such a marketable power). Despite having their IT services supplied by an external provider, the BSPs take all the responsibility for fulfilling the IT requirements to provide balancing services and are the main contact partner for the connecting TSO. It is also established that IT service providers providing services to several BSPs have to guarantee that the operation of jointly used components does not present any risks to other BSPs.

4.4 Prequalification Process in Portugal

The primary frequency control service in Portugal is considered a mandatory system service, which means that all generators connected to the transmission network regulated by the TSO Redes Energéticas Nacionais (REN) needs to provide this service in a non-remunerated scheme [31]. Therefore, market access for FCR providers through demand response and small units is not possible.

One important point that indicates there might be a possibility of opening the balancing market for demand response providers is the public consultation done by REN in May 2018 in which it proposes terms and conditions for BSPs and BRPs including demand response and distributed generation as potential providers of balancing services [32]. In this document, it is proposed that the terms and conditions will allow the aggregation of consumption installations, energy storage systems and generation systems in order to offer ancillary services to the grid. It will also establish the rules and conditions for the provision of ancillary services by these agents, as well as the prequalification process and all the requirements in order to become a balancing service provider.

4.5 Prequalification Process in Spain

Similarly to Portugal, in Spain primary frequency control is a mandatory service that needs to be provided by every generator connected to the Spanish electricity network, including distributed generators. If a generator cannot provide FCR services, it needs to contract the service from another generator to fulfil its obligations [33].

Although small-scale storage is not able to provide FCR services to the Spanish grid yet, due to the need of implementing the EB GL (which foresees the provision of balancing services through generation, demand and storage sources), a public consultation has been published in order to define a work plan for the participation of storage and demand in balancing markets. In the public consultation, modifications in the current electricity sector law are expected, as well as their minimum bid requirements, which would go from 1 MW to 10 MW and allow the aggregation of technical units for the provision of the services [34]. The expected timeline for the implementation of the new rules was the approval of the new Terms & Conditions by the end of the second quarter of 2019 and the beginning of the participation of small units in the balancing markets in the third quarter of 2020. However, the resolution that approves the new Terms & Conditions related to BSPs and BRPs was released by the end of 2019 and small units cannot participate in the Spanish balancing market yet [35].

In the Terms & Conditions for BSPs and BRPs it is established that, in order to provide balancing services to the grid, they need to go through a prequalification process and the prequalification tests will be specified in the operational procedures' documents. Meanwhile, while these documents are not updated and approved, the prequalification tests to be used are the ones for the participation of system adjustment services in the Resolution of December 18th, 2015, by the Secretary of State for Energy [36].

4.6 Market access comparison between studied countries

Despite all the countries studied being part of the FCR Cooperation (except Portugal and Spain, who do not have an open market for FCR services), the requirements and the prequalification process for each of them can differ greatly. This can be observed in the operational test, in which in Switzerland the service must be continuously provided in full power for 15 minutes, the German TSOs require it to be provided for 13.5 minutes and the Belgian TSO requires 27 minutes of continuous provision during the test. This is due to the maximum activation time of FCR services of each country during provision of the service: while Germany and Switzerland have a maximum activation time of 15 minutes, Belgium has a 30-minute maximum activation time. Therefore, it is understandable that the test to provide FCR services in Belgium has a longer continuous period.

The data to be recorded and shared with the TSO can also considerably differ from one country to the other, being the German TSOs the strictest about it and having a longer list of data to be recorded both online and offline. This can be better seen in Annex A. In the Annex, it can also be noted that Germany not only requires more data to be provided, but also requires more data on a Technical Unit level, while Belgium only requires data from a providing unit or group level.

Another considerable difference between the prequalification processes between these countries is when it comes to security & software requirements. The German TSOs provide an excel file with a checklist of all the requirements related to Information & Technology, totalling 36 requirements, and divided these requirements into different categories, such as Network, Encryption and Closed User Group. The Belgian and Swiss TSOs, however, only publish requirements related to the BSP's control system and its connection to the TSO control system. One plausible assumption is that in-depth information related to Security & Software is only available to the potential BSPs in these countries once they have started the prequalification process.

One important detail that needs to be pointed out is that, despite the Switzerland prequalification process section suggesting it has the least requirements and tests in the prequalification process for FCR services, this may not be true. As it has been mentioned before, after the BSP submits the documents and the list of the providing units, the swiss TSO needs to confirm the documents and, after that, analyses and coordinates the next steps for the prequalification process and the additional requirements for that case. The impression given by the documents provided by the TSO is that it works more closely with the BSP and analyses each case individually, which might indicate a more openness to small flexibility units.

When analysing and comparing all the prequalification processes across the different countries, despite all of them being open to small FCR providers and allowing their aggregation, it is clear that the German prequalification process imposes some restrictions to small FCR units. It is the only country between the ones analyzed with additional requirements to providing units or groups with limited energy storage. Besides that, no pooling across different TSOs areas is allowed, lowering the aggregation potential of small units around the country.

However, it is interesting to note some recent changes made by the German TSOs, showing their intention to allow more balancing services provision through small units. In a recent change in their document “Minimum requirements for the reserve provider's information technology for the provision of control reserve” a new requirement was set, adding the concept of bundling of small units and allowing the connection of micro-installations through a pool. Moreover, the obligation of connecting the technical units through closed user groups is not mandatory for the bundelling of small units, allowing it to happen via public internet with encrypted VPN. This measure represents a simplification in the process for small flexibility providers, since it is less bureaucratic and cheaper to have a connection through public internet than having a closed user group.

It is also interesting to observe that despite all efforts for the establishment of an open balancing market throughout the whole European Union and for allowing smaller providers to participate, not all countries have an open market and allow the participation of Distributed Energy Resources (DER), such as Spain and Portugal. In these countries the provision of FCR services is mandatory and non-remunerated for all generators connected to the transmission network. Fortunately, this is about to change, as these countries have been conducting studies and proposals for modifications in their current market and allow the participation of storage and demand actors to provide FCR services to the grid. These proposals have been developed for them to be aligned with the Electricity Balancing Guideline.

Another aspect to be considered when analysing a potential market to enter to provide FCR services is the possibility of providing these services to other countries without having to do another prequalification process. It is, then, interesting to consider the collaboration of a TSO in the FCR Cooperation project, in which three out of the five countries analysed are already part of. Moreover, as they have import and export limits, it is a good element to consider when deciding in which country to do the prequalification process. In Figure 22 below the map showing the import and export limits of each country participating in the FCR Cooperation project can be seen [37]. Since it is set in the SO GL that the maximum FCR export allowed is 30% of the country's needed FCR and minimum 100 MW, accessing the FCR Cooperation through Belgium or Switzerland would be an advantage. This allows for higher chances in participation in the internal market, as well as of exporting to other market participants of the FCR Cooperation.

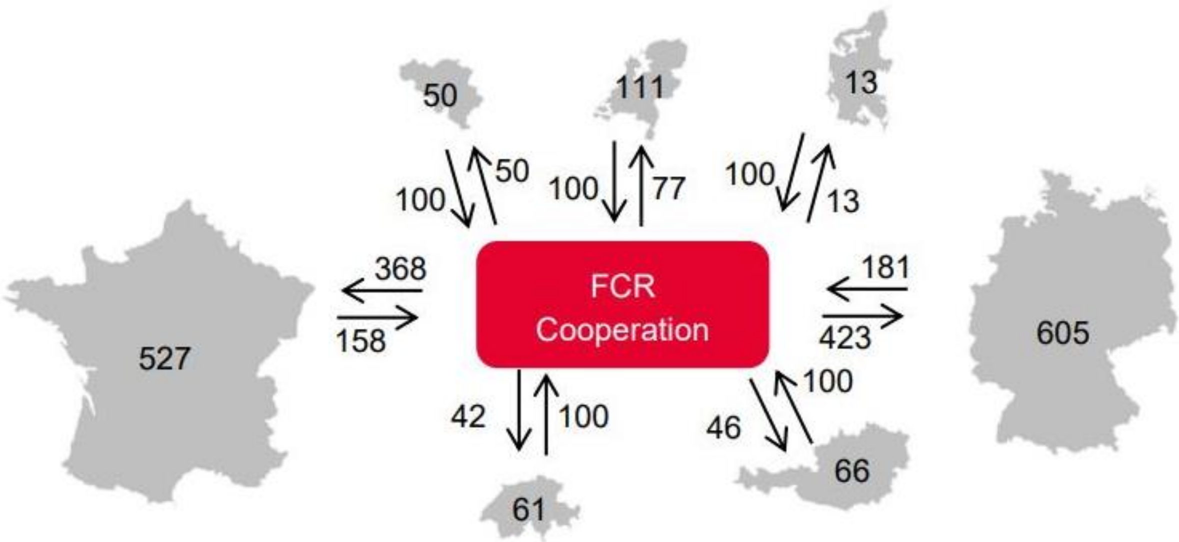

Figure 22: Demand (2019), import- and export limits in MW per country for FCR in MW [37].

