North Sea
Wind Power Hub
Programme

Regulatory & market design

Balancing of off-shore energy hubs

A study to highlight challenges regarding balancing of offshore energy hubs under the offshore bidding zone market setup

Discussion paper

#5

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About this paper

Why read this report

This document adopts the goal to develop common knowledge to support discussions regarding system operations and balancing of offshore energy hubs located in an offshore bidding zone. Both the reflection by ACER & CEER, the strategy of the EC and the position paper of ENTSO-E are used as the basis for the assessment. By providing this common knowledge ground, this document aims to further enable collaboration amongst TSOs to study this complex issue.

It is pivotal that the EC, Acer, Member States, NRAs and TSOs start commonly working towards a clear regulatory balancing framework and to address potential issues. Clarity on a regulatory (balancing) framework is both crucial to OWFs and TSOs, as it ensures a secure system on which market participants are able to calculate their business cases.

Highlights

Rather than developing a new framework, technical/legal amendments or adjustments are foreseen to enable the facilitation of OBZs.

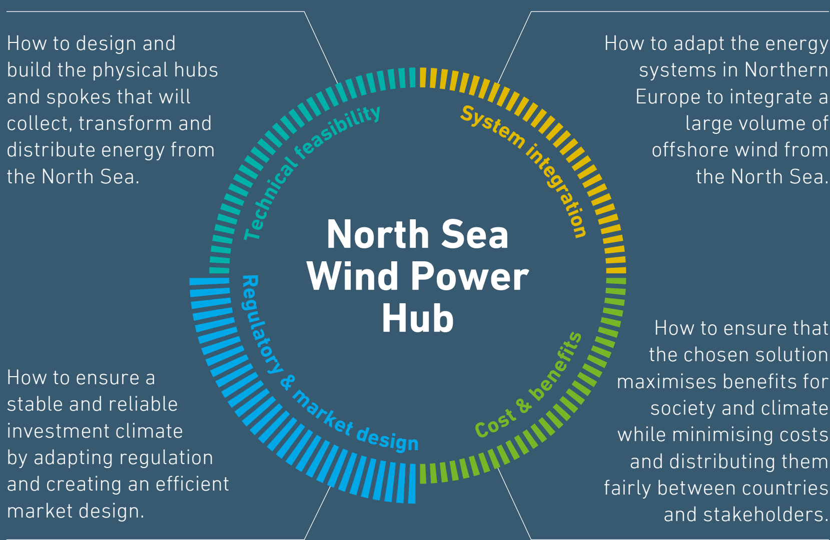
Directly including the imbalance demand of the offshore hubs in the EU balancing platforms seems more efficient than first sending the imbalance to shore where it will be part of the onshore TSO imbalance demand. However, some regulatory changes might be required to enable this.

The analysis in this paper showed that the balancing approach for the offshore hubs will have an impact on the current (onshore) process of dimensioning of reserves. No solutions were discussed since this topic requires further discussion amongst all relevant TSOs.

The big picture

The North Sea is a powerhouse of wind energy. Harnessing this power requires us to cooperate across countries and borders to build an efficient network. To show that a solution can be achieved in a cost-effective and secure manner, the North Sea Wind Power Hub is working within four key areas.

This discussion paper explores key topics within system integration.



List of abbreviations

ACE – Area Control Error
aFRR – Automatic Frequency Restoration Reserve
ATC – Available Transfer Capacity

BRP – Balancing Responsible Party
BSP – Balancing Service Provider

EC – European Commission
EBGL – Electricity Balancing Guide Line *(Commission Regulation (EU) 2017/2195)*

FCR – Frequency Containment Reserve
FRCE – Frequency Restoration Control Error
FRR – Frequency Restoration Reserves

HVAC – High Voltage Alternating Current
HVDC – High Voltage Direct Current
HM – Home Market

LFC area – Load-Frequency Control area
LFC block – Load-Frequency Control block

MARI – Manually Activated Reserves Initiative
mFRR – Manual Frequency Restoration Reserve

OBZ – Offshore Bidding Zone
OWF – Offshore Wind Farm

PICASSO – Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation

RR – Replacement Reserve

SOGL – System Operation Guideline *(Commission Regulation (EU) 2017/1485)*

TERRE – Trans European Replacement Reserves Exchange

Executive Summary

The aim of this study was to create a balancing philosophy that allows the secure operations of offshore electrical hubs under an offshore bidding zone (OBZ) setup. This philosophy describes how offshore bidding zones could be balanced. This philosophy for balancing OBZs is similar to onshore. However, it was identified that the existing regulatory framework for balancing does not yet fully accommodate the possibility to balance OBZs. Rather than developing a new framework, technical/legal amendments or adjustments are foreseen to enable the facilitation of OBZs. Clarity on a regulatory (balancing) framework is both crucial to offshore wind farms (OWFs) and transmission system operators (TSOs), as it ensures a secure system on which market participants are able to calculate their business cases.

The analysis in this paper concluded that balancing of offshore energy hubs can be managed by TSOs in several ways, just like balancing of the current onshore bidding zones around Europe. A fitting balancing philosophy for the OBZ depends on various topics such as: the current onshore balancing strategy, market design, expected level of offshore development and more.

In general, four theoretical options were identified to balance offshore energy hubs:

1. sending the imbalance onshore and solving it by means of the EU balancing platforms,
2. direct integration of the hub in the Eu balancing platforms,
3. countering the power imbalance with products located at the hub or,
4. non-market based balancing actions.

Regardless of the exact design of the balancing philosophy, it is foreseen that for the energy hubs, the European balancing platforms such as PICASSO and MARI will play a crucial role. The European balancing platforms contribute to the efficient activation of balancing reserves across European borders and consequently the efficient utilisation of the HVDC interconnectors. Directly including the imbalance demand of the offshore hubs in the EU balancing platforms seems more efficient than first sending the imbalance to shore where it will be part of the onshore TSO imbalance demand. Therefore, option 2 is the preferred option. Furthermore, the analysis in this paper showed that the balancing approach for the offshore hubs will have an impact on the current (onshore) process of dimensioning of reserves.

The overall question is not whether TSOs could balance the offshore energy hubs, but rather whether the offshore energy hubs fit the current regulatory framework so that there is no dispute whether TSOs comply with regulation or not. First analysis shows that the current legislation does not sufficiently account for offshore energy hubs and further guidance from policy makers is required on:

1. Provide clarity on the circumstances under which an offshore energy hub becomes its own synchronous area.
2. Provide clarity on whether the hub should be a LFC area or a separate area concept.
3. Provide clarity on whether System Operation Guidelines changes are required to prequalify OWFs as BSPs if the hub is no LFC area.
4. Ensure a degree of freedom to determine which (new) offshore products can be delivered by BSPs.

Naturally, the European development of offshore wind generation and its corresponding electrical infrastructure will overtake the opportunity to have certain changes to the European regulatory framework. As a consequence, it is recommended both to European and national policy-makers to decide whether a clear regulatory framework can also be developed nationally. Or, whether the current EU guidelines are sufficient for this.

This paper aims at reaching out to policy-makers and other TSOs to commonly work towards a clear regulatory balancing framework and to address these potential issues. In addition, this paper recommends to further analyse operational implication of HVDC ramping rates to address potential imbalances. Furthermore, it should be noted that this paper focussed on a pure electrical hub, offshore conversion of energy to hydrogen by means of electrolysers was therefore out of scope. Further analysis is also required to assess if and how electrolysers can be integrated in the balancing concept of an offshore bidding zone.

