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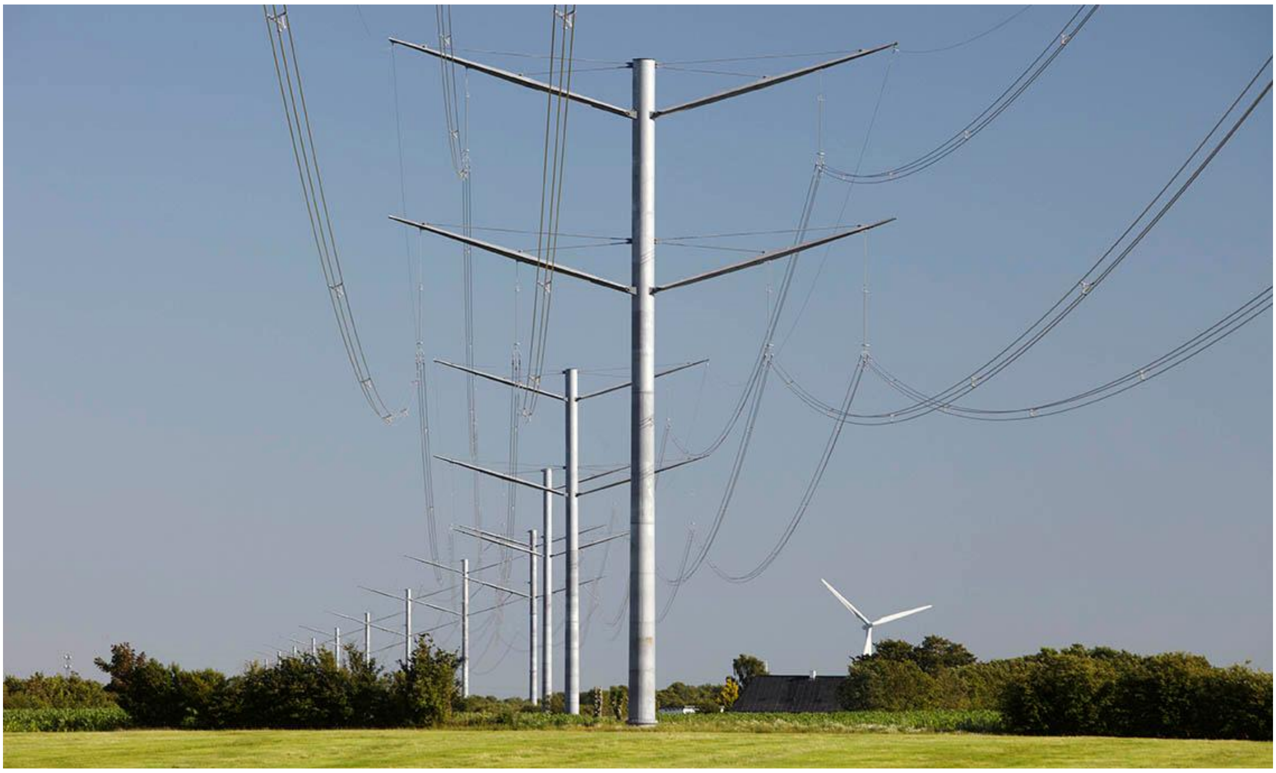
ANCILLARY SERVICES FROM NEW TECHNOLOGIES

TECHNICAL POTENTIALS AND MARKET INTEGRATION



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ANCILLARY SERVICES FROM NEW TECHNOLOGIES
TECHNICAL POTENTIALS AND MARKET INTEGRATION

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Ramboll
Lysholt Allé 11
DK-7100 Vejle
Denmark

T +45 5161 1000
F +45 5161 1001
https://ramboll.com

Rambøll Danmark A/S
DK reg.no. 35128417

Member of FRI

Executive Summary:

Ramboll has, with reference to the assignment from Energinet, described EU technical and market Regulations framework as well as Danish rules for delivering ancillary services in Denmark.

Selected technologies from the Technology Data catalogues published by the Danish Energy Agency have been chosen with the objective of clarifying their technical potential; these technologies have to a small extent already shown potential or are expected to show potential in terms of delivering ancillary services in the near future, 2-5 years from now, for the technology in question. These technologies are described in the following categories: generation plants and units, demand plants and units, renewable fuels or Power2X and finally energy storage and hybrid power plants. More examples are given in each category of the new technologies, either from scientific articles or from specific examples delivered by producers, consumers, Balance Responsible Parties (BRP's) or stakeholders that have an interest in delivering ancillary services. The examples are taken from completed pilot projects developed in cooperation with Energinet or other international TSOs, from finalised and approved projects delivering ancillary services to Energinet or from stakeholders sharing their thoughts or vision for delivering, or not delivering, ancillary services in the future from new technologies. Ramboll has been reproducing these stakeholders' positions and research articles in regard to passing on their contributions of the technical potential – and the technical and market barriers delivering ancillary services. The ancillary services in question, as agreed with Energinet, are: Fast Frequency Reserve (FFR), Frequency Containment Reserve (FCR in Western Denmark), Normal Frequency Containment Reserve (FCR-N in Eastern Denmark DK2), Disturbance Frequency Containment Reserve (FCR-D in Eastern Denmark), Automatic activated Frequency Restoration Reserve (aFRR), Manual activated Frequency Restoration Reserve (mFRR), voltage regulation and reactive power control.

Ramboll has found that there is without a doubt technical potential for delivery of ancillary services from new types of converter-based generation units with source from wind and sun, wind turbines and photovoltaic plants. Demand plants and units, such as large heat pumps or aggregated cooling equipment, which are also increasingly being supplied via converters, can already supply ancillary services or are being prepared for delivering ancillary services, when accounts are taken of dimensioning the associated thermal and/or mechanical systems accordingly. Supplementary deliveries of ancillary services from Power2X technologies are possible today, the technical potential is available, and the amount of plants will supposedly expand in the coming years. Battery energy storages can be highlighted as having excellent technical potential in terms of delivering ancillary services within the limits of the installed capacity.

For the conclusion refer to part 9.5.

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APPENDICES

1. PREFACE

As party and Danish Transmission System Operator, Energinet is dependent on having clear objectives of the delivery of ancillary services as there in all power systems must be a balance between production and consumption (demand) of power at any instant in time. Changes in production and consumption together with occurrences of incidents and disturbances in the grid affects the balance and cause grid frequency, voltage and/or power transmission phase angle deviations, which must be handled to ensure power system stability and security.

Large integration of renewable, wind, photovoltaic and other CO_2 neutral power production plants together with the development of new technologies of demand units combined with the fact that all conventional coal-fired power plants in Denmark are expected to experience a reduction in operation, triggers the consequence that ancillary services deliveries in practice should be able to be delivered from all kinds of sources.

Energinet must in the near future address how to manage deliveries of ancillary services from alternative sources and do so on market's terms; this task must be handled to ensure power system security of the future at reasonable costs.

Technical concepts such as system inertia and voltage stability are characteristics of the electrical transmission system having system robustness against frequency disturbances and other incidents in the grid. Today the inertia of the system depends on the stored energy in the rotating masses of electrical machines i.e. generators and motors (the spinning reserves). Alternative providers must be established to supplement, provide and in the long term even replace inertia coming from large convention generators. Caused by an increasingly larger amount of renewable energy production which comes from converter-based technologies, there will be a corresponding reduction in inertia since these technologies do not contribute to natural mechanical inertia. These facts have initiated research and development tasks providing ancillary services from production and demand facilities, which will be faced in the future.

The analysis assumptions for Energinet from the Danish Energy Agency 2019 [2] provide the basis of the assumptions for the analysis of the future regarding, among other things, the long-term grid investments, security of supply statements, analysis of needs for ancillary services, reporting to the European TSO networks, ENTSO-E and ENTSOG, business cases of concrete investment projects etc.

Another report published by the Danish Energy Agency, "Denmark's Energy and Climate Outlook 2019" (DECO2019) [3], looks further out into the future and describes the Danish Energy Agency's best guess regarding what the future will look like if no new measures are decided on in terms of the climate and energy areas other than those adopted by the Danish Parliament at the end of May 2019.

The analysis assumptions from the Danish Energy Agency [2] have to be used by Energinet as prerequisites for all of their analysis work: the energy outlook from DECO2019 [3] is an estimate, which will be corrected from time to time; DECO2019 [3] will only be used as a reference for diagrams or similar if reproduced here in this report.

The base reference document regarding the subject of ancillary services to be delivered in Denmark in the near future, looking 2-5 years into the future, is the document from Energinet, "Needs Assessment of Ancillary Services 2020" published on the 1st of November 2019, only in Danish language as "Behovsvurdering for systemydelser 2020" [4].

This report was initiated due to an assignment defined by the Danish Utility Regulator for Energinet to investigate and report according to a request included in a report published on the 19th of December 2018 with the Danish title "Energinets indkøb af reserver i elsystemet, -regulering, markedets funktionsmåde, perspektiv og konkurrence." The report has not been published in English, refer to [5].

The assignment in question is described and summarised in Danish in the above-mentioned report [5], on pages 12-13/137. The summary states as follows:
"Energimarkedet er kendetegnet ved hastige ændringer, hvor nye teknologier kan bidrage til større fleksibilitet og likviditet i markedet, forudsat at der ikke er unødige adgangsbarrierer for nye teknologier i markedet. Dette er nyttigt med henblik på at sikre høj systemsikkerhed samtidig med en høj andel af vedvarende energi. Hertil kommer, at et systematiseret overblik over ny teknologi er vigtigt i udviklingen af europæiske reservemarkeder. Til brug for vurderinger af udviklingen på klima- og energiområdet er der blandt andet behov for at have kendskab til data for en række teknologier. Disse data er samlet i teknologikataloger, som offentliggøres løbende af Energistyrelsen og Energinet."

The summary translated into English:
"The energy market is characterised by rapid changes, where new technologies can contribute to greater flexibility and liquidity in the market, provided that there are no unnecessary barriers to entry for new technologies in the market. This is useful in terms of ensuring high system security while maintaining a high proportion of renewable energy. In addition, a systematic overview of new technology is important in the development of European reserve markets. For the purpose of assessing climate and energy developments, there is a need, among other things, to have knowledge of data for several technologies. This data is collected in Technology Data catalogues, which are regularly published by the Danish Energy Agency and Energinet."

The request from the Danish Utility Regulator for Energinet to investigate and report is (in Danish):

1. *"Forsyningstilsynet vil anmode Energinet om fortsat at understøtte udviklingen af nye teknologier i udviklingen af markedsdesign, og at tilvejebringe et bedre overblik over potentialerne af de nye teknologier. Forsyningstilsynet anbefaler, at Energinet i den sammenhæng identificerer og arbejder for at fjerne unødvendige adgangsbarrierer og udfordringer for at gøre brug af nye teknologier på markedet for reservekapacitet og energiaktivering. Forsyningstilsynet anbefaler, at Energinet med inddragelse af markedsaktørerne og udenlandske erfaringer udarbejder og offentliggør en rapport over potentialerne fra nye teknologier med afsæt i teknologikataloget inden udgangen af 2019."*

The request from the Danish Utility Regulator translated to English:

- *"The Danish Utility Regulator requests that Energinet continue supporting the growth of new technologies in the development of market design and provide a better overview of the potential of these new technologies. In this context, the Danish Utility Regulator recommends that Energinet identifies and works to remove unnecessary entry barriers and challenges to make use of new technologies in the reserve capacity and energy activation markets. The Danish Utility Regulator recommends that Energinet, with the involvement of market players and international experience, prepares and publishes a report of the potentials of new technologies based on the Technology Data catalogue before the end of 2019."*

This request has been reformulated into an assignment from Energinet to Ramboll that includes the following main content and topics, which will be described in this report:

1. Chapter	**Preface**; the background of this report and reading instructions.
2. Chapter	**Study concept**; procedures during the preparation of this report.
3. Chapter	**Technical requirements for ancillary services**; description and give an overview of the current applicable technical requirements of ancillary services for balancing and system stabilisation in the transmission grid subject to and in compliance with existing grid codes (which shall not be described).
4. Chapter	**Ancillary services from new technologies**; identification of new technologies which have a technical potential in terms of delivering ancillary services, but which at present do not deliver or deliver to a smaller extend. Selection of one or more of the new technologies to be described, highlighting the technical and market barriers, if any, and finally perform an evaluation. The findings and conclusions of chapters 5, 6,7 and 8, which describe “the new technologies” are summarised in chapter 9.
5. Chapter	**New Technology – Generation Plants or Units**; technical potentials from wind turbines, wind power plants and photovoltaics plants including hybrid plants (wind/energy storage or photovoltaics/ Energy storage). Includes examples from national as well as international ongoing or completed projects and experience drawn from these projects. Highlights and conclusions of this chapter have been inserted into chapter 9.
6. Chapter	**New Technology – Demand Plants or Units**; technical potentials from heat pumps, cooling equipment and resident household and industrial aggregated consumers. Includes examples from national as well as international ongoing or completed projects and experience drawn from these projects. Highlights and conclusions of this chapter have been inserted into chapter 9.
7. Chapter	**New Technology – Renewable Fuels and Power2X Technology**; technical potentials of biogas, electrolysis and methanol production. Includes examples from national as well as international ongoing or completed projects and experience drawn from these projects. Highlights and conclusions of this chapter have been inserted into chapter 9.
8. Chapter	**New Technology – Energy Storage**; technical potentials of battery energy storage system, electrical vehicles and UPS-systems with battery back-up; supplemented with part 8.4 describing hybrid power plants. Includes examples from national as well as international ongoing or completed projects and experience drawn from these projects. Highlights and conclusions of this chapter have been inserted into chapter 9.
9. Chapter	**Summary and conclusions** acc. to Ramboll’s assignment.
10. Chapter	**References**; all references given for each chapter is in chronological order. Chapter 10 will be followed by required appendices, which are referred to in each of the numbered chapters.