In the next page, a table with the comparison of each segment of requirements can be seen. The table is organized in descending order from left to right, starting with the most receptive country to small FCR units to least receptive countries.

Table 5: Overview of the Prequalification Process for selected countries.

	Switzerland	Belgium	Germany	Portugal /Spain
Operation & Control				
Operational Test	Grid frequency is deviated ±200mHz in 10s, and power deviations of providing unit is recorded after 30s. Power must be provided for at least 15 minutes. Dead band is also determined in a test using hysteresis. Each TU of a providing unit is tested separately, but similar TUs do not need to be tested if agreed by the TSO.	Grid frequency is deviated progressively, every 50mHz, and in 13s (200mHz service type) or 20s (100mHz, upward and downward service types) the providing group must reach full power. It must be maintained for 2 minutes before the next step. After reaching the maximum volume, it must be maintained for 27 minutes. The max FCR power to be offered by the providing group is determined by this test and the test under operational conditions.	Grid frequency is deviated ±200mHz and the providing unit/group has 30 seconds to reach the setpoint for the first time. It has 90 seconds after the beginning of the frequency deviation to reach the stationary level and constantly provide full power, and it needs to be provided in this way for 13.5 minutes. After 15 minutes of this test, the test is repeated in the opposite direction. All TUs of all providing unit/group must complete the first operational test simultaneously.	-
Test under operational conditions	No tests under operational conditions are specified by the TSO.	Test duration: 4 hours. If there is a frequency deviation >40mHz, the TSO verifies if the BSP has responded accordingly.	Test duration: 8 hours. The data points measured feed-in, measured frequency, setpoint, and operating point must be recorded and transmitted. In case of limited energy storage, work capacity must also be measured in both directions. Failure of the	

			connection to the central control unit is simulated and the correct re-connection is checked. Showing FCR is correctly provided even if the communication link fails is required. Corresponding data is recorded decentralized for the duration of the fault and is correctly supplied after the communication connection has been restored.	
Additional req. for limited energy storage	There are no additional requirements in case the providing unit or providing group has limited energy storage.	There are no additional requirements in case the providing unit or providing group has limited energy storage.	Working capacity of the energy storage device must reach or exceed two differently defined lower limits. An energy storage management system for the providing unit/group must be proven. Adequate dimensioning of maximum feed-in or power consumption is required.	-
Availability	100% availability during tender period. If a fault occurs and it is not the BSP's fault and the availability is 99.9% or higher, no penalties apply. Penalties are applied for availability lower than that or between 99.9% and 100% that are proven to be the BSP's fault.	100% availability during tender period. In case of a fault or forced outage, the BSP needs to still provide the contracted power by transferring part or all of the contracted power to a Counterpart BSP. Capacity availability and energy availability tests can be performed to prove its availability.	100% availability during tender period. In case of a fault, appropriate measures must be activated in maximum 2 seconds after the frequency deviation. Failed service must be replaced no later than 15 minutes after the end of the quarter of an hour in which the collateralization event occurred.	-
Delivery	At least linear provision. Activation starts	At least linear provision. Activation starts at	At least linear provision. Activation starts at	-

behavior	at least 3 seconds after frequency deviation.	least 2 seconds after frequency deviation. Providing groups need to provide their services for as long as the deviation occurs; in case of limited energy storage, it needs to provide for at least 25 minutes and 2 hours, maximum, to regenerate its energy reserve.	least 2 seconds after frequency deviation. FCR services must be provided in the frequency range from 47.5 Hz to 49.0 Hz and 51.0 and 51.5Hz for at least 30 minutes and between 49.0 Hz from 51.0 Hz for an unlimited time. In case of limited energy storage, service must be delivered for the maximum period for which it is able to do it.	
Detection and elimination of faults	BSP needs to immediately inform the TSO of the fault. Elimination of fault is not specified by the TSO.	BSP needs to immediately inform the TSO of the fault, and one hour later give specific information about it. Correct provision on the first possible quarter-hour after the occurrence of the fault must be ensured, and he has 6 hours to find a backup solution.	Disruptions are to be documented and explained to the connecting TSO on request. Correct provision must be ensured again no later than 15 minutes after the end of the quarter of an hour in which the fault occurred.	-
Frequency measurement	Accuracy tolerance must be below 10mHz.	Accuracy tolerance must be below 10mHz. Setpoint frequency is 50Hz. In case of virtual providing group, each providing unit must have one frequency measurement equipment.	Accuracy tolerance must be below 10mHz. Each network point needs to have one frequency measurement equipment, regardless of how many TUs are connected.	-
Communication Test	Monitoring test is performed to check if the connection between the network controller, monitoring system and offering system is correct and data can	Nomination communication and real-time communication are tested. BSP must show the correct recording and transmitting of real-time data required.	Can last from one to two hours. BSP must show its pool is correctly connected to the TSO's control system. Including the correct recording and transmission of the measured	-

	be exchanged.		values required as real-time data.	
Security & Software				
BSP connection to TSO	Swisscom LAN interconnected network. Point-to-point control technology. Transmission protocol: IEC 60870-5-104. PIA is allowed.	Redundant communication channel between BSP and TSO. For data transmission, bidirectional link in the software TASE2/ICCP is recommended.	If the marketable power of a BSP is ≥90 MW and the central control system is required, the control system must have a locally redundant design. Point-to-point control technology.	-
Data availability	99.5%	95%	≈98.5%	-
BSP control system	No specific requirements.	Real-time communication system and its processes must be redundant. BSP's control system must have two different UPSs with minimum 8 hours of autonomy.	BSP's control system must be redundant. Automatic switch between these two redundant central control systems must appear in maximum 15 minutes. Delay on E2E transmission route must be of maximum around 5 seconds.	-
Closed user group	No specific requirements.	No specific requirements.	BSP is responsible for applying for a connection and a closed user group with the telecommunications provider. TU and control systems must be protected from other networks by using them. TUs should only communicate with each other via the central gateway to the reserve provider's	-

			control system.	
TU connection and bundling	No specific requirements.	No specific requirements.	Availability of TU connection to BSP's control system: 95%. Bundling of small TUs is allowed via public internet with encrypted VPN; closed user groups are not mandatory. A media break between bundled small TU and the pool provider is mandatory. Maximum size of a small TU is 25 kW, and maximum size for bundling of small TU is 2 MW. The connection of a micro installation is only allowed to a pool.	-
External IT service providers	No specific requirements.	No specific requirements.	Procurement of these services is disclosed as part of the prequalification process and approved by the TSO. BSPs that seek these services have the highest protection requirements.	-
Additional req.	No additional requirements.	No additional requirements.	Data transfers from and to other networks with different protection requirements are made through data hubs. Protection to the premises must be guaranteed; electrical operating rooms must be locked.	-

Chapter 5

Case Study

In this chapter, the pilot project Coffee2Grid developed between the start-up KOENA tec and its partners is presented and analysed. The pilot project aims at proving the techno-economic feasibility of aggregating professional coffee machines to provide FCR services to the grid. First, the stakeholders involved in the project are presented, followed by the description of the project and the espresso machine used in the pilot project. After that, a prequalification process is simulated using data analysis provided by KOENA tec in order to determine that minimum number of coffee machines that need to be aggregated in the prequalification test to be able to market 50kW of FCR services to the grid.

KOENA tec is a German start-up that provides data analysis and energy efficiency tools for consumers through its smart plug, focused on the gastronomy sector. It is currently developing a pilot project with Gruppo Cimbali, a traditional espresso machines manufacturer, BKW AG, a power generation and distribution utility company, and Vassalli AG, the only distributor of Cimbali machines in Switzerland, to offer balancing services to the grid through industrial espresso machines in Switzerland.

The pilot project goal is to successfully provide data-driven energy efficiency advice for operators of espresso machines, as well as to prove it is economically feasible to aggregate these espresso machines as small flexible power assets in order to provide ancillary services to the grid through BKW's virtual power plant.

The main objective of this case study is to analyze the pilot project for FCR services using traditional coffee machines and to determine the minimum number of coffee machines that need to be aggregated in order to pass in the prequalification process in Switzerland to provide 50 kW of flexible power to the grid.

5.1 Stakeholders

5.1.1 KOENA tec

KOENA tec is a German start-up founded in 2017, which provides electricity data analysis for consumers through its KOENA Energiebox – an intelligent and internet-compatible adapter plug that can be attached to any plug, analysing individual power consumption which can be seen in an online dashboard. Its target markets are energy consultants, device manufacturers and the gastronomy sector. For device manufacturers, it is specialized in catering equipment, making them IoT-capable with their Smart Plug and enabling energy monitoring of the device, energy efficiency control, power grid adjustment and predictive maintenance.