1 Introduction

In September 2022, nine North Seas Energy Cooperation (NSEC) countries agreed in a Joint Statement to reach at least 260 GW of installed capacity of offshore wind in the North Sea by 2050[1]. Intermediary targets agreed upon were 76 and 193 GW for the years 2030 and 2040, respectively. The NSEC aims to connect the nine participating countries[2] by means of an offshore grid, to promote renewable energy and boost economic growth. To integrate such large quantities of renewable energy in the grid in an efficient manner, so called offshore hybrid projects[3] or energy hubs could be used. These projects have at least a dual functionality of facilitating transmission from offshore wind to shore and cross-border trading.

In previous discussion papers, the North Sea Wind Power Hub consortium (NSWPH) extensively discussed two relevant offshore market setups: the Home Market (HM) setup and the Offshore Bidding Zone (OBZ) market setup[4,5]. The NSWPH consortium investigated how an OBZ can be established[6] and discussed the implications for OWF stakeholders[7,8].

Although various studies focused on the impact of an OBZ, not much has been investigated yet in terms of system operations (e.g., balancing), besides the (early) work of the EC, ACER and CEER, and ENTSO-E[9]. The European Commission states in its offshore renewable energy strategy[6] that "the electricity market rules were not designed with the specific needs of offshore hybrid projects", and sets out the main market rules that are still applicable. For balancing this relates to Article 5 of the Electricity Regulation[10] stating that in principle, all market participants must be responsible for the imbalances they cause in the system, and hence be a balancing responsible party. For renewable energy producers active on the market, this means that they need to bear the risk of incorrect forecasts of production. ACER and CEER published a reflection-paper[11] on the EC's offshore renewable strategy in which they conclude that changes to the current EU regulatory framework on the balance responsibility, balancing services provision, and imbalance settlement might be required. Nevertheless, further analysis of these Regulations needs to be conducted before any amendment proposals are developed.

The philosophy for electrically balancing OBZs is the same/similar to onshore, but the existing framework for balancing does not yet fully accommodate the possibility for TSOs to balance OBZs. It is rather that technical and/or legal adjustments are required than that a new framework needs to be put into existence. This can be explained by the fact that there was no need to expand the regulation offshore, as the radial connected wind farms were and are in-

1 North Seas Energy Cooperation, Joint Statement on the North Seas Energy Cooperation, 2022, link
2 Belgium, Denmark, France, Germany, Ireland, Luxembourg, the Netherlands, Norway and Sweden.
3 Whereas offshore hybrid projects refer to projects with dual functionality of combining offshore wind with cross-zonal capacities, Energy hubs even have conversion added as a third functionality.
4 NSWPH, Market setup options to integrate hybrid projects into the European electricity market, 2020, link
5 NSWPH, Market setup options for hybrid projects, 2021, link
6 NSWPH, A strategy to establish an offshore bidding zone for hybrid projects, 2022, link
7 NSWPH, Offshore Wind Market Engagement, 2021, link
8 NSWPH, Commercial Framework offshore bidding zone, 2023, link
9 ENTSO-E, ENTSO-E position on offshore development: System Operation & Governance, 2021, link
10 Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity, link
11 ACER and CEER, Reflection on the EU strategy to harness the potential of offshore renewable energy for a climate neutral future, 2022, link

herently part of the onshore bidding zones. With the introduction of offshore energy hubs, specific tasks and responsibilities are not so clear-cut. Offshore energy hubs differ from radial connected projects as they are characterised by a multinational context and separate (national) offshore bidding zones. Current electricity market principles as set out in the IEM Regulation (Regulation (EU) 2019/943) and the Electricity Balancing Guidelines (Regulation (EU) 2017/2195, EBGL) could and should apply offshore as agreed upon by ENTSO-E, and ACER and CEER: 1) offshore market participants are financially responsible for the imbalance they cause to the system, 2) the approach to become a balancing service provider (BSP) or balancing responsible party (BRP) is fair, transparent and non-discriminatory, 3) European energy balancing platforms can help to activate balancing energy to solve offshore and onshore imbalances, and 4) imbalance prices should reflect the real-time value of energy to incentivise BRPs to be in balance or help the system to restore its balance. However, it is uncertain how that fits with existing regulatory frameworks, including for example the Guidelines on Electricity System Operations (Regulation (EU 2017/1485, SOGL). Clarity on such a regulatory framework is both crucial to OWFs as for the TSOs, as it ensures a secure system on which market participants are able to calculate their business cases.

Highlight
Electricity market principles should apply offshore, but it is uncertain how that fits with existing regulatory frameworks.

Aim of this paper

This document adopts the goal to develop common knowledge to support discussions regarding system operations and balancing responsibilities and opportunities for TSOs and OWFs of offshore energy hubs located in an offshore bidding zone. It should be noted that this paper only focusses on projects with the dual functionality of facilitating transmission from offshore wind to shore and cross-border electricity trading. This means that offshore conversion of energy in the hub by means of electrolysers is out of scope of this paper.

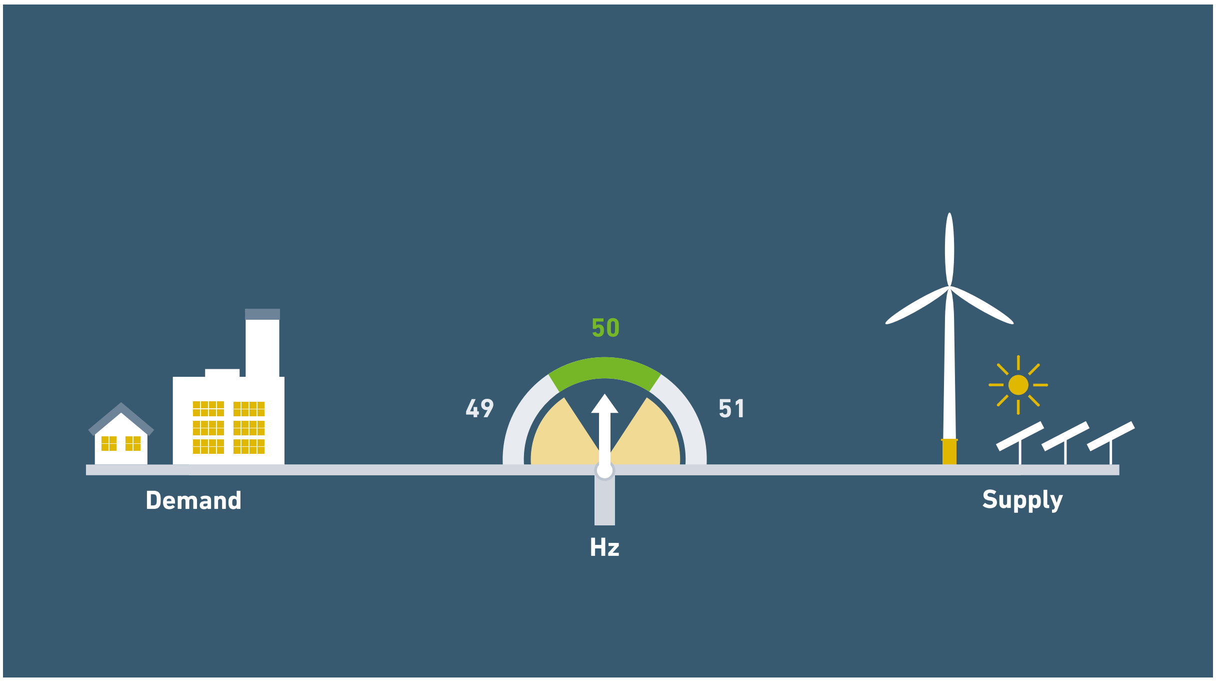
Both the reflection by ACER & CEER, the strategy of the EC and the position paper of ENTSO-E are used as the basis for the assessment. By providing this common knowledge ground and options for system operations and balancing of offshore energy hubs, this document aims to further enable discussion with National Regulatory Agencies, policy-makers and amongst transmission system operators (TSOs) to study and address this complex issue. In addition, this paper recommends to further analyse open topics such as operational implication of HVDC ramping rates to address potential imbalances.