In investigating the technical potentials and market integration possibilities of new technologies delivering ancillary services, the definition of “new technologies” is to be interpreted as a technology, which has been described and included in one of the Technology Data catalogues worked out in a cooperation between the Danish Energy Agency and Energinet. In total there are five Technology Data catalogues[1] [6]:

1. Technology Data for Generation of Electricity and District Heating
2. Technology Data for Heating installations
3. Technology Data for Renewable Fuels
4. Technology Data for Energy Storage
5. Technology Data for Energy Transport.

All five Technology data catalogues are in English. The technologies to be described with a technical potential delivering ancillary services will be selected from the first four mentioned catalogues due to the fact that the “Energy Transport” technology catalogue describes transport systems for the energy transport – for electricity by the transmission and distribution grid (overhead lines, cables and HVDC lines/sea cables), for natural gas by the distribution grid and for the district heating transmission and distribution grid.

Generally, upward regulation with a reserve can be provided either by increasing electricity production or by reducing electricity consumption. Conversely, downward regulation with a reserve can generally be delivered either by reducing electricity generation or by increasing electricity consumption.

1.1 Instruction to readers

Each chapter, apart from chapters 1 and 2 which introduce this report assignment and study concept respectively, will start with part X.1, an introduction to this chapter, and be followed by part X.2 containing the definitions and abbreviations used for the first time in the chapter in question. When defined, a definition or abbreviation will have the same meaning in the following chapters.

Footnotes are used for explanations and links related to the text and can provide additional information.

References are stated as [XX] and can be found in chapter 9.

As an addition to the reference list in chapter 9, Appendix 1 gives an overview regarding Danish legislation, rules and regulations for the energy supply sector – of electricity – regarding the legal framework for production, consumption, transmission, and distribution of electricity and markets.

Other appendices will follow Appendix 1 when needed as a supplement to descriptions given in the individual chapters.

[1] Reference stated as number [6] can be downloaded from the main page of the “Technology Data catalogues”: https://ens.dk/en/our-services/projections-and-models/technology-data The Danish website for download of the “Teknologikataloger” is: https://ens.dk/service/fremskrivninger-analyser-modeller/teknologikataloger

1.2 Disclaimer

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1.2.1 Market possibilities

This report will neither cover nor describe the market possibilities, historic or future price policies or developments of the markets. Further information on current ancillary service markets, historic prices and market development can be found on Energinet’s website:
https://energinet.dk/El/Systemydelser/indkob-og-udbud

1.2.2 Requirements of amount of reserves

Information contained in this report is valid at the date publication of this report and may not reflect any events or circumstances that could potentially change the required amount of reserve or the time schedule for changing the introduction of new type of reserve. Date/year stated is valid at present but could potentially change after the deadline of this report.

2. STUDY CONCEPT

The preface offered short version of the concept of the defined request from Energinet to Ramboll regarding the assignment of this report.

The study concept has been developed in close collaboration and iterative process between Energinet and Ramboll from late September until the 20th of December 2019.

The process tasks implemented by Ramboll are as follows:

- Preparation of the description of technical and market requirements for delivery of ancillary services in Denmark.
- Screening of new technologies described in the Technology Data catalogues, which can be evaluated as having a technical potential of delivering ancillary services.
- Screening of new technology trends of unit or plant projects implemented during the last few years as pilot projects on market conditions or with minor exceptions with dispensation given from Energinet and the Danish Energy Agency regarding the measures taken of delivering ancillary services.
- Selecting and describing the new technologies regarding their technical potential to deliver different types of reserves and services.
- Evaluate the technical potential of “the new technology” highlighting the advantages, disadvantages and technical as well as markets barriers to enter into the reserve capacity and energy activation markets.
- Participation in the player’s forum meeting on the 23rd of October 2019 with a presentation[2] for the stakeholders at the meeting of the Ramboll assignment to be carried out for Energinet – with the request of having the stakeholders’ input regarding the current and future trends of new technologies participating in the reserve capacity and energy markets.
- Present and describe “the good examples” of national, international or other TSO’s trials within pilot projects delivering the different sorts of ancillary services from “new technology sources” – and highlight the lessons learned.
- Participation in the Energinet Workshop on “Continuous voltage regulation and reactive power compensation” on the 15th of November 2019. Have a discussion with more stakeholders regarding input to this report as “good examples” delivering ancillary services including voltage regulation and reactive power compensation.
- Summarise and draw conclusions of the potential of “new technologies” delivering ancillary services in the future and their integration in the existing markets with a focus on technical as well as market barriers for their integration.

[2]The collected PowerPoint Presentation from 23rd of October can be downloaded in Energinet’s website: https://energinet.dk/El/Elmarkedet/Samarbejde-paa-elmarkedet/Aktoerarbejdsgruppen

2.1 Conditions and prerequisites of this study concept

This report has been prepared under the conditions and prerequisites with respect and compliance to the present and applicable Danish legislation, rules and regulations, which are listed below and stated in reference [1] and detailed in Appendix 1:

- Danish legislation laws relevant to the topics addressed in this report.
- Danish rules and regulation for grid connection of production, demand and storage units.
- Danish rules and regulations for electricity markets obligations.

When evaluating the technical potential of "new technologies", it is by all means the technical potential that is focused on and not whether there is a substantial volume or if it is financially attractive to establish a specific unit or plant delivering ancillary services.

To the greatest extent possible, and at their own discretion, Ramboll has asked for input from stakeholders, balance responsible parties, companies etc. Examples given in this report will reflect the information given from these entities, and Ramboll has, with loyalty, reproduced the received input without offering Ramboll's own view on this input.

The time period which Ramboll has been given to fulfill this assessment and report has been short, due to natural reasons as well as due to the limit regarding how many and how thoroughly the number of "new technologies" can be examined.

In the evaluation of the technical potential of a specific technology delivering ancillary services, Ramboll will state their expectations of the technology's properties to deliver in the future.

3. TECHNICAL REQUIREMENTS FOR ANCILLARY SERVICES

3.1 Introduction

This chapter will start highlighting the European rules and regulations regarding the technical and market requirements – with the purpose saying: The Danish rules and regulations, which are implemented now and will be in the future, are based on EU Regulations. For this assignment, the rules for the following subjects are considered as far as these rules have reached in the implementation processes: System operation (SOGL), balancing (EBGL), data exchange between TSO's, cross-border exchange (EU Regulation 714/2009), markets, grid connection of generators (RfG) and grid connection of demand (DCC) for the European electricity system.

Changes in the method description of technical conditions and market regulation in Denmark will only be changed after public consultations and approval of the Danish Utility Regulator (DUR).

The European electricity transmission system operation rules: "Commission regulation (EU) 2017/1485 of 2 August 2017" (SOGL) is established motivated of several reasons listed in the document[3] [7] having regards to the Treaty on the Functioning of the European Union and the "Regulation (EC) No 714/2009 of the European Parliament and of the Council of 13 July 2009 on conditions for access to the network for cross-border exchanges in electricity" [8] (EU Regulation 714/2009).

Note: Definition of words, designations and abbreviations used and stated as bold text (first time mentioned) in this part 3.1 can be found in part 3.2.

For this study the most important background extracted from "Whereas" of the listed items from (1) to (18) in SOGL the following must be highlighted:

- A fully functioning and interconnected internal energy market is crucial for maintaining security of energy supply, increasing competitiveness and ensuring that all consumers can purchase energy at affordable prices.

- Regulation (EC) No 714/2009 sets out non-discriminatory rules governing access to the network for cross-border exchanges in electricity with a view to ensuring the proper functioning of the internal market in electricity.

- Harmonised rules on system operation for transmission system operators (TSO's), distribution system operators (DSO's) and significant grid users (SGU's) should be set out in order to provide a clear legal framework for system operation, facilitate Union-wide trade in electricity, ensure system security, ensure the availability and exchange of necessary data and information between TSO's and between TSO's and all other stakeholders, facilitate the integration of renewable energy sources, allow more efficient use of the network and increase competition for the benefit of consumers.

- To ensure the operational security of the interconnected transmission system, it is essential to define a common set of minimum requirements for Union-wide system operation, for the cross-border cooperation between the TSO's and for utilising the relevant characteristics of the connected DSO's and SGU's.

[3]Reference [7]: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32017R1485

- All TSOs should comply with the common minimum requirements on procedures necessary to prepare real-time operation, to develop individual and deliver common grid models, to facilitate the efficient and coordinated use of remedial actions which are necessary for real-time operation in order to maintain the operational security, quality and stability of the interconnected transmission system, and to support the efficient functioning of the European internal electricity market and facilitate the integration of renewable energy sources (RES).

- Operational testing and monitoring requirements aim at ensuring the correct functioning of the elements of the transmission system, the distribution system and of the grid users' equipment. Planning for and the coordination of operational tests are necessary to minimise disruptions in the stability, operation and economic efficiency of the interconnected system.

- The operational and scheduling processes required to anticipate real-time operational security difficulties and develop relevant remedial measures involve timely and adequate data exchange. Therefore, such exchange should not be hampered by any barriers between the different actors involved.

- One of the most critical processes in ensuring operational security with a high level of reliability and quality is the load-frequency control (LFC). Effective LFC can be made possible only if there is an obligation for the TSO's and the reserve connecting DSO's to cooperate for the operation of the interconnected transmission systems as one entity and for providers' power generating modules and providers' demand facilities to meet the relevant minimum technical requirements.

- The provisions on LFC and reserves, aim at setting out clear, objective and harmonised requirements for TSO's, reserve connecting DSO's, 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.

- In order to ensure the quality of the common system frequency, it is essential that a common set of minimum requirements and principles for Union-wide LFC and reserves are defined as a basis for both the cross-border cooperation between the TSO's and, where relevant, for utilising characteristics of the connected generation, consumption and distribution systems. To that end, this Regulation addresses the LFC structure and operational rules, the quality criteria and targets, the reserve dimensioning, the reserve exchange, sharing and distribution and the monitoring related to LFC.

The general prerequisite for being approved delivering ancillary services in Denmark is that the unit, the grouped or the aggregated units can meet the implementation requirements of the RfG or the DCC.

Where required the EU Regulations implementation in Denmark follows a process, where Energinet (EN) develop the methods in a cooperation with other TSO's for Continental Europe (CE) and/or Nordic synchronous areas, conduct consultations and have the final document finalized with the approval from ACER and the Danish Utility Regulator (DUR).

These EU Regulations for “electricity subjects” are also designated Network Codes, find the codes and Energinet’s information regarding implementation on the Energinet’s website or refer to Appendix 1: https://en.energinet.dk/Electricity/Rules-and-Regulations#NetworkCodes

The load-frequency-control structure defined according to SOGL Article 139 is for the Danish TSO, Energinet, is parted in two agreements caused by Denmark electrically takes part in two synchronous areas. Western Denmark is part of CE synchronous area and Eastern Denmark is part of the Nordic synchronous area. This fact causes that the technical requirements for ancillary services are slightly different due to affiliation respectively to CE synchronous area or to the Nordic synchronous area. The common framework and system operating agreements (SOA’s) for frequency regulation products for Western Denmark, CE TSO’s agreement, and for Eastern Denmark, the Nordic TSO’s agreement are established.

The reliable system operation of the transmission system requires the instantaneous balancing of power production and consumption. The TSO, Energinet (EN), is responsible to maintain the real-time system balance by activating frequency ancillary services, automatic or manual restoration reserves, which are provided through purchase in ancillary service markets characterised by having a merit order list (MOL). EN is today part of a common Nordic regulation market. On the regulating power market, where capacity reservation takes place, the market price is formed hour by hour, which will be identical in all electricity spot market areas provided that no bottlenecks develop.

An overview of the roles and responsibilities of the Danish electricity market can be found here on Energinet’s website or in Appendix 1: https://en.energinet.dk/Electricity/New-player/Roles-and-responsibilities

The market regulations, which currently apply, can be downloaded here or refer to Appendix 1: https://en.energinet.dk/Electricity/Rules-and-Regulations/Market-Regulations

The markets for frequency ancillary services will develop during the next couple of years with reference to “Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing” [9] (EBGL) when processed and implemented, actions will be for Continental Europe area:

- Balancing platform for aFRR between European countries, named PICASSO.
- Balancing platform for mFRR between European countries, named MARI.

The approval of the European balancing platforms and implementation can be followed in the ENTSO-E website: https://www.entsoe.eu/network_codes/
The expected go-live date for the European balancing platforms at time of writing this report in the middle of 2022.

EN has a close operation and market cooperation with the other Nordic TSO’s and they have decided to implement EBGL and SOGL in a common project called Nordic Balancing Model (NBM). The development of the project can be followed on the common website: www.nordicbalancingmodel.net

Actions for a common balancing model of the Nordic area is by the current version of the road-map as listed and shown in to Figure 1:

- Updated information on go-live of Nordic aFRR capacity market expected Q1/2020.
- Commercial go-live Single price model expected Q2/2021
- TSO strategy for Nordic aFRR energy activation market expected Q2/2021.
- TSO strategy for Nordic mFRR capacity market expected Q4/2021.
- Go-live for 15 min imbalance settlement period time Q2/2023.
- mACE based mFRR balancing expected Q2/2023
- First-generation of Nordic Balancing Model[4] (NBM) in operation 2023
- Participation in the European balancing platforms after 2023.