In the pilot project, KOENA tec uses its expertise to develop a plug-and-play metering and control hardware to be used as an interface between Cimbali's espresso machines and BKW's energy trading systems. It will also implement the software and IT-concept compatible with the grid operator and BKW requirements. Besides providing balancing services to the grid, KOENA tec will also provide its usual services to the customers, providing energy monitoring and energy efficiency analysis services. Moreover, KOENA tec's tasks in the pilot project include the systems' installation at customers' premises with coordination with the national distributor and project management of the pilot project.

5.1.2 BKW Energie AG

BKW Energie AG is a power generation and distribution utility company based in Switzerland, with headquarters in Berne. It has about 10,000 employees, and it is also present in Germany, Austria and

Italy. It was founded in 1898, and nowadays its portfolio is composed of not only electricity production, but also engineering consultancy, infrastructure and environmental projects and construction and maintenance of energy, telecommunications, transport and water networks.

In order to expand its portfolio and offer an extensive range of energy solutions, BKW invests in pilot projects related to Demand Side Management, like iSMART Ittigen, which offered 5 pilot products to 265 customers with smart meters, such as products for PV monitoring, load and/or peak shaving and energy efficiency. They are also involved in the AMPARD pilot project, which aggregates the flexibility of Home Batteries to a virtual power plant for primary control, which is sold in turn to Swissgrid [38].

With that in mind, the partnership with KOENA tec is aligned with its objectives of expanding and diversifying its portfolio and services provided. In this pilot project, BKW has the vital role of integrating the flexible coffee machines into its energy trading portfolio, allowing for these devices' services to be allocated into a pool and offered in the balancing market. They also offer support for technical requirements related to the installation, metering and ICT communications from the locations to the interface at BKW control center, as well as financial and implementation support related to the prequalification process.

5.1.3 Gruppo Cimbali S.p.A.

Cimbali is a professional coffee machine manufacturer, funded in 1912 in Milan, Italy. Their main office is still based in Milan, with all four factories in Italy, but they have branch offices in several other countries. Their portfolio includes traditional machines, fully automatic machines, grinder dosers and accessories such as fridge, cup warmer and milk cooler.

In the pilot project analyzed in this case Gruppo Cimbali has several roles, besides manufacturing the coffee machines to be used. First, they offer support to KOENA tec in coordinating with the national coffee distributor for permission for them to install the metering and control modules. Their second responsibility is for the development support in extending the IoT protocol of the traditional coffee machine model to be used, enabling software updates that will implement the smart-grid temperature control proposed by KOENA tec.

5.1.4 Vassalli Service AG

Vassalli Service AG is a swiss distributor of industrial coffee machines, founded in 1961. It has the exclusive distribution and sales of the La Cimbali coffee machines in Switzerland. They offer consultancy to their customers on coffee machine purchases, as well as the installation, training on the use of the acquired machine, mobile services and regular maintenance. In the pilot project, Vassalli Service AG provides some of their selected customers that use Cimbali espresso machines to be outfitted with the KOENA tec plug and with a software update to the Cimbali IoT communication protocol, serving as a bridge between the espresso machine owners and the pilot project.

5.2 Description of the project

The main goal of the pilot project between all the partners described previously is to prove the viability (both technical and economical) of integrating espresso machines from the gastronomy sector to be used as a virtual power plant to provide frequency containment reserve services to the grid. The validation of this pilot project showing this is an attractive business opportunity will enable these partners to enter the German market with strategic advantage and a profitable, sustainable, green business model. It will also enable an expansion to other markets in other countries, such as the ones where the market access analysis was made previously in this thesis.

KOENA tec's Smart Plug is a plug-and-play device that, once connected between the appliance and the power socket, enables the measurement of electricity consumption and sends this data to KOENA tec's cloud server. Their servers, then, analyze the usage pattern of this appliance and offers recommendations to the customer on adjustments that can be made in order to save energy and money. Figure 23 below shows a summary of the smart plug functioning and its services provided.

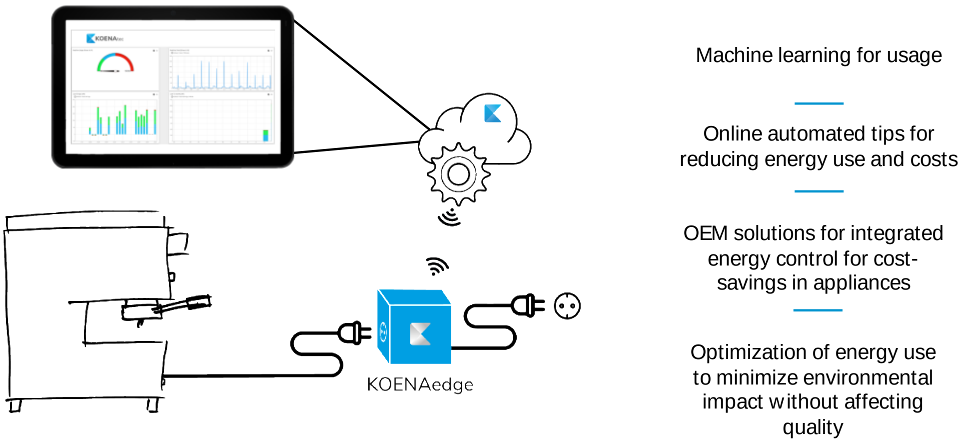

Figure 23: Summary of KOENA tec's smart plug functionalities.

In addition to the mentioned services, with the software updates and extension of IoT protocol of the coffee machines, the smart metering device will also be able to control the temperature of the coffee machines, thus providing FCR services to the grid.

The business model of this pilot project is based on two core ideas: first, the energy savings lead by the use of the smart plug, and second, the revenues coming from the FCR services to the grid. The energy efficiency gains in the restaurant is the main driven force of the project. In the target scenario, after the pilot project proven to be successful, the restaurant buys the measuring and control devices as an "add-on" when purchasing the machine. For an annual service fee, the energy savings are monitored by KOENA tec and continuously optimized. Within this annual service fee, KOENA tec also ensures Vassalli's maintenance and customer services. For the pilot project, the smart plug and a two-year subscription to KOENA tec's monitoring and optimization services.

As for the FCR services to the grid revenues, the aim of the pilot project is to prequalify and provide 50kW of FCR using traditional espresso machines from the brand Cimbali. In the pilot project, the price model for FCR delivery is bundled with the energy efficiency service, meaning that the profits coming from the FCR services will not be shared with the restaurants in the pilot project phase, and the energy efficiency service for two years and the smart plug should be enough as an added-value to them.

At the IT level, the proposed solution consists of connecting the espresso machines and KOENA tec's metering plug to their central energy monitoring server, which is in turn connected to their energy market communication server. Through an Ethernet Protocol the data is then sent to BKW through a Closed User Group to BKW's Trading Platform, where the pool of coffee machines is aggregated to other virtual power plants to allow them to participate in the balancing market, as the minimum bid in it is 1 MW.

It is important to mention that there is no control signal from the transmission grid operator to the coffee machines, which means swissgrid cannot control the coffee machines. All the control signals come from KOENA tec's servers through the metering plugs. The metering plugs receive modes of control for the appliances, informing the plugs and espresso machines how reactions to frequency changes should be parameterized. An espresso machine will only respond to these modes of control and adjust their power usage if they will not compromise the quality of the product, which is set as a priority over balancing services requests. A schematic of the IT concept of the pilot project can be seen in Figure 24.

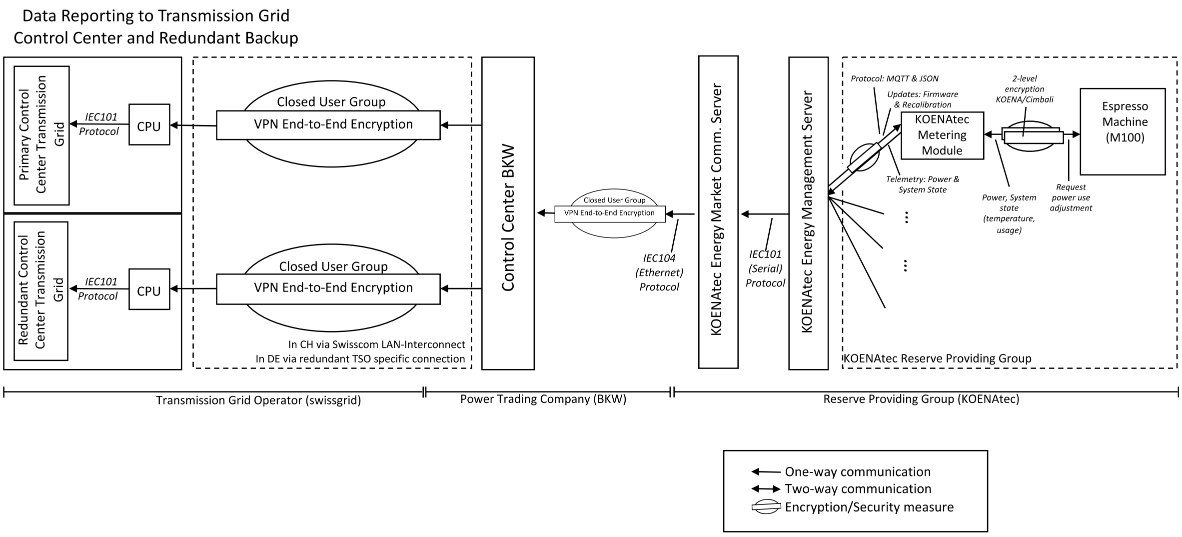

Figure 24: IT concept of pilot project between KOENA tec, CImbali, BKW and Vassalli.