2 Basics of balancing

This chapter explains the basics of balancing by introducing how it works onshore. It sets out the area responsibility structure, balancing products, cross-border exchange and Balancing Service Providers prequalification.

When discussing balancing, we are referring to the processes that European TSOs have in place to maintain the system frequency at 50Hz within each of multiple synchronous areas[12]. This process can best be explained using the Figure below, displaying a scale. The term "imbalance" refers to the difference between energy supply on one hand and demand within interconnected electrical systems (power grids) on the other hand. If too much or too little electricity is fed into the grid, the grid frequency can fluctuate and the electricity supply can be affected. The frequency can deviate from 50Hz if the scale of demand and supply is imbalanced, see Figure 1. To that regard, term "power imbalance" refers to an instantaneous difference between power infeed and offtake from the grid whereas the definition of "frequency" refers to a physical result of how well supply and demand are matched within an area. The time window for which an imbalance is calculated is known as the imbalance settlement period (ISP)[13]. Maintaining the frequency at 50Hz is important for equipment connected to the electrical system to function. It must be noted that, due to the fact that most of the national electrical systems are synchronously connected within Europe, maintaining system balance is a combined effort amongst European TSOs.

Figure 1. The balance between electricity supply to and demand from the grid affects the frequency.



[12] Synchronous area means pursuant to Commission Regulation (EU) 2016/631: "area covered by synchronously interconnected TSOs, such as the synchronous areas of Continental Europe, Great Britain, Ireland-Northern Ireland and Nordic and the power systems of Lithuania, Latvia and Estonia, together referred to as 'Baltic' which are part of a wider synchronous area", link
[13] As defined in Commission Regulation (EU) 2017/2195 establishing a guideline on electricity balancing Article 2(10).

The regulatory framework for system balancing is primarily set out by the two guidelines:

- COMMISSION REGULATION (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation[14] (hereafter **SOGL**).
- COMMISSION REGULATION (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing[15] (hereafter **EBGL**).

System balancing is a shared responsibility between TSOs and BRPs[16]. BRPs are financially responsible for maintaining the energy balance between supply and demand in each imbalance settlement period (ISP), whereas the TSOs are responsible for residual power imbalances, to be regulated towards zero within time to restore the frequency. The energy imbalances caused by BRPs are settled at the imbalance price, which should be such that the BRPs are incentivised to be in balance or help the system to restore its balance[17].

Important!

It should be mentioned that prevention of power imbalances from occurring is also an important step. Power imbalances are generally caused by e.g.:

- mistakes or uncertainties in forecasts of intermittent generation or demand,
- intentional deviations from schedules,
- malfunctions/outages, or
- using different ramping rates to transfer the wholesale market trades across the interconnectors.

The first step in the process of solving imbalance for both the BRP and TSO is preventing its occurrence.

Maintaining the system balance within the European synchronous areas[18] is important in order to maintain the system frequency. The system frequency is a common good within an entire synchronous area, and its maintenance is performed within two commonly agreed processes that are laid down within the SOGL:

1. Frequency containment process (FCP)
2. Frequency restoration process (FRP)

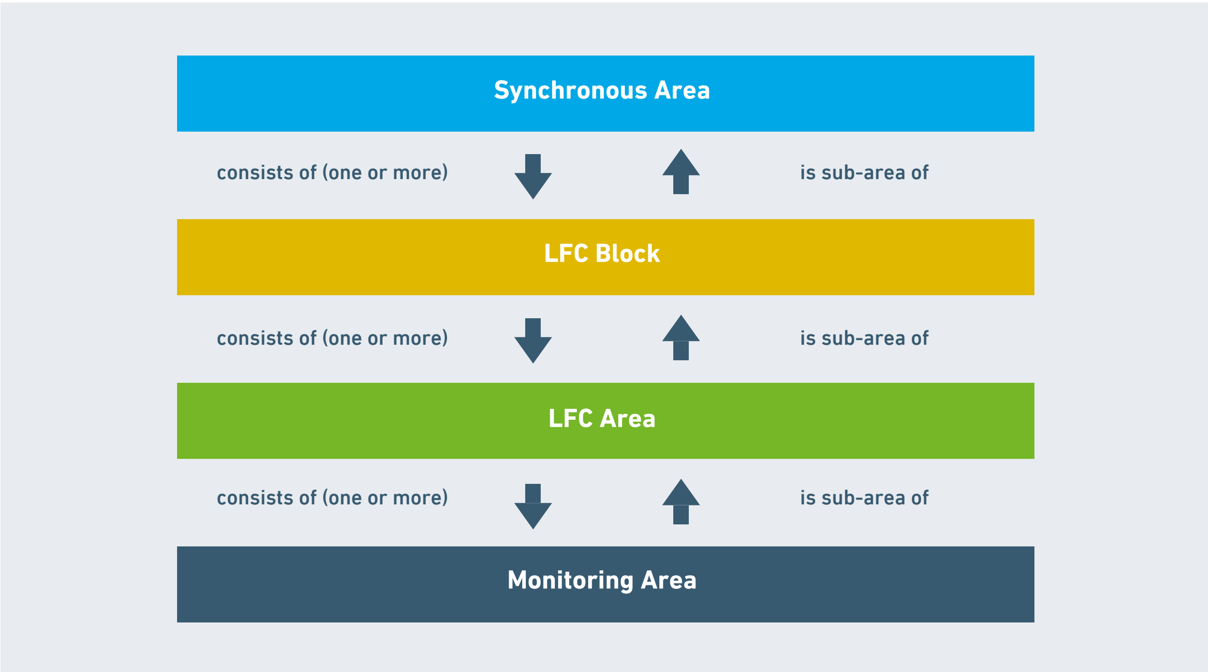
It is important to note that these processes are defined at the level of the synchronous area or subsets of the synchronous area, while imbalances of BRPs are defined at the imbalance area, which corresponds to the bidding zone or a subset of the bidding zone (scheduling areas).

[14] Commission Regulation (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation (Text with EEA relevance.), link
[15] Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing (Text with EEA relevance.), link
[16] BRPs are Balance Responsible Parties, the definition pursuant EGBL Article 2(7): "balance responsible party' means a market participant or its chosen representative responsible for its imbalances".
[17] Pursuant to Article 44 of the EBGL.
[18] Commission Regulation (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators defines a synchronous area as: "an area covered by synchronously interconnected TSOs, such as the synchronous areas of Continental Europe, Great Britain, Ireland-Northern Ireland and Nordic and the power systems of Lithuania, Latvia and Estonia, together referred to as 'Baltic' which are part of a wider synchronous area".

LFC process responsibility structure

In order to perform balancing within a synchronous area, a Load Frequency Control (LFC) process responsibility structure has been set up[19]. A schematic overview of the LFC process responsibility structure is shown in Figure 2. The term "LFC block"[20] and "LFC area"[21] are introduced to establish a distribution of responsibilities amongst TSOs for managing the power imbalances within the synchronous area. The LFC structure aims at ensuring that imbalances are solved in the geographical location in which they occur. This could be managed either physically, or by balancing energy exchanges which are accessible by the relevant TSO(s).