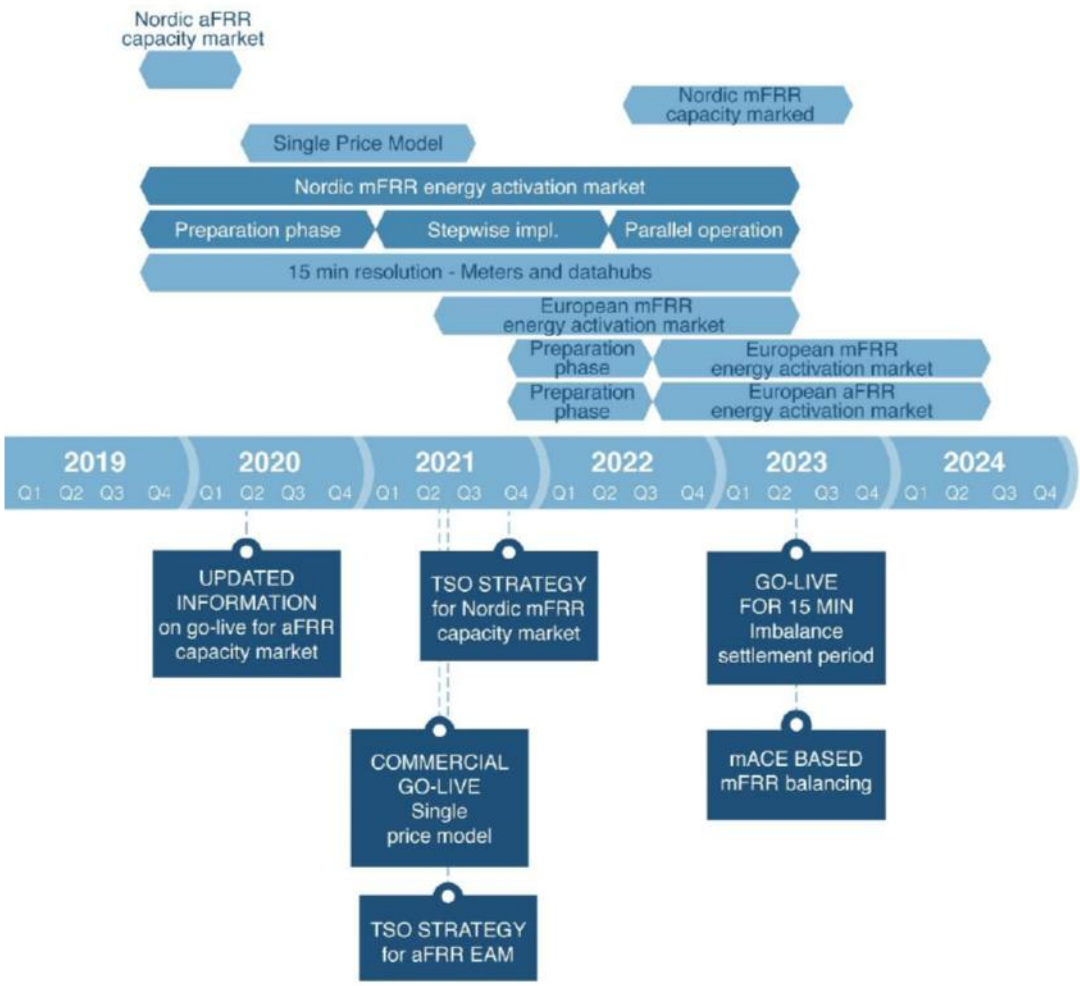


Figure 1 Road-map time-schedule of the different parts within the first-generation of the Nordic Balancing Model[5].

The technical requirements for frequency ancillary services applied and described in part 3.3 of this chapter will be according to the specifications and markets relations as existing today. The technical requirements, as they are specified today in the CE area respectively the Nordic area, are confirmed in mutual agreements between the TSO's and reviewed by the regulators, so regarding the technical requirements for existing frequency reserves no changes are expected in

[4]Road-map refer to: http://nordicbalancingmodel.net/wp-content/uploads/2019/11/NBM-Roadmap-Report-updated-after-consultation.pdf
[5]Road-map refer to: http://nordicbalancingmodel.net/wp-content/uploads/2019/11/NBM-Roadmap-Report-updated-after-consultation.pdf

2020; however, there will be introduced a new type of reserve, the Fast frequency Reserve (FFR), which will be described in part 3.3.2.

Historical frequency ancillary services/reserves have been designated as primary, secondary and tertiary reserves, which in ENTSO-E terms are adopted as follows:

- Primary reserves (FCR, FCR-D, FCR-N), instantaneously activation of a reserve for containment of an incident/disturbance.
- Secondary reserves (aFRR), replacing the primary reserves and help restore the system frequency, when activated.
- Tertiary reserves (mFRR, RR[6]), stabilising the system frequency, when manually activated within 15 minutes from the time of order.

Figure 2 illustrates the frequency reserves process in joint action within a synchronous area injecting automatically reserves, with the ENTSO-E terms defined as in part 3.2 regarding definitions and abbreviations. The figure shows the automatically response during the occurrence of an incident or disturbance starting at the plotted vertical timeline.

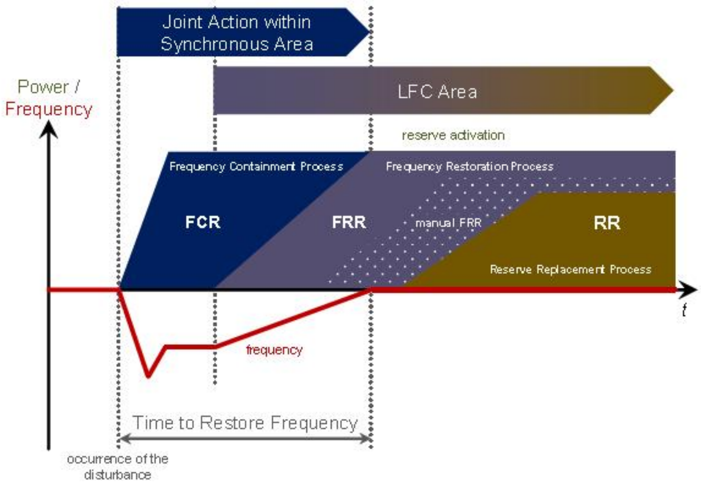


Figure 2 Dynamic hierarchy of frequency ancillary services and LFC process.[7]

After this restoration more reserves can be needed as manually activated reserves – both in the CE and in the Nordic synchronous areas the following processes are used within the Load Frequency Control (LFC) area:

- The Frequency Containment Process
- The Frequency Restoration Process

The process designated Reserve Replacement Process isn't used in CE nor in Nordic synchronous area.

The paragraphing of the next parts of this chapter will start with definitions and abbreviations used, followed by the technically descriptions of the frequency ancillary services, the test requirements and the procurement of these.

[6]RR: Restoration Reserves are not used neither in CE nor in Nordic synchronous area.

[7]Source: ENTSO-E Supporting Document for the Network Code on Load-Frequency Control and Reserves.

3.2 Definitions and abbreviations

The definitions and abbreviations used in this chapter and the following chapters, when needed, will follow the definitions used in the policy framework of ENTSO-E and as stated in:

- Article 3 of “Commission regulation (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation” [7] – SOGL – and in
- Regulation (EC) No 714/2009 of the European Parliament and of the Council of 13 July 2009 on conditions for access to the network for cross-border exchanges in electricity and repealing Regulation (EC) No 1228/2003 [8] – EU regulation 714/2009 and in
- Article 2 of “Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing” [9] – EBGL – and in
- Article of 2 “Commission Regulation (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators” [10] – RfG – and in
- Article 2 of “Commission regulation (EU) 2016/1388 establishing a network code on demand Connection” [11] – DCC.

The definition of words, designations and abbreviations are listed alphabetically; if the abbreviation is with bold letters in the text above the list, it’s definition can be found in the list below.

ACE or Area Control Error: 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, where the area control error equals ΔP+K x Δf. The ACE represents the individual remaining imbalance the LFC area is responsible for. mACE: “modernized” ACE in the Nordic synchronous area.

ACER: Agency for Cooperation of Energy Regulator, created by the Third Energy Package for further progress the completion of the internal energy market both for electricity and natural gas. ACER launched in Marts 2011 has its seat in Ljubljana, Slovenia.

Active power: The product of voltage and in-phase component of alternating current, normally measured in kilowatt (kW) or megawatt (MW).

AGC: Supplier imbalance controller.

Ancillary service: A service necessary for the operation of a transmission or distribution system, including balancing and non-frequency ancillary services, but not including congestion management. Frequency ancillary services are for balancing the transmission or distribution system. Non-frequency ancillary services are steady state voltage control, fast reactive current injections, inertia for local grid stability, short-circuit current, black start capability and island operation capability.

Balance Responsible Party or BRP: A market participant or its chosen representative responsible for its imbalances.

CE: Continental Europe (synchronous area). ENTSO-E member group: Austria, Albania, Belgium, Bosnia-Herzegovina, Bulgaria, Czech Republic, Croatia, Western Denmark (DK1), France, Republic of North Macedonia, Germany, Greece, Hungary, Italy, Luxemburg, Montenegro, Nederland, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain and Switzerland.

DataHub[8]: The DataHub is the technical prerequisite for the supplier-centric model – the market design introduced in the Danish electricity retail market in April 2016.

DCC: Abbreviation of “Commission Regulation (EU) 2016/1388 of 17 August 2016 establishing a Network Code on Demand Connection” [11], https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2016.223.01.0010.01.ENG&toc=OJ:L:2016:223:TOC

DEA: The Danish Energy Agency, in Danish “Energistyrelsen (ENS)”. The Danish Energy Agency regulates the grid companies in order to ensure that the price they charge is proportionate to the cost associated with the operation of the network.

DK1: West Denmark connected to synchronous area Continental Europe.

DK2: East Denmark connected to synchronous area Nordic.

DSO: Distribution system operator.

DUR: The Danish Utility Regulator, in Danish “Forsyningstilsynet” (FSTS).

EBGL (or GLEB): Abbreviation of “Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing [9], https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1569247109856&uri=CELEX:32017R2195

EN: Energinet.

ENTSO-E: ENTSO-E, the European Network of Transmission System Operators for Electricity, represents 43 electricity transmission system operators (TSO’s) from 36 countries across Europe. ENTSO-E was established and given legal mandates by the EU’s Third Legislative Package for the Internal Energy Market in 2009, which aims at further liberalising the gas and electricity markets in the EU. Energinet (EN) is member of ENTSO-E. The ENTSO-E Member Companies can be found here: https://www.entsoe.eu/about/inside-entsoe/members/

ENTSOG: ENTSOG, the European network of transmission System Operators for Gas; facilitation cooperation between national gas transmission system operators to achieve European Union energy goals.

EU Regulation 714/2009 [8]: The conditions for access to the network for cross-border exchanges in electricity; subject-matter and scope as quotation:
“(a) setting fair rules for cross-border exchanges in electricity, thus enhancing competition within the internal market in electricity, taking into account the particular characteristics of national and regional markets. This will involve the establishment of a compensation mechanism for cross-border flows of electricity and the setting of harmonised principles on cross-border transmission charges and the allocation of available capacities of interconnections between national transmission systems;
(b) facilitating the emergence of a well-functioning and transparent wholesale market with a high level of security of supply in electricity. It provides for mechanisms to harmonise the rules for cross-border exchanges in electricity.”

[8] Refer to Energinet’s website: https://en.energinet.dk/Electricity/DataHub

Frequency: The electric frequency of the system that can be measured in all parts of the synchronous area under the assumption of a coherent value for the system in the time frame of seconds, with only minor differences between different measurement locations, its nominal value is 50 Hz in all synchronous areas.

Frequency Containment Reserves or FCR: The active power reserves available to contain system frequency after the occurrence of an imbalance. In DK1 designation FCR is used, refer to part 3.3.1.1. In DK2 to types designated FCR-N (N: Normal operation) respective FCR-D (D: Disturbance) are used, refer to part 3.3.1.2.

Fast Frequency Reserve (or Response): FFR is a very fast reserve (significant faster than FCR), which will be introduced in the middle of 2020 in DK2.

Frequency Restoration Control Error or FRCE: The control error for the frequency restoration process, which is equal to the ACE of an LFC area or equal to the frequency deviation.

Frequency Restoration Reserves or FRR: The active power reserves available to restore system frequency to the nominal frequency and, for a synchronous area consisting of more than one LFC area, to restore power balance to the scheduled value.
Frequency restoration reserves are subdivided into:

- aFRR: Automatic activated Frequency Restoration Reserve, which former was designated Load Frequency Control (LFC), when the aFRR were activated to balance interconnectors to another (LFC) area.
- mFRR: Manual activated Frequency Restoration Reserve.

Frequency quality defining parameter: The main system frequency variables that define the principles of frequency quality. Parameters are:

- The nominal frequency.
- The standard frequency range.
- The maximum instantaneous frequency deviation.
- The maximum steady-state frequency deviation.
- The time to restore frequency.
- The time to recover frequency.
- The frequency restoration range.
- The frequency recovery range.
- The alert state trigger time.
- Maximum number of minutes outside the standard frequency range (target parameter).

Figure 3 illustrates the given frequency quality parameters.

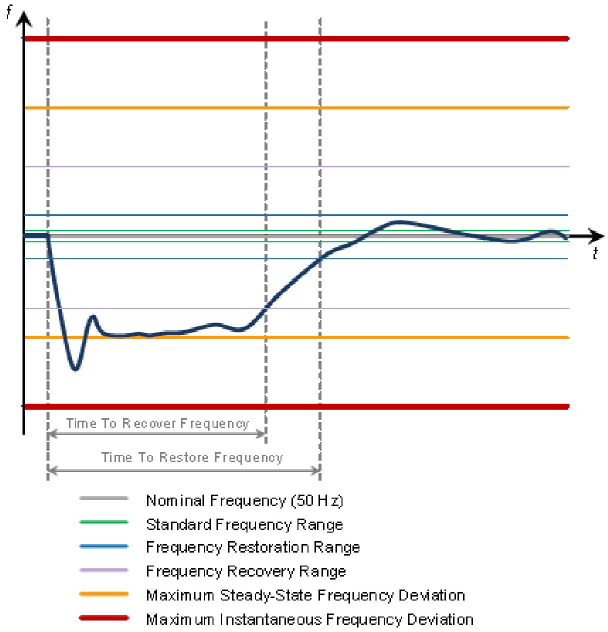


Figure 3 Frequency quality defining parameters[9]

The Table 1 below shows the frequency quality parameters, which are used for CE (DK1) and Nordic (DK2) synchronous areas.