5.3 Espresso Machine

Espresso machines are, as the name suggests, machines used to make coffee beverages. Their sizes and functionalities can vary, but their principles can be of either one of the two types: either a heat exchanger boiler type or a dual boiler type. Since the espresso machines used in the pilot project are of the heat exchanger type, an explanation will be given only for this particular type.

The most common one is the heat exchanger boiler type, in which the water in the coffee boiler is heated through a hot water & steam boiler when wrapped inside this main boiler. It is also possible that there are heat exchangers boilers wrapped inside the hot water & steam boiler, which then, through convection, delivers the heated water to the coffee boilers. In the heat exchanger configuration type, the temperature of the hot water exiting the heat exchanger depends on several parameters: the temperature of the hot water & steam in the main boiler, the surface area of the heat exchanger wrapped inside the main boiler, the temperature of the water entering the heat exchanger and the mass flow rate.

The temperature of both the coffee boiler and the hot water & steam boiler can be adjusted by the person operating the machines, but there are certain ranges at which these parameters should be maintained. The ideal temperature range of a coffee boiler should be between 90°C and 96°C to ensure the quality of the coffee, while as for the pressure of the boiler the hot water & steam boiler should be set at around 1.2 bar and the pressure of the coffee boiler is at around 9 bars [39].

The coffee machine used in the pilot project is the M100 GTA manufactured by LaCimbali. It has 3 groups of coffee boilers, as well as features such as a system that allows the customer to change the water temperature and infusion time as desired, expanding the range of beverage offered. The technical specifications of the coffee machine can be seen in Table 6 and Table 7.

Table 6: Technical Specifications of the Coffee Machine M100 GT Attiva manufactured by Cimbali [40].

	P_{max} [bar]	T_{max} [°C]	Fluid	Capacity [l]
Service boiler	2	133	Water/steam	10
Heat exchanger	12	133	Water	0.22 x 2
Coffee boiler	12	160	Water	0.40 x 3

Table 7: Electrical Specifications of the Coffee Machine M100 GT Attiva manufactured by Cimbali [40].

Installed Power [W]	6700-8000
Power Supply	220-240 V~ 220-240 V3~ 50-60 Hz 380-415 V3N~
Dimensions L x D x H [mm]	1032 x 567 x 582

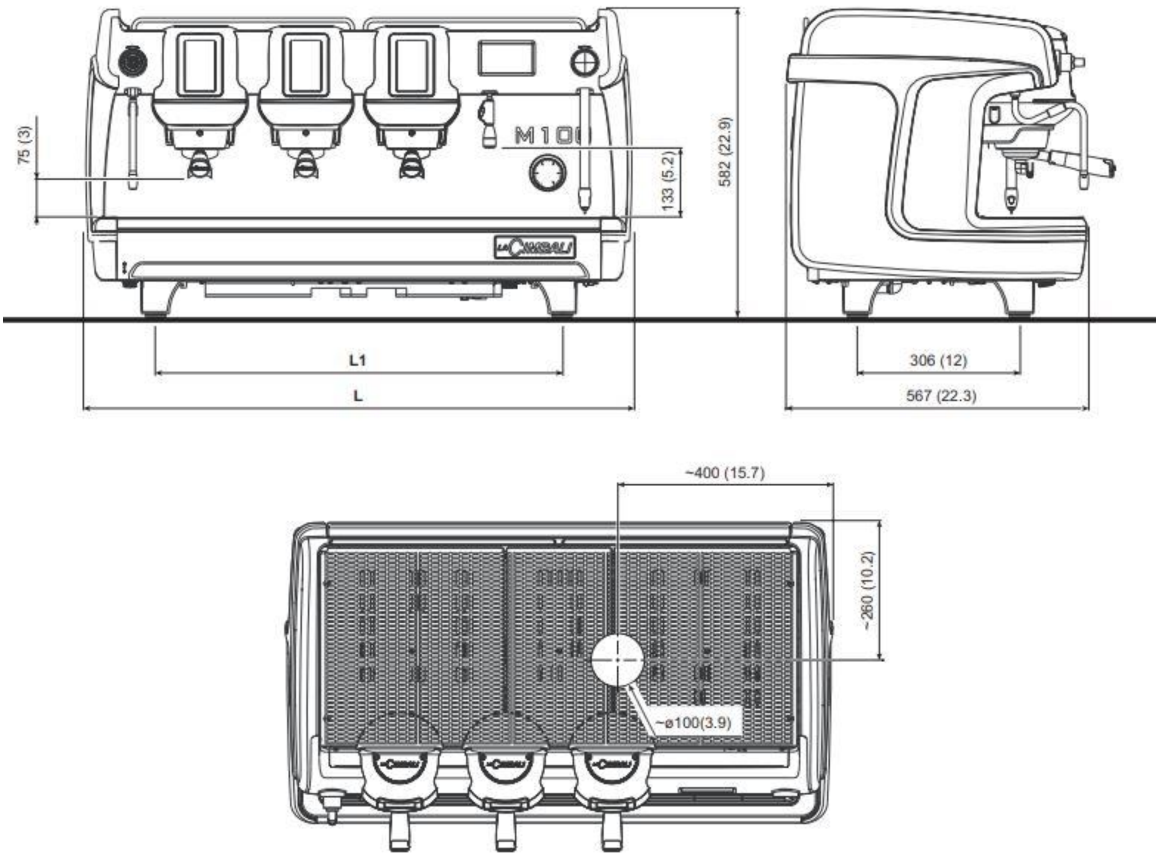

Figure 25: Drawings with dimensions of the coffee machine M100 GT Attiva manufactured by Cimbali [41].

5.4 Prequalification Test

As explained in detail in the previous chapter, each TSO in a synchronous area developed a prequalification test in order to assure the compliance with local regulations of the providers' system to deliver balancing services to the grid. For Switzerland, Swissgrid determined that an important assessment is the Capability Test, where the FCR providing group needs to provide its services to the grid, maintaining the same power within a range, for 15 minutes in each direction (positive and negative).

As explained before, in the activation of test signals, the nominal speed or grid frequency is reduced or increased from 50 Hz to either 49.8 or 50.2 Hz within 10 seconds, and the power deviations of the providing unit are recorded after 30 seconds. After that, the FCR service must be fully activated within 30 seconds of the frequency deviation, and it must be provided for at least 15 minutes. For this test, the power measured accuracy needs to be 5% of the nominal value, and the minimum and maximum threshold when reaching full activation must be 10% of the difference between power before activation and power when service is fully activated.

In this quantitative assessment, a simulation of the Capability Test will be made in order to determine the minimum number of espresso machines that need to be aggregated to successfully pass the test and provide FCR services to the Swiss grid. The goal is to be able to provide 50 kW of power to be pooled together with the virtual power plant portfolio of BKW. The methodology used for the proper analysis and results will be explained in detail in the upcoming subsections.

5.4.1 Methodology

In order to do the prequalification test simulation to determine the minimum number of coffee machines that need to be aggregated to pass this test in Switzerland, data analysis of an industrial espresso machine was performed. KOENA tec, in collaboration with one of the partners, connected one espresso machine to its KOENA Energiebox for data measurement. The espresso machine was installed in an average-sized café & bar in Stuttgart, Germany, and it serves hot and cold beverages, as well as snacks and drinks. Data was collected from March 2019 until March 2020, however, due to technical reasons related to the data acquisition, for the scope of this thesis only the data for the period of 61 days, from October 1st until November 30th of 2019, was analyzed.

For the data acquisition, the heating cycle data of the coffee machine was provided by KOENA tec, and a program in RStudio was written to be able to open, read and plot the data. The data of the power consumption is represented as a function of time and hence the period of time observed can easily be narrowed if required.