Figure 2: LFC process responsibility structure[22]



The FCP stabilises the frequency at synchronous area level after a disruption (large or small). Each TSO has the responsibility, on LFC area level, to have a certain amount of Frequency Containment Reserves (FCR) available. These reserves are automatically activated based on deviations in the frequency level, see Figure 3. The actual location of the activated reserves is not related to the location of occurrence of the imbalance.

The frequency is restored to 50Hz by the FRP. This process is also used to relocate the responsibility for managing the power imbalance to the area in which

[19] SOGL (13): "The provisions on LFC and reserves, aim at setting out clear, objective and harmonised requirements for TSOs, reserve connecting DSOs, providers' power generating modules and providers' demand facilities in order to ensure system security and to contribute to non-discrimination, effective competition and the efficient functioning of the internal electricity market. The provisions on LFC and reserves provide the technical framework necessary for the development of cross-border balancing markets."

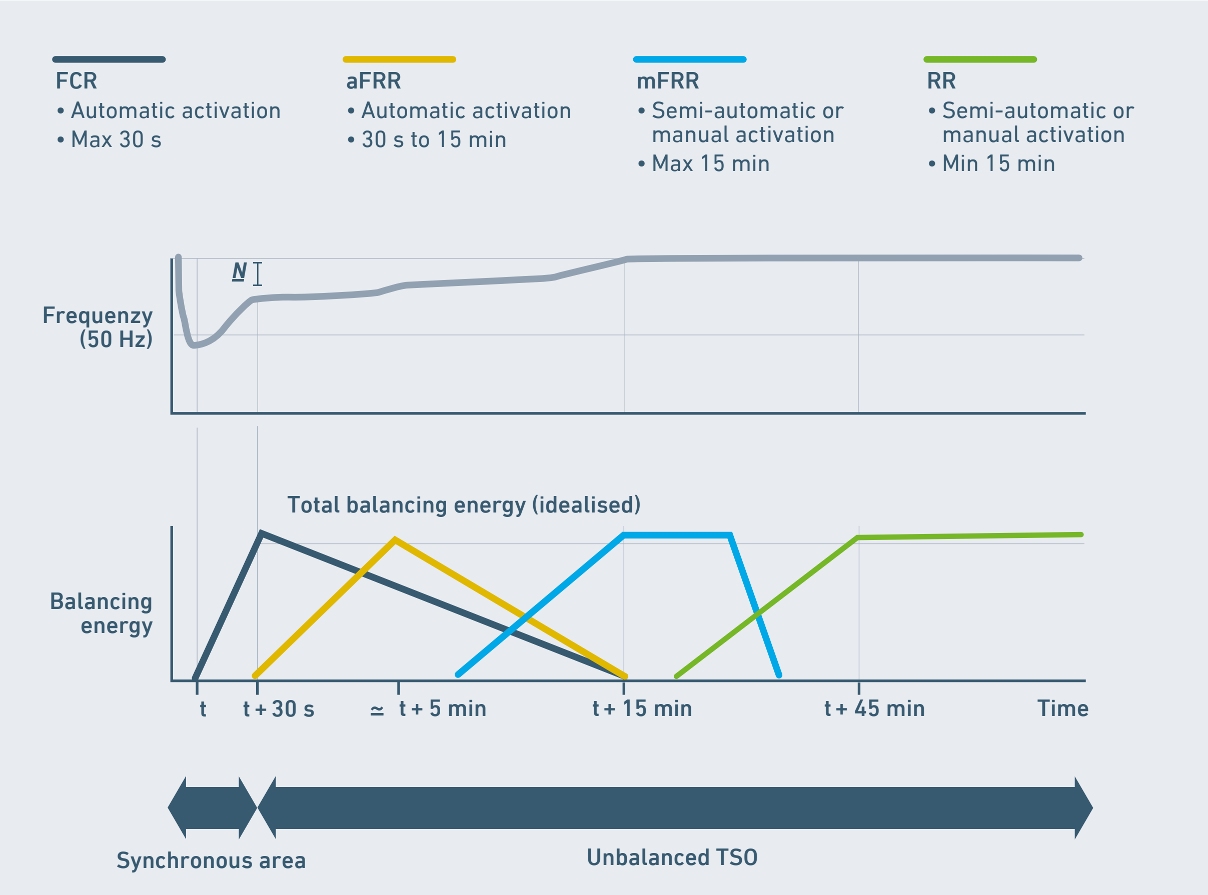
[20] SOGL art. 3.18 defines an LFC block as: "a part of a synchronous area or an entire synchronous area, physically demarcated by points of measurement at interconnectors to other LFC blocks, consisting of one or more LFC areas, operated by one or more TSOs fulfilling the obligations of load-frequency control".

[21] SOGL art. 3.12 defines an LFC area as: "a part of a synchronous area or an entire synchronous area, physically demarcated by points of measurement at interconnectors to other LFC areas, operated by one or more TSOs fulfilling the obligations of load-frequency control".

[22] ENTSO-E Position on Offshore Development System Operation & Governance, 2 July 2021, Link

the power imbalances have occurred. Consequently, FRP does not only take into account the local power imbalance within the LFC area, but also the frequency deviation, and is used to restore the frequency. Within a LFC block, operational agreements are arranged concerning the process of the dimensioning of Frequency Restoration Reserves[23] (FRR) and Replacement Reserves[24] (RR).

Figure 3: Balancing market processes for frequency restoration[25].



Cross border exchange of balancing energy

To further provide liquidity for balancing markets, prevent distortions while ensuring security of supply and strengthen the European electricity market, the EBGL sets out the establishment of European platforms for the exchange of balancing energy. These platforms can be distinguished by the (standard) products and participation is implemented on LFC area level. The platforms are the following[26]:

- IGCC: Imbalance Netting (IN)
- PICASSO: The Automatic Frequency Restoration Reserves (aFRR)
- MARI: Manual Frequency Restoration Reserves (mFRR)
- TERRE: The Trans European Replacement Reserves Exchange (RR)

[23] Pursuant to SOGL Article 157(1).
[24] Pursuant to SOGL Article 160(2).
[25] ENTSO-E Annual Report 2019, chapter 2 Market, Link
[26] More information about the different platforms can be found via the official ENSTO-E Website, Link

One important aspect of the European platforms for the exchange of balancing energy is that it allows the exchange of the Area Control Error (ACE). The ACE is defined pursuant to SOGL article 3(19), as the sum of the power control error ('ΔP') and the frequency control error ('K*Δf')[27]. The FRP is based on the ACE of an LFC area, and FRR can be activated accordingly from the European balancing platforms. In essence, using the European balancing platforms for the exchange of the ACE allows TSOs to exchange power imbalances and to solve them in different geographic areas. In addition, the IGCC platform can help avoid the simultaneous activation of FRR in opposite directions, between TSOs in their respective LFC areas, enhancing the efficiency of balancing within Europe.

Highlight
The European balancing platforms allow the participating TSOs to exchange balancing energy and more efficiently solve imbalances.