	CE (DK1)	Nordic (DK2)
Nominel frequency	50 Hz	50 Hz
Standard frequency range	± 50 mHz	± 100 mHz
Maximum instantaneous frequency deviation	800 mHz	1000 mHz
Maximum steady-state frequency deviation	200 mHz	500 mHz
Time to restore frequency	15 minutes	15 minutes
Time to recover frequency	Not used	Not used
Frequency restoration range	Not used	± 100 mHz
Alert state trigger time	5 minutes	5 minutes
Maximum number of minutes outside the standard frequency range	15000 minutes	15000[10] minutes

Table 1 Frequency quality parameters[11]

GLEB: Same as EBGL, Abbreviation of “Commission Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing [9], https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1569247109856&uri=CELEX:32017R2195

Imbalance Netting: A process agreed between TSO’s that allows avoiding the simultaneous activation of FRR in opposite directions, taking into account the respective FRCE’s as well as the activated FRR and by correcting the input of the involved frequency restoration processes accordingly.

[9]Reference: ENTSO-E Supporting Document for the Network Code on Load-Frequency Control and Reserves.

[10]The goal for frequency deviations outside normal frequency band is not more than 10000 min/year. However, Table 1 shows the frequency quality target parameter, which is considered as the absolute maximum.

[11]Reference: SOGL

Imbalance Netting Process: A process agreed between TSO's that allows avoiding the simultaneous activation of FRR in opposite directions, taking into account the respective FRCE's as well as the activated FRR and by correcting the input of the involved frequency restoration process accordingly (reference to Article 146 of SOGL).

K-factor of an LFC area or LFC block: A value expressed in megawatts per Hertz (MW/Hz), which is as close as practical to, or greater than the sum of the auto-control of generation, self-regulation of load and of the contribution of frequency containment reserve (FCR) relative to the maximum steady-state frequency deviation.

Load-Frequency Control area or LFC area: 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.

Load-Frequency Control block or LFC block: 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.

MARI: Manually Activated Reserves Initiative.

MOL: Merit Order List.

NBM: Nordic Balancing Model, website: http://nordicbalancingmodel.net/about/

Nordic: Nordic synchronous area. ENTSO-E member group: Eastern Denmark (DK2), Finland, Norway and Sweden.

Nordic Analysis Group or NAG: System operation analysis group of ENTSO-E organised with TSO's representatives of the Nordic synchronous area (Eastern Denmark (DK2), Finland, Norway and Sweden). One of their working tasks is the Inertia2020-project.

Region Group Nordic or RGN: Group in ENTSO-E of TSO's representatives from the Nordic synchronous area i.e. members from Eastern Denmark (DK2), Finland, Norway and Sweden.

PICASSO: Platform for the International Coordination of the Automatic frequency restoration process and Stable System Operation.

Players: Several types of players are active on the electricity market, and in practice a player often has two or more roles, operating simultaneously as producer, end customer, electricity supplier and balance responsible party (BRP).

Rate of Change of system Frequency or RoCoF: Calculated as df/dt; network code RfG and DCC requires that the TSO's shall specify the df/dt (RoCoF), which a power generation module (RfG) or a Demand Unit (DCC) at least shall be capable of withstanding.

Reactive power: The product of voltage and the out-of-phase component of alternating current, normally measured in kilovar (kvar) or megavar (Mvar). Reactive power is produced by capacitors, overexcited generators, regulated inverters and other capacitive components and is absorbed by reactors, under-excited generators and other inductive components.

Reactive power control (Q-regulation): The automatic change in reactive power output from a generating unit in response to a reactive power control set-point received via a signal.

Replacement Reserves or RR: The active power reserves available to restore or support the required level of FRR to be prepared for additional system imbalances, including generation reserves.

RES: Renewable Energy Sources.

Reserve provider: A legal entity with a legal or contractual obligation to supply FCR, FRR or RR from at least one reserve providing unit or reserve providing group.

Reserve providing unit: A single or an aggregation of power generating modules and/or demand units connected to a common connection point fulfilling the requirements to provide FCR, FRR or RR.

Reserve providing group: An aggregation of power generating modules, demand units and/or reserve providing units connected to more than one connection point fulfilling the requirements to provide FCR, FRR (or RR).

RfG: Abbreviation of “Commission Regulation (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators” [10], https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:JOL_2016_112_R_0001

SOGL: Abbreviation of “Commission regulation (EU) 2017/1485 of 2 August 2017 establishing a guideline on electricity transmission system operation” [7], https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32017R1485

SGU: Significant Grid User.

SOA: System Operation Agreement.

TenneT TSO GmbH or TTG: TenneT (TTG) is the TSO in Northern Germany with transmission grid connections to Western Denmark (DK1).

Time Control Process: The process for time control, where time control is a control action carried out to return the electrical time deviation between synchronous time and UTC time to zero.

Transmission System Operator or TSO: Energinet (EN) is the TSO in Denmark. The role of the TSO are described in Article 22 of SOGL.

Unity power factor (operation condition): the condition is when no reactive power is flowing from or out of the generation source.

Voltage control: The manual or automatic control actions at the generation node, at the end nodes of the AC lines or HVDC systems, on transformers, or other means, designed to maintain the set voltage level or the set value of reactive power.

3.3 Ancillary services to be delivered in Denmark - established technical requirements

This part will describe and give an overview of technical demands applicable to each ancillary service, which EN requires for respectively DK1 and DK2 according to established rules. The general test requirement will be described in part 3.4 and the general commercial conditions and procurement will be described in part 3.6.

The existing rules for technical requirements can be downloaded from Energinet's website as follows: "Ancillary services to be delivered in Denmark tender conditions" in English[12] [12] and in Danish[13] version respectively.

The tender conditions for ancillary services describe the requirements that a balance responsible party (BRP) must meet in order to participate in the markets for ancillary services.

To sell ancillary services to EN, the market player must conclude a master agreement with EN. As a prerequisite the market player must be a balance responsible party for production or demand in DK1 or DK2. Further the plant/unit delivering the ancillary services must be approved by EN. "Prequalification of units and aggregated portfolios" in English[14] [13] and in Danish[15] are available for downloading from Energinet's website.

[12] https://en.energinet.dk/Electricity/Rules-and-Regulations#AncillaryServicesSupplierRequirements
[13] https://energinet.dk/El/Systemydelser/indkob-og-udbud/Krav-til-systemydelser
[14] https://en.energinet.dk/Electricity/Rules-and-Regulations/Approval-as-supplier-of-ancillary-services---requirements
[15] https://energinet.dk/El/Systemydelser/indkob-og-udbud/Krav-til-systemydelser

3.3.1 Frequency ancillary services to be delivered in DK1 and DK2

The demands for the delivery of frequency ancillary services in DK1 and DK2 are slightly different due to affiliation respectively to the CE and Nordic synchronous area and historical causes. EN buys reserves separately for each of the two areas.

3.3.1.1 Frequency ancillary services in Western Denmark (DK1)

For DK1 the following frequency ancillary services will be described here and listed as part of a table for having an over-view of all frequency ancillary services, which is shown in Appendix 4, this appendix also gives the figures of requirement needs for 2020 acc. to [4].

- Frequency Containment Reserve (FCR) for automatic activation.
- Automatic Frequency Restoration Reserve (aFRR) as capacity reservation (power) for automatic activation (energy).
- Manual Frequency Restoration Reserve (mFRR) for manual activation by EN.

Gaining an understanding of how the load-frequency-control structure in CE synchronous area are agreed acting among the TSO's, refer to Appendix 2. Figure 4 shows the processes, if a disturbance (d) happens in the LFC block area of DE-LU-DK (scheduling/monitoring area of DK1) - extracting the "Figure 2 of Appendix 2" and modifying without the "Reserve Replacement Process" gives the LFC control structure processes for DK1:

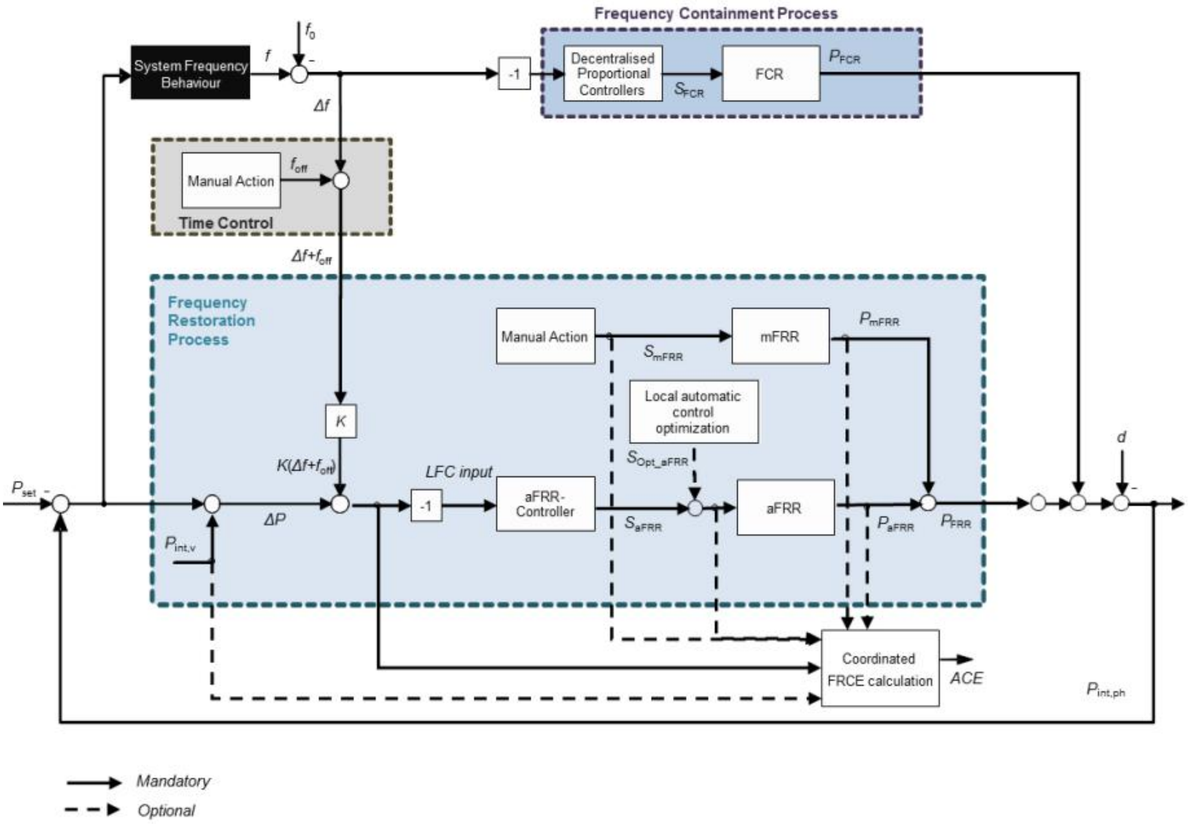


Figure 4 CE Synchronous area control process[16] (for LFC block of DE-LU-DK and control area of DK1).[17]

Then the activation processes will take place restoring the frequency back to nominal value of

[16]Refer to Appendix 2.

[17]Refer to Appendix 2 – "Figure 2" without "Reserve Replacement Process".

50 Hz.
The processes agreed for the LFC Block DE-LU-DK are:

- The Frequency Containment Reserve process (FCR activation)
- The Frequency Restoration Reserve process (aFRR activation followed by mFRR activation),
- The Time Control Process,
- The Imbalance Netting process,
- The Cross-Border FRR activation process

FCR:
All TSO members of CE synchronous area share the responsibility for ensuring the availability of enough FCR for a large fault disturbance (Reference Incident). The regulation SOGL Article 153 defines the rules. The FCR amount in total for the CE area is +/-3,000 MW. Energinet's share is determined by generation and consumption in DK1 relative to total generation and consumption of the CE synchronous area and the amount is fixed once a year, in 2019 an amount of +/- 20 MW in DK1. In 2020 Energinet's amount of FCR will be +/- 21 MW in DK1, refer to [4].

The FCR reserve activation must be implemented as a local controller on “the unit” (production or demand) typically on process level and signal for activation is measured locally. The unit must already be connected to the power system and in operation. Traditionally the primary reserves has been supplied by hydro, steam, nuclear[18] or gas driven turbines connected with a synchronous generator. The extra or less power output of the generator can be achieved by increasing or decreasing the torque applied to the turbine's rotor, regulating the flow/energy input of the drive media, a schematic diagram is shown in Figure 5.