The calculation of the number of coffee machines to be aggregated for the prequalification test is done by analyzing the heating cycle of an espresso machine with similar specifications as the *Cimbali* one and applying the appropriate margin increase given the difference in the installed power between the two coffee machines. Different calculations were made for the provision of FCR services in the positive direction (injection to the grid) and negative direction (energy storage) given the heating cycle structure of an espresso machine.

By making an initial examination of the data available, it was concluded that since the hot water/steam boiler is only turned on during brief periods, it is not a good source for FCR services in the positive direction. The hot water/steam boiler will be used for energy storage, while the coffee boiler, which presents a more stable power consumption for a longer period, will be used to reduce the coffee machine's energy consumption. Moreover, as the energy consumption of both boilers is cyclical, the coffee machines will be divided in groups that will be aggregated together, meaning that when a group is providing FCR services, the other groups will not contribute to the service, and as soon as it stops either injecting energy or storing energy, a new group will be turned on.

5.4.2 Available Data

KOENA's Energiebox data collection is done by collecting power data from the three phases of the coffee machine separately in seconds resolution and continuously transfers them to the main server. The three phases are connected to the electrical equipment in the following manner: phase 1: hot water/steam boiler and coffee boiler, phase 2: coffee boiler, phase 3: hot water/steam boiler and a pump.

To simplify the data analysis and calculation, when collecting and plotting the heating cycle of the espresso machine the three phases were summed and they cannot be differentiated in the graphs. However, to clarify the heating cycle of the coffee machine, an example of a heating cycle with the different phases of the machine was made and can be seen in Figure 26.

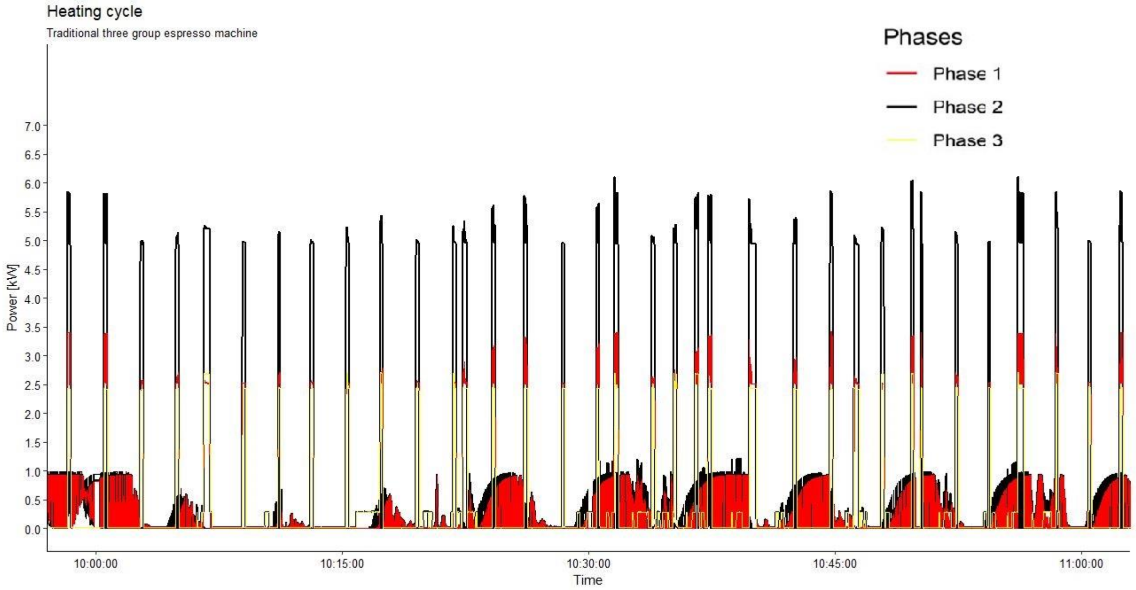

Figure 26: Heating cycle of a coffee machine.

In the graph it is worth making note of the occurrence of recurring high peaks, which represent the heating of the hot water and steam boiler to maintain the temperature at the optimum setting. In phases 1 and 2 periodical and more flattened power usage signify the Proportional Integral Derivative (PID) controller is working to maintain the water temperature of the coffee boiler at the ideal temperature.

The coffee machine selected is a La Marzocco Linea Classic model EE. Although the data analysis was not performed for the same coffee machine model as the one that will be effectively used to provide FCR services to the grid, they have similar operating modes and specifications. In Table 8 and Table 9 below the technical and electrical specifications of the La Marzocco Linea Classic model EE can be seen.

Table 8: Technical Specifications of the Coffee Machine Linea Classic model EE manufactured by La Marzocco [39].

	Pmax [bar]	Fluid	Capacity [l]
Service boiler	3	Water/steam	11
Coffee boiler	16	Water	5

Table 9: Electrical Specifications of the Coffee Machine Linea Classic model EE manufactured by La Marzocco [39].

Installed Power (min-max) [W]	4930-7790
Power Supply	200 V~ 220 V-V3~ 380 V3~
Dimensions L x D x H [mm]	930 x 560 x 455

By comparing these specifications with the ones of *Cimbali* M100 GT Attiva, it is clear that they both have similar specifications, with the ones from *Cimbali* having a higher average installed power: while the average of the *Cimbali* espresso machine is 7350W, the average of the *La Marzocco* one is 6360W. Given this power difference, it was decided to apply a margin increase of 15% in the calculations, as the *Cimbali* espresso machine has about 15% more installed power than the *La Marzocco* one.

5.4.3 Results and Discussion

- Negative Control Direction

Looking more closely at the heating cycle of the espresso machine (Figure 27), it is clear that the hot water/steam boiler consumes about 5kW power for about 12 seconds when no coffee is being prepared, and that the distance between two peaks is, on average, of about 120 seconds.

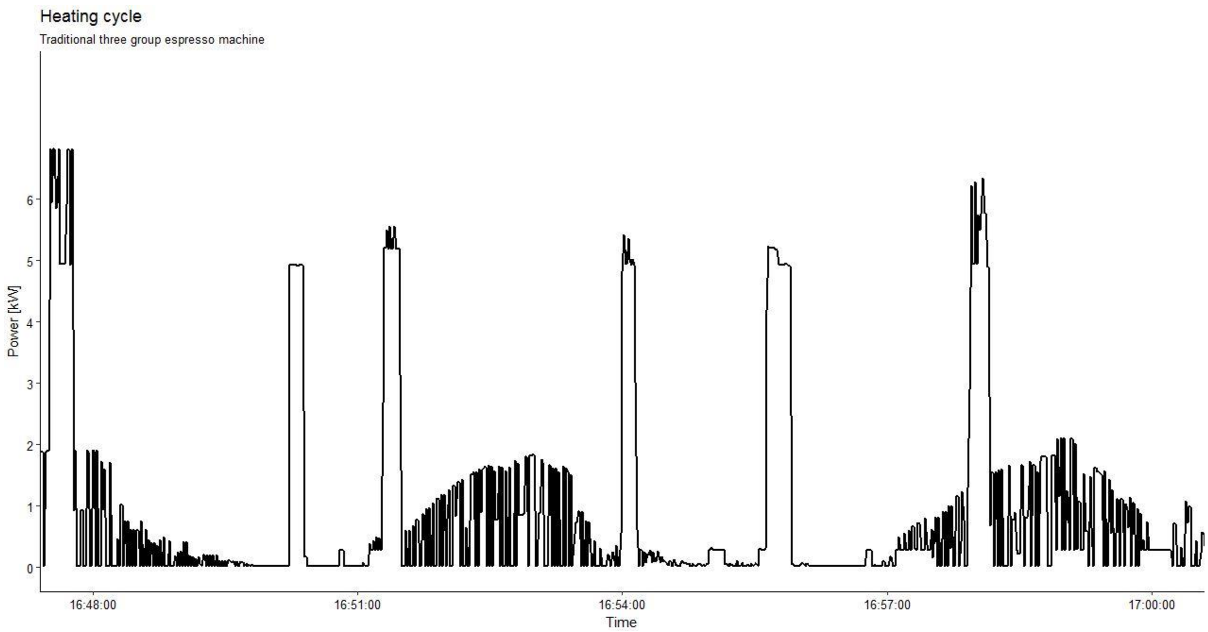

Figure 27: Heating cycle of coffee machine La Marzocco on October 10th, 2019.

By applying a margin increase of 15%, one coffee machine can store energy when needed by the grid with a power of 5.75kW for 12 seconds. Enabling the coffee machine to store energy for a longer period with the same power could potentially compromise the quality of the beverages served, as the boiler would achieve a higher temperature than the optimum one for coffee serving. In order to avoid that, the coffee machines were divided into groups, and each group would operate for 12 seconds by providing FCR services in the negative direction. These would then have a "resting period" of 120 seconds, while other groups of coffee machines provide the balancing service needed to the grid. Considering the total length between the start of the first group and the end of last group of coffee machines (132 seconds), a total of 11 groups are needed to pass the prequalification test for the swiss market.