Terms & Conditions related to balancing

The EBGL sets out a guideline for the implementation of the European platforms for the exchange of balancing energy pursuant to article 19 (TERRE), 20 (MARI), 21 (PICASSO) and 22 (IGCC). One key element that is mentioned in all articles is the requirement of a framework for harmonisation of the terms and conditions related to balancing[28]. It should be pointed out that the European balancing platforms is based on a TSO-TSO model, where BSPs send in bids to their connecting TSO and don't have direct contact with other TSOs. Nevertheless, for market participants, to be able to provide balancing energy for their relevant TSO they must become BSPs through a pre-qualification process for each of the standard products[29]. This implies that each Member State (MS) of the European Union has their own pre-qualification process which is carried out by the "reserve connecting TSO" which refers to the TSO responsible for the monitoring area[30], see Figure 2, to which a reserve providing unit or reserve providing group is connected.

[27] ACE: the sum of the power control error ("ΔP"), that is the real-time difference between the measured actual real time power interchange value ('P') and the control program ('P0') of a specific LFC area or LFC block and the frequency control error ('K*Δf'), that is the product of the K-factor and the frequency deviation of that specific LFC area or LFC block. The area control error then equals ΔP+K*Δf.
[28] Pursuant to EBGL Article 18.
[29] Pursuant to SOGL Article 159 (FRR) and Article 162 (RR).
[30] The monitoring area is defined according SOGL article 3.145 as: "a part of the synchronous area or the entire synchronous area, physically demarcated by points of measurement at interconnectors to other monitoring areas, operated by one or more TSOs fulfilling the obligations of a monitoring area".

3 Balancing processes for offshore hubs

Balancing of offshore energy hubs can be managed in several ways, just like we see multiple ways of balancing current onshore bidding zones around Europe. The chosen balancing philosophy of the OBZ may depend on the current balancing strategy of the connected onshore market areas, market design, expected level of offshore development and other factors. This chapter will try to illustrate how TSOs can manage imbalances occurring at offshore energy hubs. The adaptations to the regulation that are required to make balancing of offshore energy hubs fit within the regulatory framework are listed in chapter 5.

3.1 Principles of balancing processes for offshore energy hubs

As was also stated in the beginning of this paper, the philosophy for balancing OBZs is the same/similar to onshore, but the existing framework for balancing does not yet fully accommodate the possibility to balance OBZs. It's more some technical/legal adjustments than an actual new framework that needs to be put into existence. Focusing on the most relevant aspects of an energy hub, namely the OBZ market setup and the characteristics of the HVDC infrastructure, some conditions for balancing processes of offshore energy hubs should be highlighted:

1. The offshore hub is expected to contain **no or only limited offshore load assets to solve imbalances** occurring at the hub.
2. The offshore **HVDC converter stations are assumed technically capable of solving any frequency deviations** that occur at the offshore energy hub by adjusting the input/output setpoints of the converter stations and sending the power imbalance onshore via one of the interconnectors.
3. It is assumed that there are **no technical constraints within the hub** and hence energy or imbalance can be transported without limitations within the hub.
4. A prerequisite of bringing offshore power imbalances to the onshore system is that there is interconnection capacity available. Hence, power imbalances occurring in the OBZ cannot be brought onshore without taking into account the limitations in Available Transmission Capacity (ATC) between these bidding zones. The bidding zone border (BZB) between the OBZ and the onshore bidding zone can be seen as a bottleneck in terms of capacity available for balancing. This is the reason why the energy hub cannot be included in the same LFC area as this may result in cross-zonal constraints when activating FCR and FRR. Hence, **the energy hub should be a separate balancing area**.
5. The energy hubs (e.g. small artificial islands or offshore platforms) **do not constitute synchronous areas**[31] **or subsets thereof** as they are connected by HVDC interconnectors and include no/limited AC assets with frequency[32].

[31] In case it is deemed as a separate or part of an existing synchronous area, certain exemptions are required (see chapter 5).

[32] This however, might be different for the Bornholm island as the island has around 40.000 inhabitants. Naturally an AC grid is present to facilitate the electrical demand of the inhabitants.

As a consequence of these conditions and prerequisites, power imbalances that occur within the OBZ can only be managed by:

Option 1	Bringing the power imbalance onshore first causing the imbalance to be registered in the onshore system and then solving it via the EU balancing platforms
Option 2	Including the imbalance of the hub directly in the EU balancing platforms, and solving the imbalance onshore while considering cross-zonal constraints
Option 3	Countering the power imbalance with products located at the offshore hub
Option 4	Non-market based balancing actions within the offshore hub

Important!

The power imbalances occurring in the hub can be considered as solved within the offshore hub either by exchange of active power with the onshore system, or by physical activation of power within the hub itself. However, since these hubs do not constitute synchronous areas or subsets thereof, balancing actions within the hub itself might be technically similar to frequency containment or restoration processes, however pursuant to legislatorial definitions it is not part of the FRP and FCP.

In the following sections, the above-mentioned methods to solve the power imbalance in the OBZ are discussed in more detail, and the advantages and disadvantages are given.

3.2 Option 1: Solving the power imbalance onshore through the European balancing platforms

When a power imbalance occurs at the hub, an immediate response is required to prevent a collapse of the offshore system. If capacity is available on one or more of the HVDC-cable, the offshore converter station and cable(s) can provide the immediate response that is required. By doing so, the immediate power imbalance is transported to either the domestic or other connected onshore area(s). Once onshore, the hub imbalances can be netted with the onshore imbalance. The total imbalance of the onshore LFC area then still needs to be balanced. The EU balancing platforms are used to efficiently solve imbalances by activation of the cheapest balancing reserves while taking cross-zonal capacities into account. These power imbalances can only be solved through the balancing platforms if they are first measurable within the onshore LFC area and included in their ACE. Indirectly the power imbalances of the offshore hubs, insofar as they are brought onshore, are then solved within the international markets.

The step of bringing the power imbalance onshore will induce a frequency deviation in the onshore synchronous area. The frequency deviation is then mitigated with the automatic FCR activation within the FCP.

In short this can be summarised in:
1. Offshore imbalance is brought to shore by adjusting the flows on the HVDC interconnectors
2. Offshore imbalance is netted with onshore imbalance and simultaneously influences onshore frequency
3. Frequency deviation is mitigated with the automatic FCR activation within the FCP
4. The EU balancing platforms make the most cost efficient choice of activating cross-border reserves to solve the imbalance.

Important!

It is important to keep in mind that these actions stabilise the situation and that the BRP causing the imbalance remains in imbalance. The HVDC interconnectors, having a flow different from the scheduled flow, also remain in imbalance.