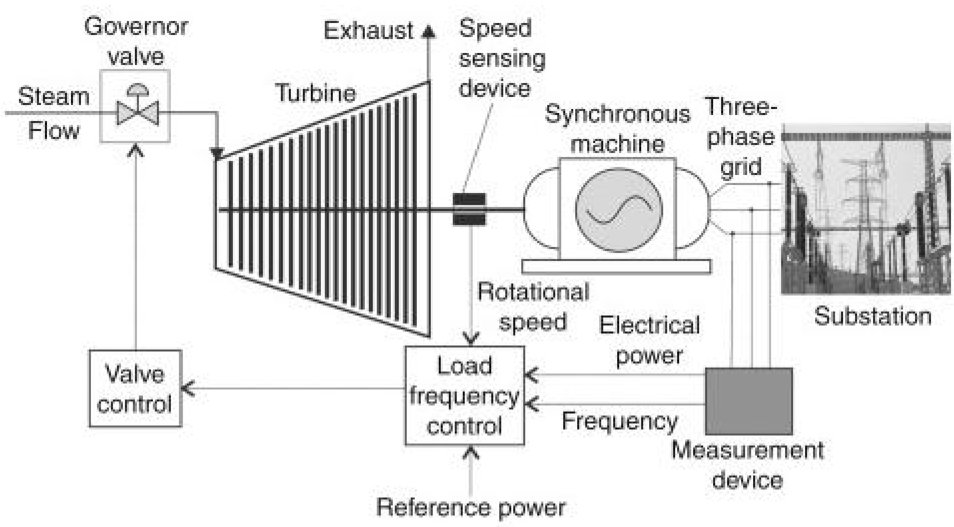


Figure 5 Schematic diagram[19] of the frequency control system of a synchronous generator.

The generation capacity available for fast regulation due to frequency variations of the reference frequency, 50 Hz ± 200 mHz, in the CE synchronous area power system comes from the so-called spinning reserves, which can provide full regulation of power within a few seconds and following this by intervention of the turbine and engine speed governors. Danish thermal power plants are

[18]No nuclear power plants are established in Denmark.
[19]Reference: Reproduction of Figure 22 from J.A. Carta, in Comprehensive Renewable Energy, 2012.

built or retrofitted to ramp with an average of 4 % per minute in a response to the demand for flexibility of the production and voltage regulation by droop control – refer to part 3.3.3.1.

The majority of FCR in DK1 is today delivered by thermal power plant, natural gas power plants and electrical boiler plants. Activation is performed using the local measurement of frequency. The power response to frequency deviation ± 200 mHz with ± 20 mHz dead band is shown in Figure 6 – FCR power response without the ± 20 mHz dead band is also allowed, refer to Figure 7.

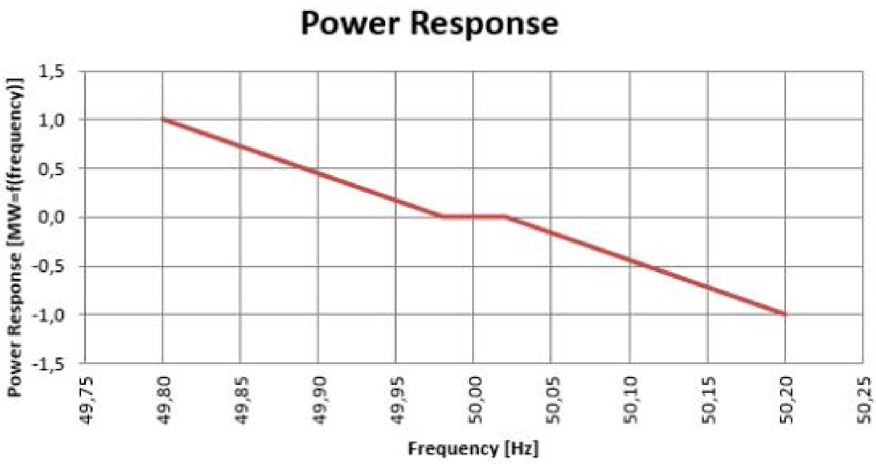


Figure 6 FCR power response curve for ± 200 mHz frequency deviation with ± 20 mHz dead band.[20]

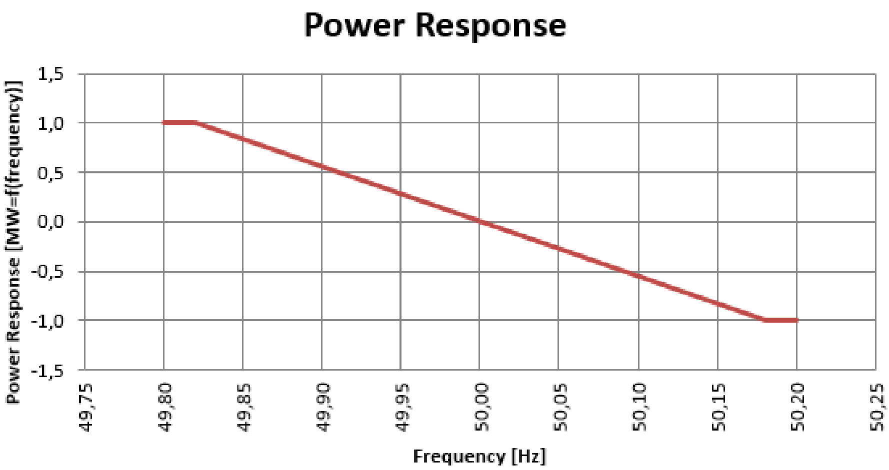


Figure 7 FCR power response curve for ± 200 mHz frequency deviation without dead band.[21]

Electrical boiler plants are capable regulating the water flow to the boiler tank or movement of the boiler's electrodes inside the tank within the required response time to deliver FCR. An example of an electrical boiler plant (product PARAT Halvorsen AS) is shown in Figure 8, the frequency activation signal gives the control signal, which changes the water level within the electrode chamber; notice that other types of electrical boileres exist than the one shown.

[20]Source: Energinet
[21]Source: Energinet

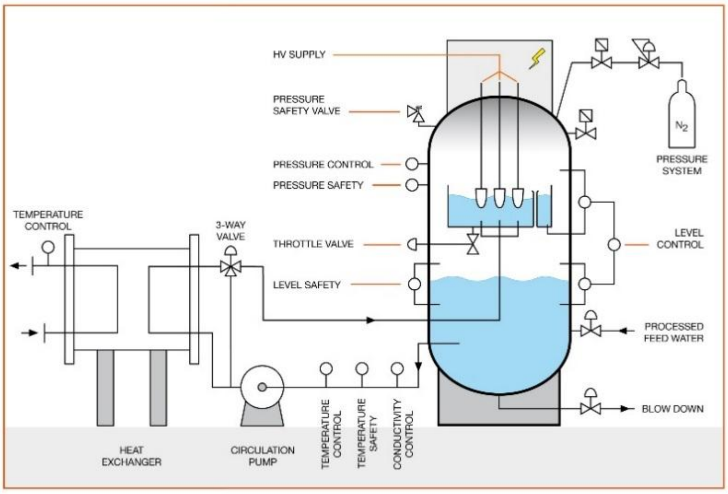


Figure 8 Principle diagram of electrode boiler generation system (product PARAT Halvorsen AS)[22]

A delivery of FCR may be made up of supplies from several production or from several demand units with different properties, which collectively aggregated can provide the required response within the required response time.

An over-view of all technical requirements for delivery of FCR in DK1 are stated in Appendix 4 Table 1 and Appendix 4 Table 2; measurements accuracy and signals requirements in Appendix 4 Table 3.

aFRR:

The demand for aFRR in DK1 is determined after Synchronous Area Operational Agreement, Annex 1, Policy on Load-Frequency Control and Reserves[23], refer to Appendix 2: The amount of aFRR for TSO EN is fixed to be +/- 90 MW. The value isn't expected to change significantly during the next years. The purposes of this reserve are first to replace FCR, considering that FCR could have limited availability (minimum delivery time requirement of FCR is 15 min), to restore the frequency to 50 Hz and secondly to restore any imbalances in the grid interconnections to follow the agreed scheduled operation plan. The aFRR activation acts to minimise the area control error (ACE) as shown on Figure 4:

$$ACE = \Delta P + K \times \Delta f$$

aFRR supply capacity can be delivered by plants or units in operation or fast-starting units, coming from a single unit or from an aggregated portfolio of units from a BRP, which have the communication line to EN. It must be possible to supply the requested reserve within 15 minutes.

Starting from January 2020 the required amount of aFRR will be purchased by having monthly capacity auctions in DK1, the required amount of aFRR for 2020 are +/- 90 MW in DK1, refer to [4].

From 2020 and forth, EN will give a notification for purchase of aFRR from approved suppliers. It must be possible to supply the aFRR within ≤15 minutes response time, which requires supply from units in operation or alternatively, the reserve can be supplied by a combination of plants in

[22]Figure 8 is reproduced with permission from PARAT Halvorsen AS brochure trough product retailer in Denmark as:scan/Michael Vejlgaard.
[23]ENTSO-E website: https://consultations.entsoe.eu/system-operations/synchronous-area-operational-agreement-policy-1-lo/

operation and fast-starting plants. The reserve to be supplied within any coming 5 minutes period must be provided by plants in operation. The regulation signal is sent online from EN to each BRP.

The regulation is automatically performed by activation signal from EN. If the BRP does not have an AGC the configuration of the balancing control follows the principles in Figure 9.

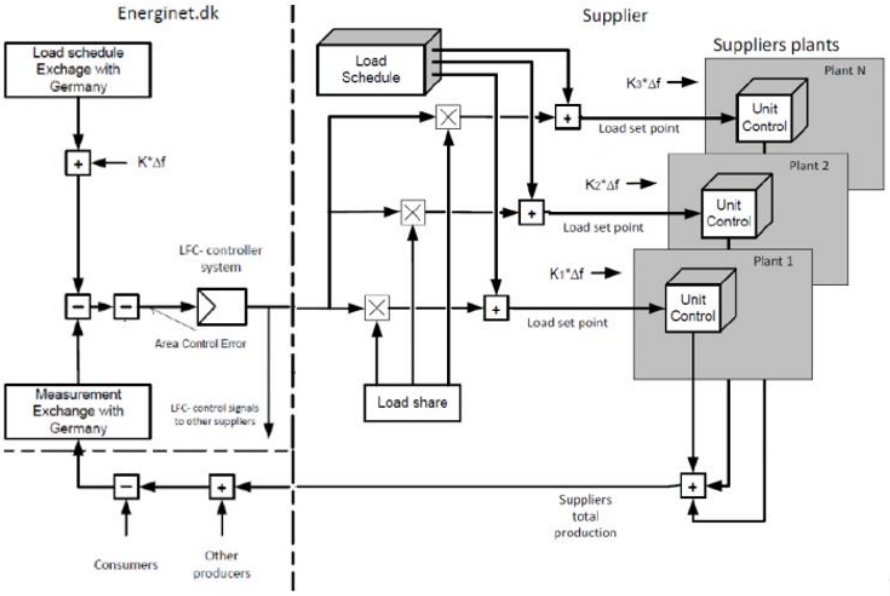


Figure 9 Principle for the design of the activation signal for delivering FCR and/or aFRR, where BRP has no AGC.[24]

If the BRP has an AGC implemented the configuration of the balancing control follows the principles in Figure 10.

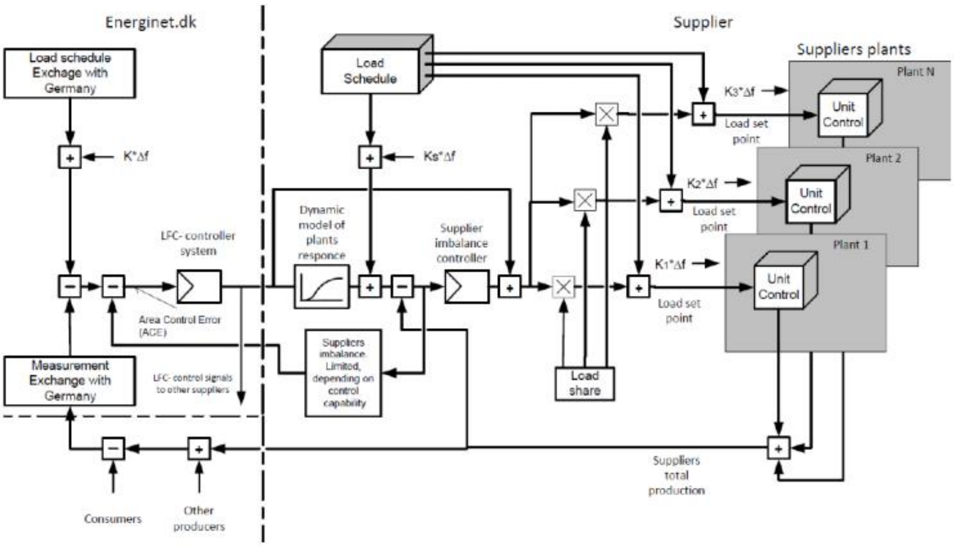


Figure 10 Principle for the design of the activation signal for delivering FCR and/or aFRR, where BRP has an AGC.[25]

[24]Source: Energinet
[25]Source: Energinet

Plants/units, which have been approved delivering FCR, can also most likely be approved delivering aFRR provided that the delivery of the reserve can be maintained continuously. The delivery must proceed until the frequency has returned to nominal value of 50 Hz (Δf goes to zero with regards to Figure 4) and the ACE is reduced to zero.

An over-view of all technical requirements for delivery of aFRR in DK1 are stated in Appendix 4 Table 1 and Appendix 4 Table 2; signals requirements in Appendix 4 Table 3.

mFRR:
In the event of a substantial imbalance between generation and consumption in DK1, that cannot be corrected by FCR or aFRR, EN will activate available reserves of mFRR (manual Frequency Restoration Reserve) for tertiary control measure. The SOGL have an additional criterion, which is the ability to cover 99 % fractile of the annual imbalances on LFC block level.

According to the applicable agreements with TTG and Statnett regarding DK1, it is demanded that disconnection of the largest production unit in DK1 (N-1 fault) do not affect the neighbors.