For the calculation of the number of coffee machines each group is composed of, the following calculation was done:

$$\frac{50\ kW}{5\ kW * 1.15} = 8.7\ coffee\ machines$$

Rounding it up gives a total of 9 coffee machines per group. Multiplying it by the number of groups needed gives the total number of coffee machines that need to be aggregated to pass the prequalification test in the swiss market for FCR services in the negative direction, marketing 50kW power: **99 coffee machines**.

- Positive Control Direction

To provide balancing services in the positive control direction, only the coffee boiler is going to be used. From analyzing Figure 28, it is possible to see that the coffee boiler, although not reaching a peak power as high as the hot water/steam boiler, consumes energy for a longer, more stable period when being heated to reach the optimum temperature for coffee beverages, which is considered the base load of the coffee machine. It is also interesting to note that the coffee boiler spends, on average, two minutes on and two minutes off. Comparing it to the negative direction case, this implies a higher number of coffee machines per group are required to be able to provide 50kW of power.

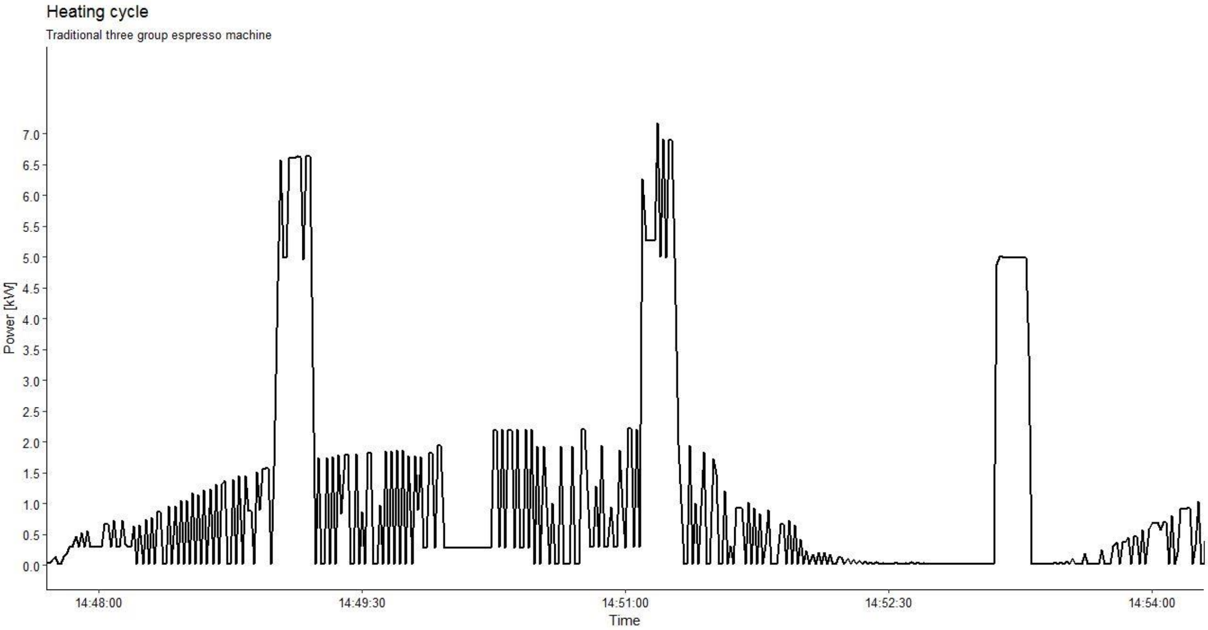

Figure 28: Heating cycle of coffee machine La Marzocco on October 10th, 2019.

As for the power each coffee machine can inject to the grid, the power consumption pattern of a coffee boiler varies greatly, ranging from 0 to 2kW in a matter of seconds. Applying the same margin increase of 15% used for the negative control direction, one coffee boiler of a *Cimbali* coffee machine has a peak power of 2.3kW for 120 seconds.

As the coffee boiler is turned on when the temperature reaches the minimum allowed to ensure the product quality (about 90 degrees Celsius) and it is turned off when it reaches the maximum allowed (96 degrees Celsius), that means that every minute the temperature of the coffee boiler will vary 3 degrees Celsius. This can be better seen in the Figure 29 and Figure 30 below, considering a group of 16 coffee machines.

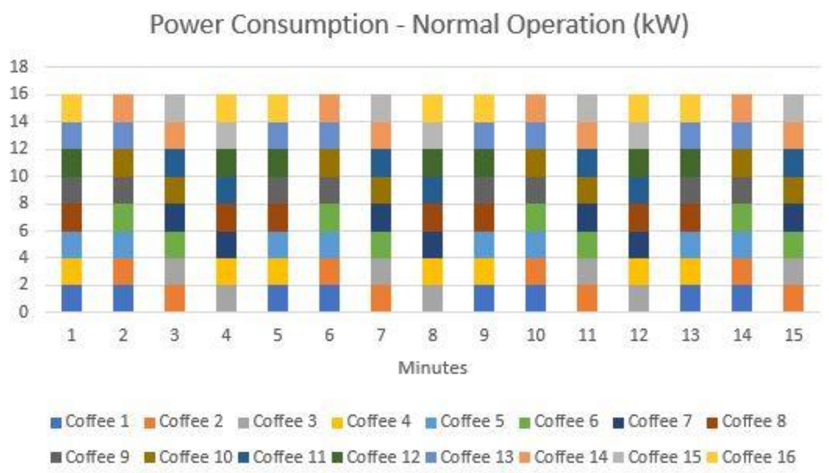

Figure 29: Simulation of power consumption during normal operation of coffe boilers of 16 coffee machines.

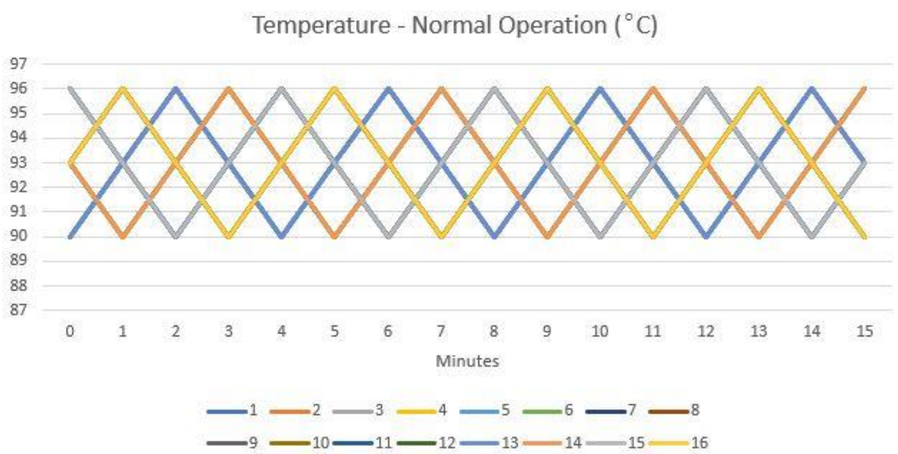

Figure 30: Simulation of temperature during normal operation of coffee boilers of group of 16 coffee machines in Celsiues degree.

Following this logic, that means that if instead of 2kW of power is consumed, the coffee boiler consumes half of it (1kW), the temperature of the boiler will be maintained. Thus, if optimal temperature is reached, less power can be consumed during the participation in the FCR services to the grid.

For the simulation of the prequalification test in the positive control direction, the change in the normal operation of the coffee boiler was applied and a decrease in the power consumption was made, considering that in the 15 minutes of the test the coffee machines will vary their temperature from the highest possible to the lowest. In order to rationalize the quantity of coffee machines to be used in the prequalification test, the optimal temperature range of the coffee boiler was extended to 89.5-97°C instead of 90-96°C. The simulation of the FCR participation of a group consisting of 16 coffee machines can be seen in Figure 31 and Figure 32.

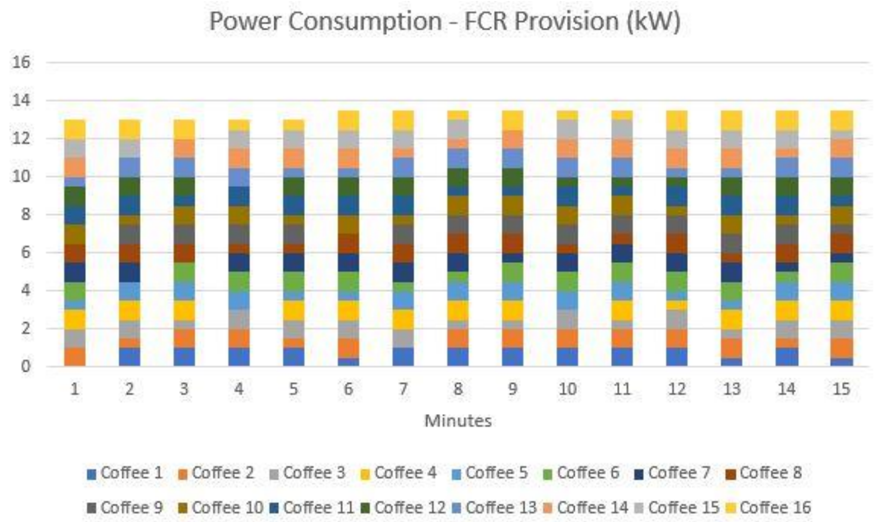

Figure 31: Simulation of group of 16 coffee machines power consumption during prequalification test in positive direction in kW.