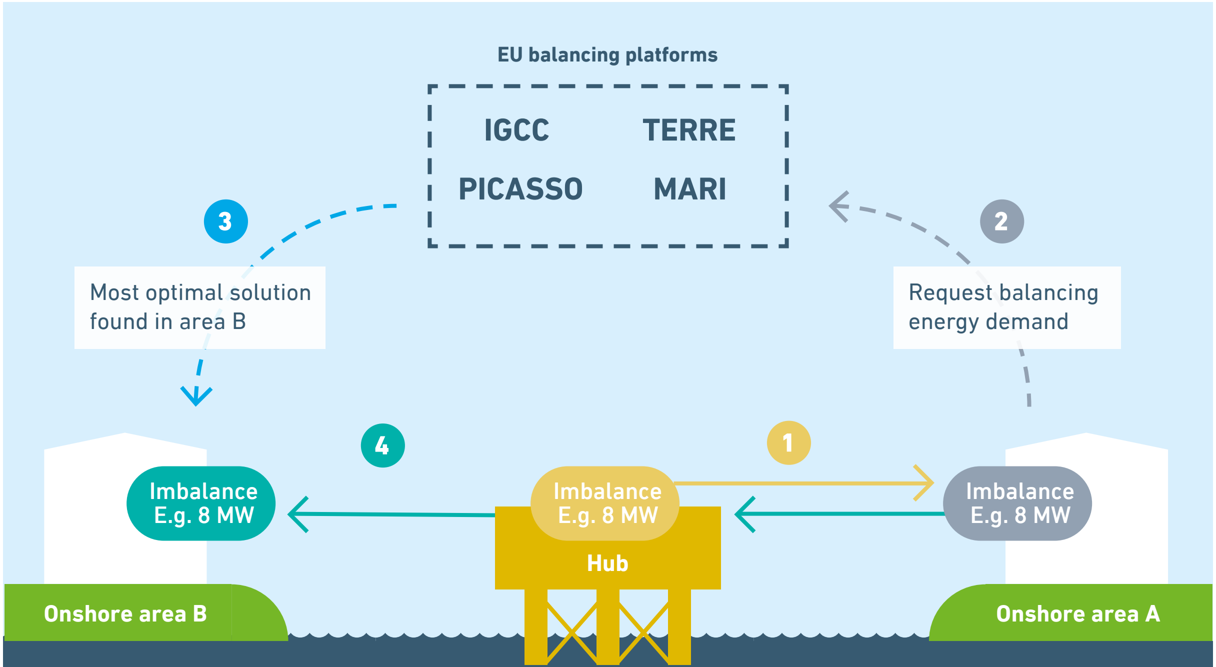
Integration of balancing markets in the EU balancing platforms allows for international coordinated imbalance netting and procurement of balancing energy. For the PICASSO and IGCC platforms this process occurs automatically, which means that the imported power imbalance from the offshore hub is either (partially) netted or solved there where the cheapest bids for aFRR are available. The cheapest bids could also be from another synchronous area.

Even though this option takes cross-zonal capacity into account and optimises FRR activation on a larger scale, this option has still some deficits:

A. First, this option might in some situations be counterproductive when, as a result of the EU balancing platforms, the imbalance is send back in the opposite direction via the hub, see Figure 4. The ramping limitations on the HVDC interconnectors will further decrease the speed to solve the imbalance. In case the ramping limitations do not allow that the offshore imbalance are brought onshore fast enough, this could result in curtailment of the offshore wind energy on the offshore hubs to avoid damage.

B. Another disadvantage of this option is that there is no process in place yet to automatically determine whether there is sufficient cross-zonal capacity on the HVDC interconnectors to send the offshore imbalance onshore, which is a prerequisite as explained in the beginning of this chapter. In case it is the desire to first bring the offshore imbalance to a dedicated onshore LFC area, this may result in capacity constraints. A solution would be to add an additional step to determine where the offshore imbalance can be sent by analysing available cross-zonal capacities.

Figure 4: Option 1: sending the offshore imbalance to a dedicated shore



1. Bring the offshore imbalance to a dedicated shore (onshore area A).
2. Imbalance is first netted in onshore area A and the residual balance demand is sent to the EU balancing platforms.
3. Solution of the EU balancing platforms results in further netting and/or activation of reserves in onshore bidding zone B, since the most optimal solution is located there.
4. Imbalance is brought to onshore area B.

> **It would be more efficient to directly send the offshore imbalance to the onshore area B.**

Note: 8 MW is a randomly chosen number

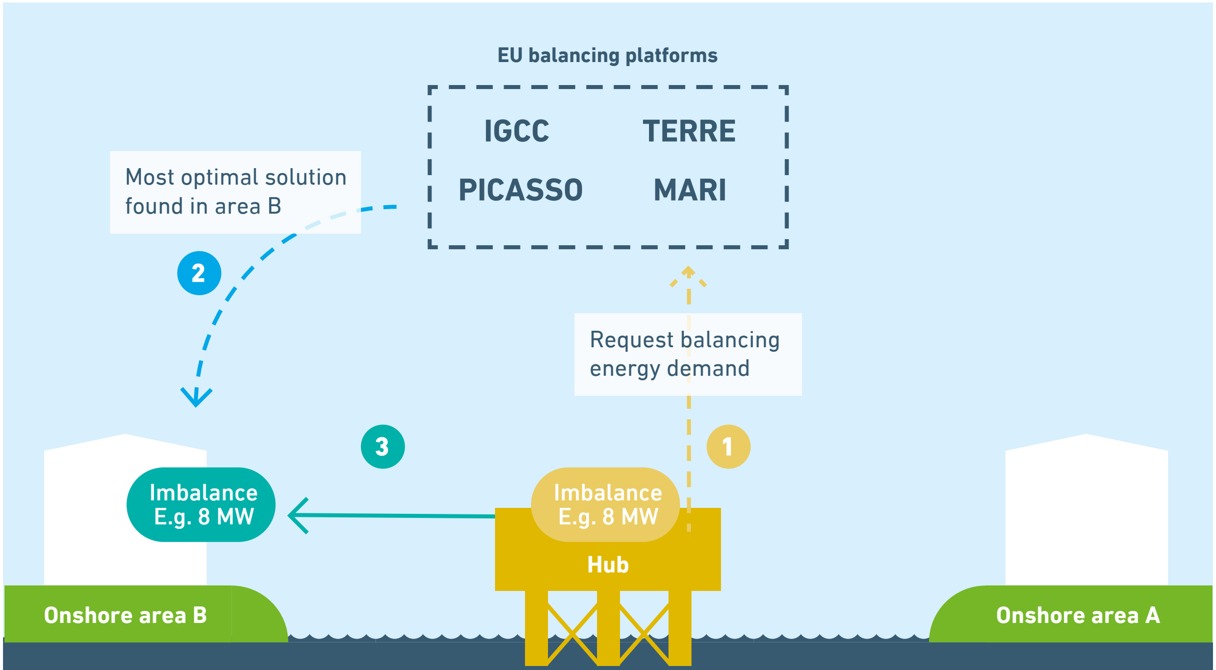
3.3 Option 2: Direct integration of the energy hubs in the balancing platforms

Compared to bringing the imbalances first physically onshore as described in option 1, direct integration of the energy hubs in the EU balancing platforms would be more efficient. The direct integration of energy hubs in the European balancing platforms requires the point of measurement of the imbalance to be located inside the balancing area of the energy hub. This implies that the TSO will calculate the imbalance (FRCE / ACE for an AC system) on the energy hub and send a request to the balancing platforms. The direct integration of the energy hubs in the balancing platforms would require real-time measurements of actual aggregated load and generation on the energy hub as input to the balancing platforms, as well as changes to the Implementation Frameworks (see chapter 5).

As a result of direct integration of the energy hubs in the EU balancing platforms, the schedules for the connecting HVDC interconnectors are adjusted to reflect the new balanced flow and thus bringing the energy island back at a balanced situation. This action from the TSO does not change the position of the BRP causing the imbalance, provided the imbalance is caused by production or consumption units connected to the energy island.

By solving their imbalances directly through the request for active power through PICASSO and IGCC, and possibly through requests for active power through the MARI platform, would ensure a more efficient participation of the offshore hubs within the balancing markets and utilisation of the HVDC interconnectors. This avoids that ramping restrictions are applicable twice to exchanges to other onshore LFC areas and thus increase the speed of solving the offshore power imbalance as compared to option 1, see Figure 5.

Figure 5: Option 2: direct integration of the offshore energy hub into the EU balancing platforms



1. Offshore imbalance is directly sent to the EU balancing platform.
2. Solution of the EU balancing platforms results in netting and/or activation of reserves in onshore bidding zone B, since the most optimal solution is located there.
3. Imbalance is brought to onshore area B.