The reserves aFRR and mFRR are dimensioned as a total amount of capacity. The sum of aFRR and mFRR must cover disconnection of the largest production unit in DK1. The largest unit considered in 2019 was Skagerrak 4 HVDC connection of 682 MW. The EN demand for procurement of mFRR were thus 582 MW as the amount of aFRR was counting for 100 MW. A subpart of the 582 MW mFRR, an amount of 300 MW, shared between DK1 and DK2 via the Great Belt HVDC connection between DK1 and DK2. The remaining part 282 MW was purchased in the mFRR capacity market with a market time unit of one hour. For 2020 the reserves aFRR and mFRR still are dimensioned as a total amount of capacity to purchase, the largest unit is now the COBRA cable of 684 MW (the cables capacity of 700 MW minus losses of 16 MW). The rule sharing with DK2, as previous with an amount of 300 MW via the Great Belt HVDC connection between DK1 and DK2, gives a remaining part of 284 MW, which are to be purchased for DK1 in 2020.

The manual reserves are both an upward and a downward regulation reserve, which is activated by EN's control room in general to relieve the aFRR in DK1 and the FCR-N in DK2 in the event of substantial imbalances and ensures balance in the event of outages or restrictions affecting production facilities and interconnections. Purchase of downward mFRR regulation in DK1 isn't necessary caused by more than enough voluntary bids available in the regulating power market. The mFRR must be supplied in full amount within 15 minutes after activation order. The mFRR is activated by amending operational schedules or consumption forecasts following the prior exchange of schedules between EN and suppliers/BRP's.

A delivery may be made up of supplies from several production units with different properties, which collectively can provide the required response within the required response time. A delivery may also be made up of supplies from several demand units with different properties, which collectively can provide the required response within the required response time. Any system for such combined deliveries must be verified by EN. A delivery cannot be made up of supplies from a mix of production and demand units.

An over-view of all technical requirements for delivery of mFRR in DK1 are stated in Appendix 4 Table 1 and Appendix 4 Table 2; signals requirements in Appendix 4 Table 3.

3.3.1.2 Frequency ancillary services in Eastern Denmark (DK2)

For DK2 the following frequency ancillary services will be described and listed as part of the table for having an over-view as shown in Appendix 4:

- Frequency Containment Reserve (FCR-N); frequency-controlled normal operation reserve for automatic activation.
- Frequency Containment Reserve (FCR-D); frequency-controlled disturbance reserve for automatic reservation.
- Automatic Frequency Restoration Reserve (aFRR) as capacity reservation (power) for automatic activation (energy).
- Manual Frequency Restoration Reserve (mFRR) for manual activation by Energinet.

Gaining an understanding of how the load-frequency-control structure in Nordic synchronous area are agreed acting among the TSO's refer to Appendix 3.

FCR-N:
In the event of frequency deviations FCR-N ensures that the equilibrium between production and demand is restored, keeping the frequency close to 50 Hz.

FCR-N is an automatic regulation provided by production or demand units, which by means of control equipment respond to grid frequency deviations. FCR-N consists of both upward and downward regulation and is provided as a symmetrical reserve, where upward and downward regulation reserves are procured together.

The TSOs within the Nordic synchronous area are jointly responsible for the supply of FCR-N. Each individual TSO contributes to the total FCR-N Nordic synchronous area. The combined requirement of total 600 MW, EN is obliged to supply a proportionate share. The share to be supplied by EN is determined by the production and consumption taking place in DK2 relative to the entire Nordic production and consumption and is determined once a year for a calendar year. For next year 2020 the amount of FCR-N for DK2 are +/- 18 MW.

A delivery may be made up of supplies from several production units with different properties, which collectively can provide the required response within the required response time.
A delivery may also be made up of supplies from several demand units with different properties, which collectively can provide the required response within the required response time. Any system for such combined deliveries must be verified by EN.

A delivery can be made up of supplies of production and demand units, if the balance responsibility party for the production and demand units rests with the same BRP.

The power response to frequency deviation ± 100 mHz is shown in Figure 11.

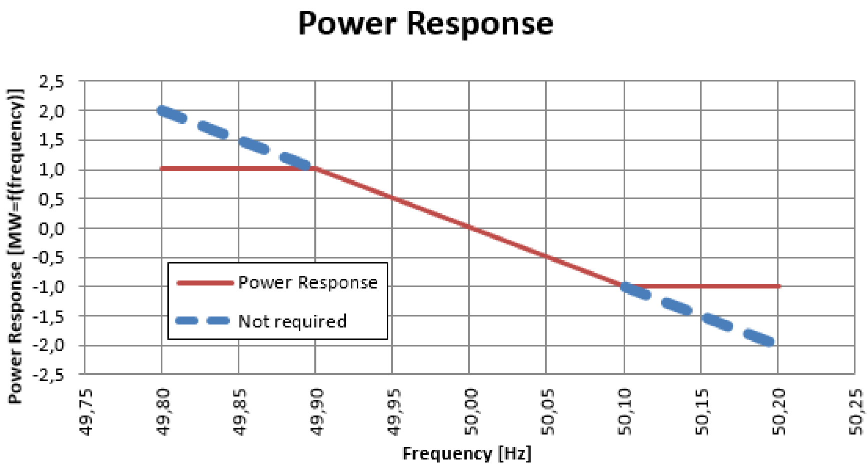


Figure 11 FCR-N power response curve for ± 100 mHz frequency deviation.[26]

The same types of plants delivering FCR in DK1 delivers FCR-N in DK2; refer to part 3.3.1.1 page 22 - 23 for a short description.

An over-view of all technical requirements for delivery of FCR-N in DK2 are stated in Appendix 4 Table 1 and Appendix 4 Table 2; measurements accuracy and signals requirements in Appendix 4 Table 3.

FCR-D:
In the event of major system disturbances, the frequency-controlled disturbance reserve is a fast reserve used for regulating the frequency following substantial frequency drops resulting from the outage of major production units or lines.

FCR-D is an automatic upward regulation reserve provided by production or demand facilities, which by means of control equipment respond to grid frequency deviations. The reserve is activated automatically in the event of a sudden frequency drop to under 49.9 Hz and remains active until balance has been restored or until the mFRR takes over the supply of power. In ultimo 2021 the downward regulation of FCR-D will also be implemented in the Nordic synchronous area with requirements mirrored from the upward regulation.

Each individual TSO contributes to the total amount of FCR-D in the Nordic synchronous area. The requirement is the dimensioning fault (largest nuclear power station in operation) and the share between the TSO’s is distributed in proportion to the dimensioning faults of each individual area. EN's share is determined by the largest dimensioning fault in DK2 and is fixed each Thursday for the coming week. The requirement in 2019 for DK2 was 176 MW[27]. The FCR-D requirement for DK2 is partly covered by the HVDC interconnections between Jutland and Sweden Konti-Scan (75 MW), between Germany and Zealand Kontek (50 MW) and between Funen and Zealand the Great Belt link (18 MW), the residual quantity of 33 MW has in 2019 been procured through the market.

The requirements in 2020 are expected to be of the order of magnitude of + 44 MW, where Konti-Skan, the Great Belt link and Kontek will not participate in delivering FCR-D (the HVDC links can only be used for emergency power regulations).

[26]Source: Energinet
[27]Reference in Danish: Behovsvurdering for systemydelser 2019.pdf

A delivery can be made up of supplies from several production units with different properties, which collectively can provide the required response within the required response time. A delivery may also be made up of supplies from several demand units with different properties, which collectively can provide the required response within the required response time. Any system for such combined deliveries must be verified by EN.

The power response for FCR-D takes over from FCR-N if the disturbance gives frequency deviations larger than ± 100 mHz; the frequency response is shown in Figure 12.

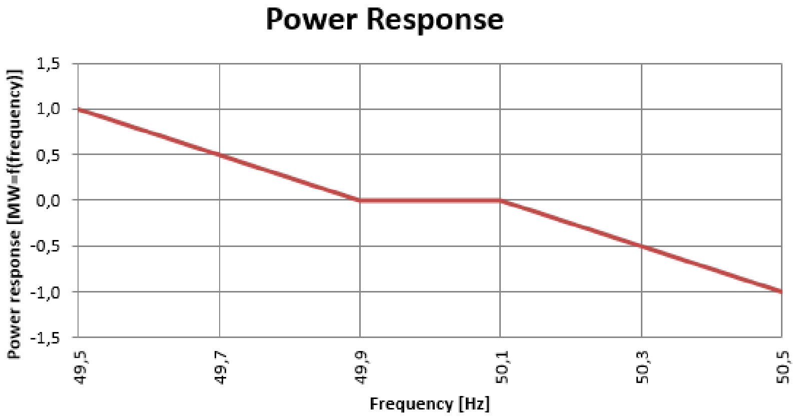


Figure 12 FCR-D power response curve for frequency deviation ≥ ± 100 mHz.[28]

The same of plants delivering FCR in DK1 delivers FCR-D in DK2; refer to part 3.3.1.1 page 22 - 23 for a short description.

An over-view of all technical requirements for delivery of FRC-D in DK2 are stated in Appendix 4 Table 1 and Appendix 4 Table 2; measurements accuracy and signals requirements in Appendix 4 Table 3.

aFRR:

Today there is no market for capacity of aFRR in DK2. To take counteractions against the observations regarding the deterioration of the frequency in the Nordic synchronous area during the last 15 years, with reference to [4], planning is underway for a new aFRR market to be established during 2020 in the Nordic area. The expectations are that the needs of aFRR capacity in the Nordic area increases from 300 MW in 2019 to 600 MW in 2021. The needs for 2020 in DK2 are expected to vary between ± 12 to ± 30 MW. Under the tasks of NBM, a common Nordic aFRR capacity market in 2020 will be established with the anticipation a market for energy activation of aFRR in 2023, refer to Figure 1.

An over-view of all technical requirements of delivering aFRR in DK2 are stated in Appendix 4 Table 1 and Appendix 4 Table 2; signals requirements in Appendix 4 Table 3.

The market requirements are stated as “to be determined” (TBD) in Appendix 4 Table 4 to Appendix 4 Table 10 as on hold for this new capacity market in 2020.

[28]Source: Energinet

mFRR:

As stated in the description of delivering mFRR in DK1, the manually activation of mFRR in DK2 occurs in the event of a substantial imbalance between generation and consumptions, that cannot be restored by FCR-N and FCR-D in DK2, the manually reserve will be activated by an order from EN to the players committed by contract with EN

The need for mFRR DK2 is dimensioned as a ratio between the largest unit in DK2 and the largest unit in the southern part of Sweden. Based on the existing units, the requirements in 2020 is announced by EN to be 623 MW [4]. DK2 shares 300 MW mFRR with Svenska Kraftnät in the southern part of Sweden, so if the requirement is larger than 323 MW in DK2, EN can receive up to 300 MW from Sweden. The purchase of mFRR in DK2 can be up to an amount of 638 MW due to ambient temperature differences during the year. Until the end of 2020 EN will purchase mFRR (200 MW) on long term contract concluded with contracted suppliers, refer to EN website (in Danish): https://energinet.dk/El/Systemydelser/indkob-og-udbud/Laengerevarende-aftaler

After 2021 the demand will still be based on N-1 criteria; a new market design will be implemented with monthly and daily procurement of capacity and an expected exchange of capacity reserves with DK1. The market design is currently being developed.

An over-view of all technical requirements for delivery of mFRR in DK2 are stated in Appendix 4 Table 1 and Appendix 4 Table 2; signals requirements in Appendix 4 Table 3.

3.3.2 Fast Frequency Reserve provision in the future

Within a current Inertia2020-project, which is established in the Nordic Analysis Group (NAG) of the Region Group Nordic (RGN) in the ENTSO-E organisation, a process has been initiated to develop a market for delivering of Fast Frequency Reserves (FFR). FFR is a very fast reserve (significant faster than FCR). The clarifications of the required needs for FFR as well as a market model for this reserve are expected to be ready in the middle of 2020 [4].

The FFR has properties comparable with the spinning reserve (inertia) and that's why the FFR sometimes is designated "synthetic" inertia. The same type of reserve is in UK designated Firm Frequency Reserve with the same abbreviation FFR; in the next part the formal technical requirements of FFR in the Nordic synchronous area will be described with reference to the document "Technical requirements for Fast Frequency reserve Provision in the Nordic Synchronous Area" [14]. From this report quotation:

"In order to participate in the Fast Frequency Reserve markets, it is necessary for FFR providing units and FFR providing groups, jointly referred to as FFR providing entities[29], to be prequalified. The prequalification process ensures that FFR providers have the ability to deliver FFR as required by the TSO and that all necessary technical requirements are fulfilled. The prequalification shall be performed before a provider can deliver FFR and shall consist of documentation showing that the provider can deliver the FFR as agreed with the TSO. The technical requirements, the specific documentation required and the process for prequalification are described in this document. The prequalification process includes:

1) Verification of the properties of the FFR providing entity
2) Accomplishment of prequalification tests
3) Setting up telemetry data to be sent to the reserve connecting TSO in real-time, and data logging for off-line validation purposes.

FFR has to be suitable with respect to:

- The power system frequency stability needs
- The providers' capability to provide FFR
- Market solutions for auctions and trading

Therefore, two different FFR support durations are specified:

- Long support duration FFR (with a support duration of at least 30 seconds)
- Short support duration FFR (with a support duration of at least 5 seconds)

The two different support durations have different requirements on the speed of deactivation. The provider can freely choose which support duration to prequalify for, given the different deactivation requirements.

There are three different combinations for frequency activation level and maximum full activation time, that are equally efficient for FFR provision, and the FFR provider can freely choose the most suitable combination for each specific providing entity:

- 0.7 s maximum full activation time for the activation level 49.5 Hz
- 1.0 s maximum full activation time for the activation level 49.6 Hz
- 1.3 s maximum full activation time for the activation level 49.7 Hz

It has been concluded that underfrequency situations are much more critical than overfrequency situations. Therefore, FFR is defined only for underfrequency situations."

[29] The word "entities" is used in the report to designate both "FFR providing units and FFR providing groups".