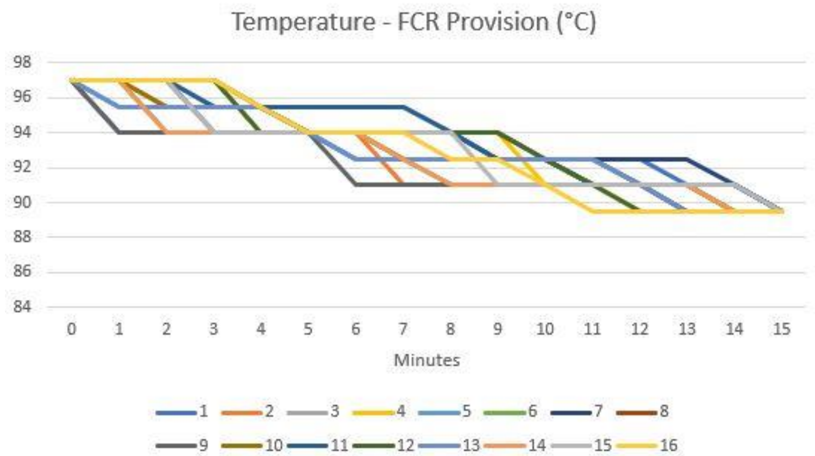

Figure 32: Simulation of temperature during prequalification test of coffee boilers of group of 16 coffee machines in Celsiues degree.

As it can be seen by comparing the two tables, by reducing the power consumption while maintaining an acceptable temperature, each minute the group of coffee machines can provide 2.5kW of FCR services to the grid in the positive control direction. Applying the margin increase due to the different nominal power of the Cimbali coffee machine, a group of 16 Cimbali coffee machines can provide 2.875kW of FCR services in the positive direction during the 15 minutes of the prequalification test. Thus, in order to be able to market 50kW of power in the swiss electricity grid, a total of **278 coffee machines** need to be aggregated.

KOENA tec and its partners have planned to aggregate between 50 and 75 coffee machines for the prequalification test in the swiss FCR market. The results through data analysis of the heating cycle of a coffee machine are higher than the expected value by the start-up. This difference can be related to the fact that, although having a similar technical specification, the coffee machine to be used in the prequalification test and the one with available data provided by KOENA tec might have a slightly different power profile. This can result in a smaller gap between one peak power from the hot water/steam boiler and another for the Cimbali coffee machine, which means that fewer groups of coffee machines would be necessary during the prequalification test.

However, the main cause of the difference between the results presented in this thesis and the ones expected by KOENA tec is that, when the company performed calculations of the number of machines to be aggregated, the company assumed the test would not be performed during operation hours. In this sense, the optimal temperature range of the coffee boiler was not considered, and the temperature range during FCR services was greater than the allowed for maintaining the quality of the beverages served.

One possibility to reduce the number of needed coffee machines is to schedule the prequalification test for when the coffee machines are being turned on. At this time, the boilers require constant power for a longer period, as can be seen in Figure 33. Although this might be feasible, in the sense that a prequalification test can be scheduled for a time when the coffee machines are off and only turn them on when the test will begin, it is not a realistic method, as once a pool is prequalified to provide FCR services, these services might be provided during operational hours, when the restaurants or cafés are working and might be serving beverages.

Another possibility to reduce the number of coffee machines to be aggregated is to have less groups of coffee machines for the test in the negative direction and having the groups in the positive direction to operate for a longer time. Once again, although this is feasible, it is not a recommended measure to apply during the prequalification test. One of the main cores of the pilot project is to create added value to the coffee machine users and, if this method is applied, there is a high risk of the boilers achieving an either higher (negative control direction) or lower (positive control direction) temperature than desired, which will potentially compromise the quality of the beverages served.

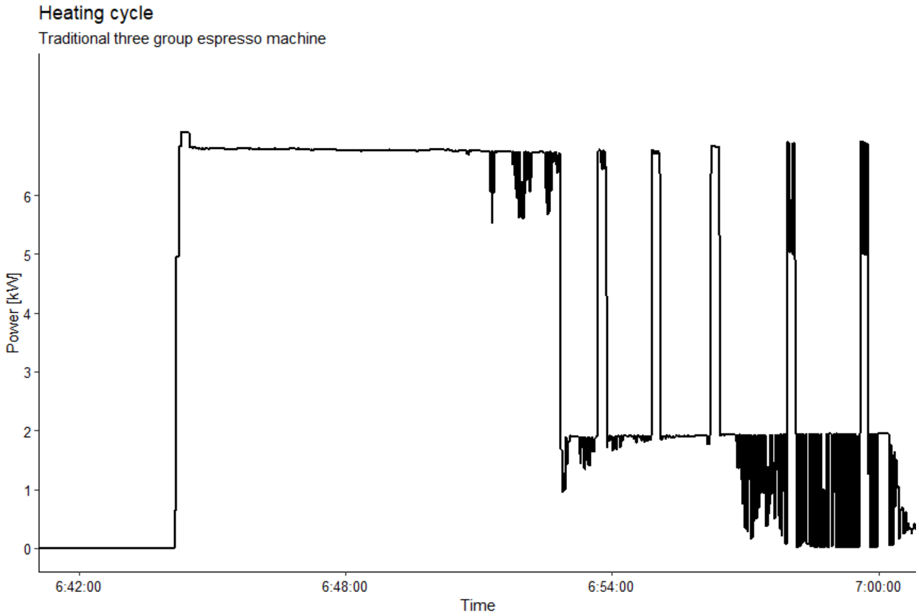

Figure 33: Power profile of a coffee machine when being turned on.

Chapter 6

Conclusions

This chapter finalises this work, summarising conclusions and pointing out aspects to be developed in future work.

6.1 Summary and Implications

This work was developed with the aim of qualitative analysing and comparing different market accesses in the European Union for small flexibility-based FCR providers. As allowing aggregation of small electricity producers and/or consumer loads for providing balancing services is still a fairly recent development, regulations are constantly changing and there are not up-to-date studies related to this subject. This thesis, then, contributes to the awareness of current regulations on balancing markets in the EU for potential small flexibility-based FCR providers. For the analysis, five different countries were chosen, based either on their geographical location, participation in the FCR Cooperation or market potential of cafés: Switzerland, Belgium, Germany, Portugal and Spain.

To have a better understanding of the market studied, an overview of the balancing market was done through the use-case methodology, laying out its main stakeholders, product definitions and how the actors interact to each other. Moreover, before delving into the different prequalification processes of each country, it was essential to first analyze what are the common rules applied to all countries in the European Union. The main documents that provided this information are the Guideline on Electricity System Operation and the Guideline on Electricity Balancing. The first one determined, among other things, the technical minimum requirements for FCR providers in the EU, such as the minimum accuracy of frequency measurement, full activation time and full activation frequency.

The EB GL established the possibility of a common market between TSOs, stating that if TSOs would like to exchange balancing capacity, they shall develop a proposal with harmonized rules and processes. With that in mind, the proposal for the FCR Cooperation was created, a project that now counts with the participation of ten TSOs of seven different countries, being three of them having their prequalification process analyzed in this study (Switzerland, Belgium and Germany). It is a common market which aims at integrating the FCR balancing market in the EU in order to increase competitiveness, efficiency and security of supply, while creating incentives for new BSPs and different technologies to provide FCR services. In their proposal, common rules are set, such as the minimum and maximum bid size, the amount limit on imports and exports of each country in relation to their capacity and the auction frequency. Regarding the prequalification process, it is left for each TSO to organize their own and set their own process and rules.

In the following chapter the market access analysis for FCR services of the different countries was performed. For that, the prequalification process of each of these countries was explained and later compared, in order to determine which country has less entry barriers for small FCR providers. Out of the five countries compared, the one that appears to have less entry barriers and shows greater possibilities of working in a case-to-case basis, is Switzerland. Its TSO, Swissgrid, besides not having extra entry requirements for providers with limited energy storage (the case of small flexibility-based providers), after receiving the initial documentation from the potential FCR provider, evaluates this documentation in order to determine if any additional tests or requirements should be requested by them. Additionally, in the prequalification tests set by the TSO of each country (in the case of Germany, set by its four TSOs), the time at which the service must be continuously provided at full power also varies greatly, being Germany the country with less restrictive time (13.5 minutes), followed by Switzerland (15 minutes), and Belgium by far the most restrictive one, requiring the provision of full power for 27 minutes, which might hinder the provision of FCR services from small providers with limited energy storage.