> **Resulting in an efficient solution of mitigating the imbalance.**

Note: 8 MW is a randomly chosen number

To sum up the energy islands could be operated and balanced using the European balancing platforms similar to any onshore LFC area with its own ACE.

3.4 Option 3: Countering the power imbalance with products located at the offshore hub

The offshore imbalance can also be solved by activation of balancing energy provided by reserves located at the offshore hub. However, as mentioned in the introduction of this chapter, the assumption is that there is no or limited load located at the hub. Hence, potential balancing products can only be offered by the connected offshore wind farms.

OWFs are most likely able to provide downward balancing services, upward services on the other hand, is not so clear-cut. In order to rely on upward balancing services, it might be required to reserve an amount of the generation capacity of the OWFs. For example: when the imbalance is in downward direction and upward generation capacity would need to be reserved, than the OWF developer would need to sell less energy in the wholesale markets than it would be capable of. It would be more efficient for the OWF developers to provide downward balancing actions. These options will not always suffice to solve the imbalance: e.g. when not enough capacity is reserved to cover the downward imbalance. Furthermore, this option might be deviating from the optimal market outcome as the electricity with low-marginal costs might be of better use elsewhere in the system to fulfil demand. Last, balancing with solely local reserves is not in accordance with the requirements of the EBGL to use the European balancing platforms.

Highlight

Direct integration of the hubs in the balancing platforms would ensure a more efficient participation of the offshore hubs within the balancing markets and utilisation of the HVDC interconnectors.

3.5 Option 4: Non-market based balancing actions within the offshore hub

As alternative to all previous described options and a somewhat “out of the box” concept, the offshore imbalance can also be solved by non-market based balancing actions for the offshore hub. These non-market based balancing actions could refer to, amongst others, curtailment of large surpluses of offshore wind that would have caused a drop of system security below an acceptable threshold. These actions may only be used in situations where no other market-based solutions can be used. This can for example be in situations where the imbalance occurs faster than it can be solved due to e.g. ramping limitations of the HVDC infrastructure and/or onshore balancing reserves. And secondly, where the OWF causing the imbalance is the only one who can solve the imbalance by providing balancing energy, and hence, may have an incentive to create an imbalance if the reimbursement for providing balancing energy is higher than the imbalance price.

It is important to comprehend that this option can only support in reducing positive imbalances. In addition, curtailment would result in less efficient dispatch when this energy could be used to satisfy onshore demand or stabilise the onshore system.

Summary

Focusing on the options described above, it can be concluded that option 2 results in the most efficient and feasible balancing methodology for offshore energy hubs, namely by including the ACE (or something similar) of the energy hub, which is a separate balancing area, directly into the EU balancing platforms. Direct participation in the platforms allows for activation of the cheapest balancing energy across participating TSOs within the limitations of the system security.

4 Dimensioning of reserves

The previous chapter describes the current regulatory (balancing) framework and illustrates how TSOs are able to manage imbalances occurring at the offshore energy hub. This chapter will further focus what impact distributing the power imbalance onshore has on the existing process for the dimensioning of reserves.

4.1 Impact of offshore development on the dimensioning of reserves

When talking about the impact of offshore hubs, perhaps one of the most challenging topics is the impact on the current dimensioning process of reserves. The impact on the dimensioning of reserves is very much linked to the chosen system design, but also to the future development and expansion of offshore grids and hubs. Energy hubs could be constructed and interconnected in a way so that the loss of the largest dimensioning unit is limited to a certain volume. How this should be done to ensure system stability in the future, should be discussed between all relevant TSOs. As previously mentioned, reserves are dimensioned on either synchronous area level (FCR) or LFC block level (FRR) and have an impact on multiple TSOs. Dimensioning of reserves, in the light of offshore development, is therefore a topic that should and will be discussed amongst relevant TSOs.

Today dimensioning of reserves is calculated based on a combination of:
- The highest possible lack of a system component,
- Probabilities of a trip with regards to historic data, and
- Historical imbalances.

Since there is no historic data available of an offshore grid with hubs, the second and third calculation basis is not so easily done. Naturally, other methods could be thought of that could be used until data comes available for energy hubs. With respect to the first possibility, the more grid components are added to the offshore grid, the more impact it will have on dimensioning.

4.2 Accounting for offshore imbalances in dimensioning

Depending on the chosen system design, some reflections can already be made. Chapter 3 discusses the inclusion of the power imbalances of the offshore hubs in the international balancing platforms in two options: either by first bringing the power imbalances physically onshore (Option 1 in Chapter 3), or by more efficiently directly integrating the offshore hubs in the international balancing platforms for requests for active power (Option 2).

In the first case (Option 1), the power imbalances are physically being brought onshore and included in the ACE of the respective onshore LFC area before being included in the FRP and international balancing processes. Therefore, it can be assumed that most occurrences of power imbalances are also measured in the onshore LFC area of the directly connected onshore bidding zone. As such, they would be automatically included in the stochastic/probabilistic dimensioning process within the LFC block of this TSO. However, there will also be cases when the interconnectors between the OBZ and the directly connected onshore bidding zone LFC block are congested, so some of the power imbalances will be brought onshore in another LFC area and subsequently influence the dimensioning processes of this LFC area. In other words, the balancing process in an OBZ can have an impact not only in the dimensioning of FRR in the onshore LFC area of the directly connected onshore bidding zone, but also on those of another TSO operating another LFC block. Additionally, this other TSO can be in a different synchronous area, meaning that the FCR dimensioning of a different synchronous area could also be impacted.

In the second case (Option 2), where the offshore hubs are directly integrated in the international balancing platforms, the power imbalances are measured offshore within the OBZ, and are therefore not automatically included at all in any LFC block FRR dimensioning processes. Therefore, for this case it needs to be agreed between the relevant TSOs how the power imbalances in the energy hubs are accounted for in their dimensioning processes.

In any case this requires discussion among relevant TSOs. In this paper, the topic will not be further discussed, but it is recommended to bring the dimensioning of reserves discussion to relevant TSO bodies.

Highlight

The dimensioning process may be impacted by energy hubs and offshore bidding zones. Further discussion amongst all relevant TSO is required.

5 Challenges in current regulatory framework(s)

The previous two chapters illustrate how TSOs could manage the imbalance occurring at the offshore energy hub and how the dimensioning process of the balancing reserves in the onshore grid is impacted. This chapter will further elaborate on challenges foreseen in the current regulatory (balancing) framework.

The main challenges foreseen in current EU-regulation revolves around the fact that the offshore energy hubs do not clearly fit the definition of the areas that are used in the current LFC responsibility structure, which are discussed in chapter 2. Due to the HVDC characteristics, and the possibility of different designs of the offshore energy hubs, it becomes difficult to say whether or not there would be a frequency present offshore. This may depend on whether there is an AC grid present at the hub or not. In addition, even if there is an AC grid present on the hub, it would be a very small and probably isolated grid in comparison to the onshore network. As a result, the term "Load Frequency Control" used in the area concepts is not so clear-cut for offshore energy hubs.