The technical requirements more specific:

- The FFR volume is quantified in MW.
- FFR for underfrequency is defined as a positive value (either as an increase of power or a load reduction to the system).
- The activation requirements for both long and short duration FFR are the same, while deactivation requirements differ.

Activation:
The activation times are shown in Table 2; the activation may be a step or a ramp or something similar, the shape is nor critical.

Alternative	Activation level [Hz]	Maximum full activation time [s]
A	49.7	1.30
B	49.6	1.00
C	49.5	0.70

Table 2 Activation times of FFR for alternative A, B and C combining the activation level and full activation time[30]

The prequalified FFR capacity and the FFR overshoot are determined and defined as in Figure 13.

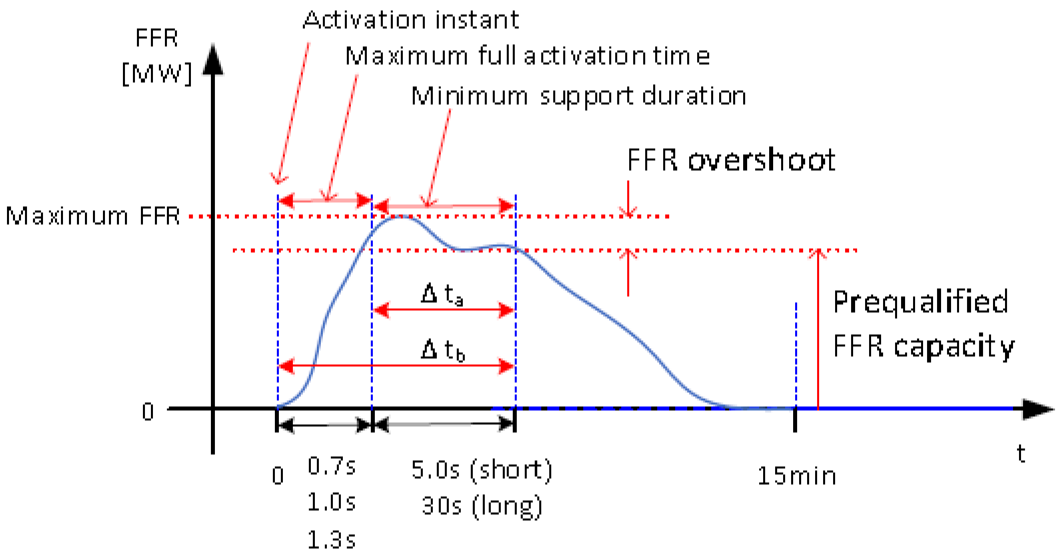


Figure 13 Definition of prequalified FFR capacity; FFR in MW & FFR overshoot in percent, activation time at t=0[31]

The calculation algorithm for minimum support power in MW in the time slot Δt_a is stated in [14] as well as the calculation algorithm for the maximum acceptable overshoot, maximum overshoot percentage is 35 % pf the prequalified FFR capacity.

Deactivation:
During the deactivation, refer to Figure 14, FFR must not exceed the maximum FFR within the time slot Δt_b, i.e. from the activation instant to the end of the minimum support duration, acc. to Figure 13.

[30]Table 2 is the reproduction of table within reference stated as [14] page 6.
[31]Figure 13 is the reproduction of "Figure 1" within reference stated as [14]

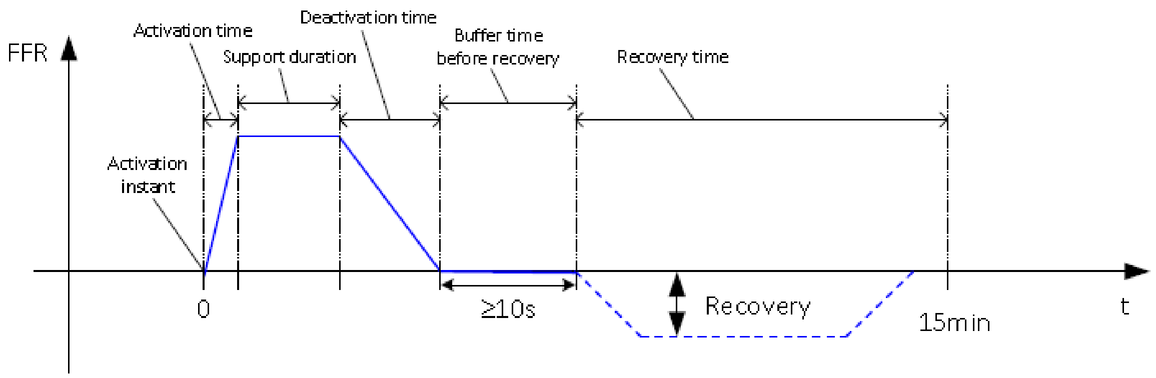


Figure 14 FFR recovery requirement; activation time at t=0[32]

Recovery:
The FFR providing entities must be fully prepared for a new cycle of support within 15 min, as shown in Figure 14. Some entities might provide several cycles without recovery, while others need recovery after each cycle. There is no requirements on the shape of recovery, it may be stepwise. The recovery must not start before a time corresponding to the activation time, plus the support duration, plus the deactivation time, plus 10 s has elapsed from the activation instant, refer to Figure 14. The recovery FFR MW, according to Figure 14, must not exceed 25 % of the prequalified FFR capacity; calculation algorithm refer to [14] page 8 in the document.

Repeatability:
After activation, the FFR providing entity must be ready for a new activation cycle within 15 min. This requirement is, however, not valid, if the frequency is still below 49.8 Hz and the FFR provision is still active, refer to Figure 14.

In the overall over-view of all technical requirements of frequency ancillary services in Appendix 4, the FFR technical requirements are not included, while the market preparation is still in progress and as so cannot be defined in this report (market model expected in the summer of 2020).

Latest news regarding FFR delivery in DK2:
Here close to deadline of Ramboll's report, Energinet has announced on the 13th of December 2019 the stakeholder's public consultation regarding "Methodology for technical requirements for and new procurement method of fast frequency reserve (FFR) in DK2" – consultation period from the 13th of December 2019 until the 23rd of January 2020. Refer to Energinet's website:
https://energinet.dk/El/Systemydelser/Nyheder-om-systemydelser/Horing-af-FFR-metode

The justification report of 13th December 2019 for the introduction of FFR in DK2 is titled "Fast Frequency Reserve – Solution to the Nordic inertia challenge" can also be downloaded.[33]

The consultation documents, in Danish and English, can be downloaded in Energinet's website:
https://energinet.dk/El/Nettilslutning-og-drift/Horinger/Hoeringer/Horing-af-FFR-metode
In addition to above stated; the test requirements delivering ancillary services has been updated including test requirements for FFR. The new version can be downloaded in the English document

[32] Figure 14 is the reproduction of "Figure 2" within reference stated as [14]
[33] Same Energinet website: https://energinet.dk/El/Systemydelser/Nyheder-om-systemydelser/Horing-af-FFR-metode

"Prequalification of units and aggregated portfolios" [13]:
https://en.energinet.dk/Electricity/Rules-and-Regulations/Approval-as-supplier-of-ancillary-services---requirements
and the Danish "Prækvalifikation af anlæg og aggregerede porteføljer" [13]:
https://energinet.dk/El/Systemydelser/indkob-og-udbud/Krav-til-systemydelser

The procurement model in DK2 for FFR capacity is stated in part 5. of the consultation documents, refer to: https://energinet.dk/El/Nettilslutning-og-drift/Horinger/Hoeringer/Horing-af-FFR-metode

Ramboll's report cannot reach to include the methodology description, test requirements and procurement model – due to the time constraints and the deadline of this report. Due to this fact, the part "Latest news regarding FFR delivery in DK2" will also be written in part 3.4 and in part 3.6.

3.3.3 Non-frequency ancillary services

Non-frequency ancillary services are steady state voltage control, reactive power control, fast reactive current injections, inertia for local grid stability, short-circuit current, black start capability and island operation capability.

The electrical systems properties required to maintain the system stability are in this report, as agreed with EN, limited to evaluate the properties from "the new technologies" regarding:

- Voltage and reactive power control
- Inertia

The adequate response of an electrical system, if a short-circuit fault occurs, is to clear the fault as fast as possible. The detection of the short-circuit fault depends on the size of short-circuit current delivered towards the point of failure. The production units (generation units) and consumption units (e.g. directly driven motors) connected in the system are suppling short-circuit energy into the fault. These units must provide enough short-circuit energy to achieve selectivity in the system – the closest short-circuit protection to the fault must react first, if this protection fails, up-stream back-up proception must react.

The discussions whether "the new technologies" are capable delivering enough short-circuit energy to the system will not be included in this report. Only a general statement as follows will be given: "New technologies equipped with inverters will cause short-circuit current limitation, the inverter will limit the short-circuit current for protection of the internal DC-circuit and therefore limit the short-circuit energy delivered. This fact means, that equipment supplied by or equipped with inverters will only supply a limited amount of short-circuit energy in grid fault situations. Review of protection schemes must be performed, and circuits must be secured properly regarding the short-circuit protection settings."

The "short-circuit power issue" is not as simple as stated above to solve in the long run; that's the reason why, this report will not address this issue.

Black start and island operation are special subjects', which neither are treated in this report.

3.3.3.1 Voltage regulation and reactive power control

To ensure a stable and optimised normal operation of the transmission grid resulting in as low losses as possible, the demand of continuous voltage regulation occurs. Voltage regulation in the transmission grid must be performed locally in the grid, where needed – the voltage is not a feature, which can be transported through the system, as the voltage is a condition in any point of the electrical system. Voltage regulation equipment must be available, where the need for voltage stabilisation arises. The active and reactive power balance, which is preferred having a unity power factor, in other words as close as possible to 1 (reactive power amount as close as possible to 0 MW), are inextricably linked together by Ohms law and the local load flow to the voltage value and control in the transmission-, distribution- and the low-voltage grid. The voltage master control is set from the TSO's – here Energinet's – control room, giving all transmission grid connected units (production, consumption and DSO's distribution grid) the main voltage signal setpoint in the locally connection points between the transmission grid and the connected units.

As today in the Danish transmission grid, EN operates with five synchronous compensators, two Voltage Source Converter (VSC) of HVDC links and one Static Var Compensator (SVC) besides the inductors, transformers and capacitors installed in the transmission grid to set and control the transmission grid voltages; the common values are 400 kV, 150 kV, 132 kV in the Danish transmission grid, refer to Figure 15. For optimisation of the losses in the grid, the set-point of the voltage will be as high as possible with regards to the insolation systems dimensioned for the transmission and distribution high-voltage grid components (transformers, switch-gear, inductors, capacitors, surge arresters etc.), cables and overhead lines.

Figure 15 Over-all picture showing the Danish TSO's, Energinet's, locally voltage settings in a snapshot.[34]

The conventional production power plants connected to the transmission grid will have to adjust their generator output voltage setting through the ordered set-point given by EN as a control message. Danish thermal power plants are built or retrofitted to ramp with an average of 4 % per minute in a response to the demand for flexibility of the production and voltage regulation by droop control. The droop control measure is agreed to be the average of 4 % for all generators to give relatively the same reaction. The droop control scheme is shown in Figure 16 [15].

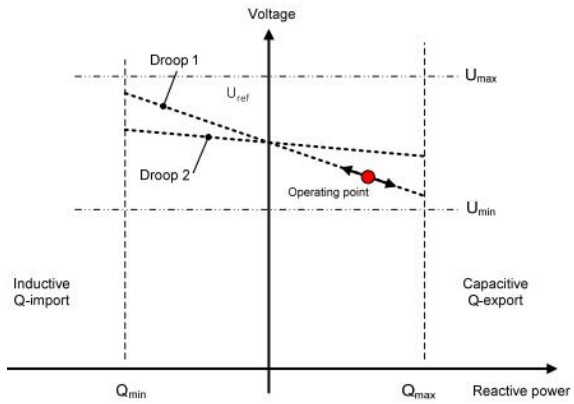


Figure 16 Regulation of generator units; voltage control regulator by droop control.[35]

[34]Source – reference [15]: Energinet, Evgenia Dmitrova – Workshop "Kontinuert spændingsregulering of reaktiv effektkompensering" presentation 2019-11-15; mail correspondence between Evgenia Dmitrova Energinet and Ramboll/HEKN dated 2019-11-18.

[35]Source – reference [15]. Only one droop line is active at the time; in DK the droop setting is 4 % as standard.

The renewable generation in Denmark connected to the transmission grid, wind and photovoltaics power generation, have been operated typically in reactive power control mode (Q-regulation).

As a future demand [4], EN will with reference to the grid connection requirement, the RfG, require that all generation units connected in the transmission grid must as a standard setting be in control mode voltage regulation and only if EN is asking for it – go to control mode reactive power regulation. Together with this voltage regulation provision requirements must EN ensure, that the reactive power transfer from the producers must be as close to neutral in the point of connection (POC) or give compensation for delivery of reactive power; Mvar-compensation rules will be part of a method description of voltage regulation.

This new concept of voltage regulation support, as a method description of voltage regulation provision requirements in the Danish transmission grid, will be described by EN in a cooperation with the Danish Energy Agency during 2020; this work is planned to be supported by a stakeholder group of representatives from production plants owners, DSO's and other stakeholders and the result is planned to be submitted for approval at DUR in the middle of Q2/2020 – refer to Figure 17 [15].