One interesting point to mention is that, even though there are efforts to have a harmonized balancing market in the European Union, there are different levels of commitment throughout the economic block, and countries are in different stages of development of an open market. This is the case of Portugal and Spain where the primary frequency control is still considered a mandatory service that should be provided by all generators connected to the transmission network regulated by the TSO in the area (in Spain, in addition, even distributed generators have to provide balancing services). Despite that, efforts are being made and both TSOs from Portugal and Spain have developed public consultations, proposing terms and conditions for BSPs and BRPs including demand response and distributed generation as potential providers of balancing services.

In addition to the qualitative analysis, a case study was developed, presenting the pilot project between the German start-up KOENA tec, the espresso machines manufacturer Gruppo Cimbali, the utility company BKW AG and Vassalli, the distributor of Cimbali machines in Switzerland. In this project, industrial coffee machines are aggregated to provide FCR services to the grid, thanks to KOENA tec's smart plug that can control the power output of the coffee machine. The goal of the pilot project is to prove the techno-economic feasibility of aggregating coffee machines from the gastronomy sector to provide FCR services to the grid. Their intention is to provide 50kW of marketable power in the Swiss grid using between 50 and 75 coffee machines. In this sense, a simulation of the prequalification test was performed to determine the actual number of coffee machines that should be used to pass the prequalification process and provide 50kW power to the grid. This was done through data analysis of the power profile of a coffee machine with similar specifications as the one to be used in the pilot project and applying a margin of 15% due to the difference in the installed power of the machines. This data was gathered from one of the smart plugs from KOENA tec that was connected to this coffee machine for one year.

As in the swiss balancing market it is determined that a BSP needs to provide services in both directions (upward and downward), calculations were conducted for both. Due to the different power profiles of the coffee boiler and the hot water/steam boiler, for the downward direction, only the hot water/steam boiler was used, and for provision in the upward direction, only the coffee boiler was used. As a result, different values of the minimum number of coffee machines were found for provision in each direction: while for the downward direction, 99 coffee machines shall be used, for the upward direction 278 coffee machines will have to be used.

6.2 Limitations and future work opportunities

The evaluation on market access in different countries in the EU was based on an extensive research on the current regulations of each country regarding FCR provision and on the common market regulation in the EU and its efforts for a harmonized market. As there are no articles with updated information on this matter, the study was limited to official documentation published by the TSOs, and not much information with the point of view of other stakeholders could be found. This includes information on additional requirements that TSOs can have for some BSPs after they deliver the documentation during the prequalification process, such as the swiss TSO Swissgrid.

Furthermore, due to time and space scarcity in this paper, planned countries to have their market access analyzed and compared could not be added in it. Some countries with an established balancing market and a certain level of openness to small aggregators, such as France, Netherlands, Italy and Denmark could not be evaluated. As future work proposal, an analysis of the balancing market and their prequalification processes in these countries should be considered, as it would enhance the understanding of the different balancing markets and processes to enter them, as well as all the possible processes for it.

In the simulation of the prequalification test for the case study, the data analysis methodology was applied using 61 days of data of a coffee machine with similar specifications than the Cimbali one. A margin of 15% increase was applied due to the power difference between the coffee machine that will be used and the one with available data. This implies an uncertainty to the method, as the actual power difference might be lower or higher than 15%. For an optimal calculation, data from the same model of coffee machine to be used to provide FCR services would be used for the data analysis, which would enhance the reliability of the results.

This shows also an important limitation of this study: the lack of different data available. The data analysis was performed based on only one coffee machine installed in Germany, and power profile of only 61 days was analyzed. There is, then, a high probability that the results are inaccurate and the actual power profile of the coffee machines to be used are greatly different from the one analyzed in this paper. A future work proposal is to analyze the data of multiple coffee machines and for a period longer than 61 days.

A future work opportunity is to examine the potential impact on product quality on providing FCR services to the grid with this equipment. Despite the use of groups of coffee machines for a period not exceeding the limit set by the data analysis, an examination of multiple coffee machines providing FCR services in a real-life environment would prove the assumptions made on this paper are accurate and, in fact, the quality of the products are not compromised by the use of them as FCR providers.

Annex A

Data Points to be Recorded – Prequalification Process

This annex presents the data points that need to be recorded during the prequalification process of each country to provide FCR services to the grid.

A.1 Switzerland

The recording/archiving/transmission (in case of offline data) or the transmission (in case of real-time data) is done in accordance with the specifications in Table 10. The meaning of the entry cells of the table are as follows:

- X: the recording/archiving/transmission (in case of offline data) or the transmission (in case of real-time data) of the data point for the aggregation level is mandatory.
- (X): the recording/archiving/transmission (in case of offline data) or the transmission (in case of real-time data) of the data point for the aggregation level is mandatory upon request of the connecting TSO.

Name of data point	Unit	TU	Providing Unit	pool
Active power with frequency deviation of +200 mHz	MW	Offline: X Real time: -	Offline: X Real time: -	Offline: - Real time: X
Active power with frequency deviation of -200 mHz	MW	Offline: X Real time: -	Offline: X Real time: -	Offline: - Real time: X
Measured active power	MW	Offline: X Real time: -	Offline: X Real time: -	
Measured frequency	Hz	Offline: X Real time: -	Offline: X Real time: -	
Control power target value (1)	MW	Offline: X Real time: -	Offline: X Real time: -	
Actuator	Unit %	Offline: (X) Real time: -	Offline: (X) Real time: -	
Statics s	Unit %	Offline: (X) Real time: -	Offline: (X) Real time: -	

Table 10: Data points to be recorded for prequalification process in Switzerland [24].

[1] Calculation of control power target value $P_{setpoint}$:

$$P_{setpoint} = P_{tg\_opTU} + P_{correction}$$

Where P_{tg_opRU} is the target operating point of the TU and $P_{correction}$ is the internal adjustment of the target operating point of the TU, taking into account short-term influencing factors.

A.2 Belgium

The correct recording and transmission of some real-time data is essential for passing the prequalification process for FCR services in Belgium. Elia requires the correct monitoring of one datapoint per Providing Unit in order to accept it as an FCR provider. The real-time data required for the prequalification test and also for the settlement is the measured active power in MW with its Quality Flag, which indicates if the data is valid (VAL), substituted (SUB) or invalid (INV). If the Providing group has limited energy storage, the BSP needs to provide one additional datapoint per Providing Unit: the measured energy content available in MWh of the Providing group with limited energy storage and its quality flag. For the availability test, two datapoints per Providing group and Service Type are necessary: the setpoint value and the feedback value, which is the mirrored value of the test value sent back to the TSO [42].

A.3 Germany

The recording/archiving/transmission (in case of offline data) or the transmission (in case of real-time data) is done in accordance with the specifications in Table 11. The meaning of the entry cells of the table are as follows:

- X: the recording/archiving/transmission (in case of offline data) or the transmission (in case of real-time data) of the data point for the aggregation level is mandatory.
- (X): the recording/archiving/transmission (in case of offline data) or the transmission (in case of real-time data) of the data point for the aggregation level is mandatory upon request of the connecting TSO.

Name of data point	Unit	TU	RU/RG	pool
Feed-in (or power consumption)	MW	Offline: X	Offline: X	Offline: X

		Real time: (X)	Real time: (X)	Real time: X
Operating point	MW	Offline: X Real time: (X)	Offline: X Real time: (X)	Offline: X Real time: X
Control power measured value	MW	Offline: X Real time: (X)	Offline: X Real time: (X)	Offline: X Real time: X
Pool allocation	(Pool ID)	Offline: X Real time: (X)	Offline: X Real time: (X)	
Status	(ON or OFF)			Offline: X Real time: X
Measured frequency	Hz	Offline: X Real time: (X)	Offline: X Real time: (X)	Offline: (X) Real time: (X)
Control power target	MW	Offline: (X) Real time: (X)	Offline: (X) Real time: (X)	Offline: (X) Real time: (X)
Work capacity (with limited energy storage)	MWh	Offline: X Real time: (X)	Offline: X Real time: (X)	Offline: (X) Real time: (X)
Current reserve performance	MW	Offline: (X) Real time: (X)	Offline: (X) Real time: (X)	Offline: (X) Real time: X
Rule book	MW	Offline: X Real time: (X)	Offline: X Real time: (X)	Offline: X Real time: (X)

Table 11: Data points to be recorded for prequalification process in Germany [30].

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