A clear vision on how offshore hubs should be balanced was illustrated in chapter 3. This vision follows fundamentals of the current LFC responsibility structure and balancing processes meant for onshore. The question is not whether TSOs could balance the offshore energy hubs, but rather whether the offshore energy hubs fit the current regulatory framework so that there is no dispute whether TSOs comply with regulation or not. Some concrete examples are illustrated below:

Synchronous area

First of all, as stated in chapter 3, based on the definition of a synchronous area it seems that an offshore energy hub cannot be a separate synchronous area if it is a purely DC system and therefore, asynchronously connected to the onshore system. In addition, if the offshore energy hub consists of an AC system, it should be considered whether it makes sense to deem such a small area a synchronous area or if it is instead an isolated AC system. The SOGL only allows for a certain amount of reserve sharing and exchange between synchronous areas and at the same time there is a desire to avoid an obligation for having reserves physically at the energy hubs. This could for example be clarified by defining the energy hubs as isolated ac systems with common dimensioning with the onshore LFC block.

Highlight
To ensure that energy hub development is not delayed, clarity from European and national bodies is required on multiple regulatory challenges.

Furthermore, one of the key processes performed on synchronous area level is the FCP. Applying FCP within a hub may not be necessary since the offshore HVDC converter stations are technically able to manage offshore imbalances. This is even the case for when there is a small (isolated) AC grid present on the hub. However, as a consequence, it should be considered whether bringing the immediate power imbalance to the connected onshore LFC area(s) affects the dimensioning of FCR within the connected synchronous area.

LFC area

Secondly, to be able to properly account for exchanges of active power meant to solve offshore power imbalances by integrating it in the existing markets for balancing energy onshore, it becomes clear that the offshore energy hub should become its own balancing area. However, the offshore energy hubs do not seem to fit the current term of a "LFC area" due to the possible lack of a frequency at the hub and the asynchronous connection (via HVDC interconnectors) to shore. Pursuant to regulation, LFC areas are defined as an entire synchronous area or a subset thereof. Without clarity on the point raised before regarding the applicability of the synchronous area definition to offshore energy hubs, it is also unclear whether the offshore energy hub can become a LFC area.

Whether an OBZ is an LFC area or not affects whether a TSO could use the European platforms for the exchange of balancing energy to manage offshore imbalances. For example, the aFRR Implementation Framework is currently completely based on LFC areas and monitoring areas. Amendments are necessary to allow cross-border exchanges of energy via the platforms affecting the onshore FRP between LFC areas and offshore hubs.

Prequalification of BSPs

Finally, it should be possible for TSOs to prequalify BSPs on the hubs. As a consequence, the SOGL should be amended to explicitly allow for prequalification regardless of the hubs being part of synchronous areas or not. However, there should be a degree of freedom for the TSO to determine which (new) product(s) can be delivered by the BSPs as this might depend on the technical configuration of the offshore energy hub itself.

Summary

To summarise, the points above can be translated into the following policy asks:

1. Provide clarity on the circumstances under which an offshore energy hub becomes its own synchronous area.
2. Provide clarity on whether the hub should be a LFC area or a separate area concept.
3. Provide clarity on whether System Operation Guidelines changes are required to prequalify OWFs as BSPs if the hub is no LFC area.
4. Ensure a degree of freedom to determine which (new) offshore products can be delivered by BSPs.

Naturally, the European development of offshore wind generation and its corresponding electrical infrastructure will overtake the opportunity to have certain changes to the European regulatory framework. As a consequence, it is recommended both to European and national policy-makers to decide whether a clear regulatory framework can also be developed nationally. Or, whether the current EU guidelines are sufficient for this.

6 Conclusion

Balancing of offshore energy hubs under an OBZ requires a coordinated approach as the hubs are connected to several countries. European balancing platforms can be an efficient way to manage the imbalances occurring at the offshore energy hub. With information from TSOs on system imbalance, available bids from market participants and available cross-zonal transmission capacity, European balancing platforms contribute to the efficient activation of balancing reserves across European borders.

First analysis shows that current legislation does not sufficiently account for such innovative offshore infrastructure. Depending on the design of the hub (e.g., DC or AC), the current LFC responsibility structure falls short in terms of clarity about whether it applies or not. Concrete examples were presented such as the synchronous area, LFC block and LFC area. Furthermore, the key processes performed on synchronous area level are the FCP and FRP. However, the current manner of providing FCP and FRP may be redundant for an offshore energy hub as the offshore HVDC converter stations are technically able to manage offshore imbalances.

Although a clear vision is illustrated on how offshore energy hubs could be balanced, clarity on physical and financial responsibilities and processes must be given to offshore RES generators and TSOs in the connection agreements and national grid codes already before tendering the wind areas. As a result, clarity should be obtained on the European and national regulatory (balancing) framework for offshore hubs in order not to risk delaying any project timelines.

Highlight

Although a clear vision is illustrated on how offshore energy hubs could be balanced, clarity on physical and financial responsibilities and processes must be given timely provided.

Therefore, policy-makers and other TSOs should commonly work towards a clear regulatory balancing framework and to address these potential issues. The regulatory framework for balancing offshore energy hubs should be built in such a way that it defines only the minimum necessary in the European guidelines. Experience with a broader spectrum of offshore energy hubs should be obtained before making detailed harmonised legislation for the entire offshore meshed grid. The concept needs to be scalable, and the balancing philosophy must allow for participation in the balancing platforms, MARI, PICASSO, IGCC and TERRE.

7 Next steps

Given the innovative nature of offshore energy hubs, a suitable balancing philosophy has yet to be defined. In this paper, NSWPH presents a base for discussion. The described philosophy and challenges will have to be further investigated regarding their implications for specific case studies (configurations, capacities). Nevertheless, the consortium identified another topic that require attention in the near future: the HVDC ramping limitations. This chapter will further elaborate on this specific point.

HVDC ramping limitations:
HVDC ramping limitations are necessary for various reasons of operational security. Ramping limitations of HVDC associated in an offshore context can have various effects on the overall performance and stability of both the offshore wind farms and the connected onshore power grid. Ramping limitations should be such that they don't "trap" offshore wind imbalance in the offshore power grid. Normally, ramping of HVDC cables within synchronous areas does not cause an imbalance issue. However, the ramping of HVDC cables between synchronous areas and also between OBZs and the connected TSOs is expected to cause imbalance issue at OBZs because the countermeasures for imbalance are not as effective as within synchronous areas.

In particular, ramping limitations for the HVDC in the balancing timeframe are required to ensure the stability of the onshore and offshore wind grid also within the balancing timeframe. The frequent change over the HVDC cables due to the balancing exchange (for example, the optimization cycle in PICASSO is every 4 seconds) contrasts with the normal operation of the HVDC. It is foreseen that the balancing platforms take into account the ramping limitation of HVDCs between synchronous areas as an allocation constraint: it is then important to also include the ramping of HVDC multi-purpose interconnectors between the OBZs and onshore TSOs in the balancing platforms.

Assuming the ramping limitations on the HVDC cable within the balancing timeframe is permitted in the regulations, it would limit the possibility for immediately sending the power imbalances occurring in the OBZ to onshore. Therefore, there should be further research in the relation between the required ramping limitations on the HVDC cables and the (possibly collective) installations within the OBZ.

Balancing role of electrolysers in an energy hub:
As stated in the introduction of this paper, this paper focussed on a purely electrical hub without (or with limited) load. The NSWPH energy hub concept usually has three functions: 1) collect the offshore wind energy; 2) connect to multiple countries; and 3) convert the energy to hydrogen. This paper focussed on the electrical balancing concept of energy hubs as a TSO responsibility and left electrolysers are out of scope. However, it is not unthinkable that electrolysers can play a role in future offshore balancing markets. Further analysis is required to assess if and how electrolysers fit within the offshore electricity balancing concept of energy hubs.

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