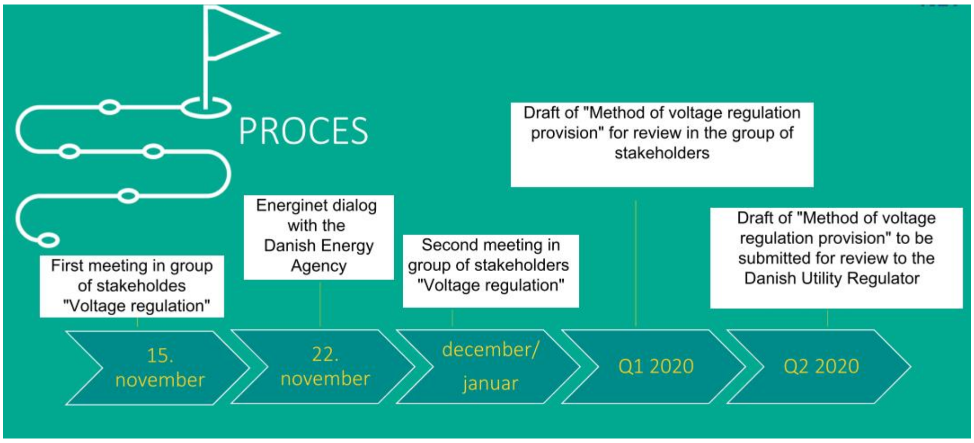


Figure 17 Planning schedule of "Method description of voltage regulation provision" in the transmission grid.[36]

For further information regarding continuous voltage regulation in normal operation and during fault situations refer to reference [4], where an overview of the European perspective or already implemented rules regarding voltage regulation and reactive power regulation is shown.[37]

Discreet voltage regulation or passive reactive compensation:
The demand of passive reactive compensation is manly caused by the installation of cables and to lesser extent overhead lines in the grid and can be most critical during low-load circumstances. Cables and overhead lines will be compensated with inductors strategically placed in the grid.

The technical regulation TF 2.1.3 [16] gives the "Demand for exchange of reactive power (Mvar) in the boundary between the transmission grid and the distribution grid"[38]. The rules for the DSO's are specified in this document – the demand per main distribution substation (at the DSO's grid of a 150/60 kV transformer, 132/50 kV transformer etc.) is to be inside a ± 15 Mvar-ribbon

[36]Source – reference [15]: Energinet, Evgenia Dmitrova – Workshop "Kontinuert spændingsregulering of reaktiv effektkompensering" presentation 2019-11-15; mail correspondence between Evgenia Dmitrova Energinet and Ramboll/HEKN dated 2019-11-18.

[37]Reference to Table 24 in [4].

[38]TF 2.3.1 [16] (in Danish) can be downloaded on Energinet's website: https://energinet.dk/El/Nettilslutning-og-drift/Regler-for-systemdrift

as showed in Figure 18 – if the ± 15 Mvar limit is exceeded, compensation actions in the distribution grid must take place.
This maximum limit of ± 15 Mvar is expected also to be the maximum limit for production units connected to the transmission grid in the future – or a ΔQ of ± 15 % of the production unit's nominal power – referring to the coming new method description of voltage and reactive power regulation in the transmission grid.

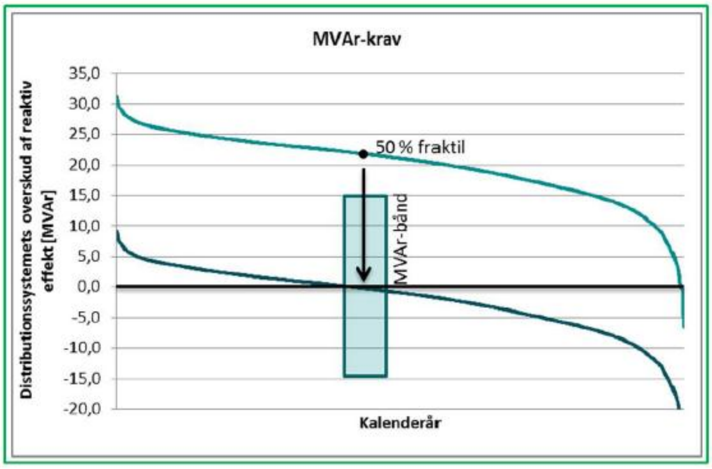


Figure 18 Mvar-ribbon for DSO's main substations illustrated together with the yearly duration curve.[39]

[39]TF 2.3.1 [16] (in Danish) "Figur 2" reproduced as Figure 18.

3.4 Ancillary services to be delivered in Denmark – test requirements

In EN document "Prequalification of units and aggregated portfolios" [13] the requirements for the mandatory tests are stated for the intention of approving the prospect of delivering frequency reserves of the various types i.e. FCR (DK1), FCR-N (DK2), FCR-D (DK2), FFR (DK2), aFRR (DK1 and DK2) and mFRR (DK1 and DK2) for production as well as demand units, aggregated units or plants.

The overall size of a unit determines whether it is a stand-alone unit or can form part of an aggregated portfolio – so the provider or market participant decides whether an unit below the maximum limit for an aggregated portfolio will be tested as a stand-alone unit or as part of an aggregated portfolio – the test requirements for each type with respect to type of reserve are defined in [13]. For FCR in DK1, as an example, the maximum power amount approval of an aggregated portfolio is 3 MW – larger aggregated portfolio requires separate tests per ≥ 3 MW aggregation. The total amount can afterward be pooled together when offering the reserve in the market. The different reserve types have different maximum tests aggregated portfolio MW sizing, refer to [13].

Each type of reserve has specific test procedures – as an example, Figure 19 shows the minimum requirements for response of FCR-D in DK2, when a frequency signal (deviation from 50 Hz) is applied by the market participant and the response of the system are logged.

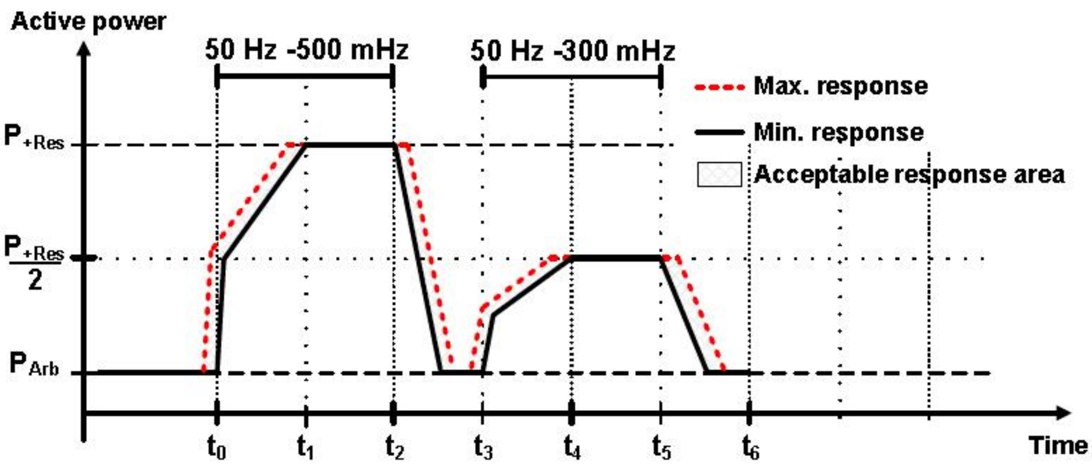


Figure 19 Minimum requirements test for the response of FCR-D of a stand-alone unit.[40]

The time parameters are given in tables in [13] – and these times match the time requirements, in this example for FCR-D, the 5 s delivery of half the volume and full availability after 30 s, refer to Appendix 4 Table 2. The logging must be documented in CSV files, Excel-files, SCADA-prints[41] or other formats agreed with EN.

Before testing of the unit, aggregated units or plants these test requirements for getting the approval must be studied very carefully and followed; EN requires a representative from EN to witness the execution of the final tests.

[40] Figure 19 is reproduced from [13].

[41] Only accepted if resolution and time scaling is of a quality that makes verification of the technical requirements for the ancillary service possible.

When the tests are finalised, the test protocol accepted by EN – then the market participant will be approved and permitted to make bids in the reserve capacity market. EN will perform subsequently reserve delivery spot checks from time to time during delivery periods.

The template for the test protocol [17] can be downloaded in Energinet website[42]. After approval EN and the market participant will sign a "Main agreement for the provision of ancillary services".

If the agreement with EN is based on an aggregation of units, the aggregator agrees to maintain an updated list of the ancillary services units at the provider's disposal. Quote from [17]: "Documentation must include information about MW, type, location and possibly consumption pattern for a given period. Documentation will be added to on an ongoing basis when requests are made for prequalification of new technologies. The proposed solution includes the option to select consumption technology and the subsequent option to enter specific requested data for the technology selected. If a certain technology is not available, because it has not been used before, the market participant may contact Energinet, and the technology will be added with specific requests for information. The amount of information requested will depend on the total potential of the technology. Furthermore, the preparation of a positive list for technologies expected to be widely used in the future is under consideration, with the aim of facilitating the process, e.g. for electric vehicles, where charging station standardisation is expected."

To be noticed is the following for the planning phase to be considered: The cost of information technology (IT) connection, maintenance, measurement systems, grid tariffs etc. for reserve energy provisions and the testing acc. to [13] must be paid by the service provider.

The test requirements of FFR will be implemented in a coming new version of the document [13].

Latest news regarding FFR delivery in DK2:
Here close to deadline of Ramboll's report, Energinet has announced on the 13th of December 2019 the stakeholder's public consultation regarding "Methodology for technical requirements for and new procurement method of fast frequency reserve (FFR) in DK2" – consultation period from the 13th of December 2019 until the 23rd of January 2020. Refer to Energinet's website:
https://energinet.dk/El/Systemydelser/Nyheder-om-systemydelser/Horing-af-FFR-metode

The justification report of 13th December 2019 for the introduction of FFR in DK2 is titled "Fast Frequency Reserve – Solution to the Nordic inertia challenge" can also be downloaded.[43]

The consultation documents, in Danish and English, can be downloaded in Energinet's website:
https://energinet.dk/El/Nettilslutning-og-drift/Horinger/Hoeringer/Horing-af-FFR-metode
In addition to above stated; the test requirements delivering ancillary services has been updated including test requirements for FFR. The new version can be downloaded in the English document "Prequalification of units and aggregated portfolios" [13]:
https://en.energinet.dk/Electricity/Rules-and-Regulations/Approval-as-supplier-of-ancillary-services---requirements
and the Danish "Prækvalifikation af anlæg og aggregerede porteføljer" [13]:
https://energinet.dk/El/Systemydelser/indkob-og-udbud/Krav-til-systemydelser

[42] English version: https://en.energinet.dk/Electricity/Rules-and-Regulations/Approval-as-supplier-of-ancillary-services---requirements
Danish version: https://energinet.dk/El/Systemydelser/indkob-og-udbud/Krav-til-systemydelser
[43] Same Energinet website: https://energinet.dk/El/Systemydelser/Nyheder-om-systemydelser/Horing-af-FFR-metode

The procurement model in DK2 for FFR capacity is stated in part 5. of the consultation documents, refer to: https://energinet.dk/El/Nettilslutning-og-drift/Horinger/Hoeringer/Horing-af-FFR-metode

Ramboll's report cannot reach to include the methodology description, test requirements and procurement model – due to the time constraints and the deadline of this report. Due to this fact, the part "Latest news regarding FFR delivery in DK2" will also be written in part 3.3.2 and in part 3.6.

3.5 Settlement and technical requirements for metering, IT communication etc.

Before going to describe the market requirements for delivering ancillary services in Denmark, more technical requirements exist. These will be highlighted below; but not described in detail as all requirements are included in the respective documents – all documents described is prepared by Energinet within the framework of the Danish Electricity Supply Act ("Elforsyningsloven"), Appendix 1, part 1.

In the document Regulation D1: Settlement metering, [1], Appendix 1, part 7 – the Danish rules regarding the detailed regulation and requirements for the relevant market participants in the Danish electricity market as regards to handling of metered data described. The regulation is primarily aimed at the grid companies and specifies the obligations and tasks that come with the responsibility for metering electricity and sending metered data to the DataHub. The regulation also describes the market participants's rights concerning receipt of metered data and calculated values from the DataHub.

In the document Regulation D2: Technical requirements for electricity metering, [1], Appendix 1, part 7 – the Danish rules regarding including before mentioned regulation D1 is described in Regulation D2 as:

"Energinet's Regulations D1 and D2 describe the practical and technical requirements relating to settlement metering. Regulation D1 stipulates that all meters in the system have one and only one metered data collector and that this collector is always a grid company (DSO). It also stipulates that grid companies have access to all meters in the grid company's (DSO's) grid areas, including meters in local units. As grid companies are metered data collectors, they are, among other things, responsible for ensuring that:

1. Meters are installed in pursuance of current regulations.
2. Metering sites always comply with the technical requirements in this regulation, including requirements for metering accuracy, remote meter reading, checking and maintenance of metering systems in operation as well as the provision and updating of documentation.
3. 15/60 metered data to be used for settlement purposes are remote-read daily and quality-checked.
4. Metered time series are distributed to all legitimate recipients at the same time.

The grid company (DSO) may delegate some of its metering tasks to metering point administrators, as defined in Regulation D1, but the main responsibility for ensuring that tasks are solved in pursuance of regulations, that data are treated confidentially and independently of commercial interests and that data are only distributed to legitimate recipients always rests with the grid company (DSO). The discretionary policy is outlined in Regulation G, which is available at Energinet's website."

In the document Regulation E1: Settlement of environmentally friendly electricity generation, [1], Appendix 1, part 7 – the Danish rules regarding subsidies settlement and payments describing the responsibilities, obligations and rights of the grid companies (DSO's), which are in charge of settling subsidies and the plant owners, which have to give all required information relevant for settlement of subsidies (master data). Energinet and the grid companies (DSO's) implement the various settlement rules and terms, supervise and check the payments of subsidies etc. based on the information given. Besides this Regulation E1 another document exists[44]: "Compensation for offshore wind farms ordered to perform downward regulation", which states the compensation

[44] Download in Energinet's website: https://en.energinet.dk/Electricity/Rules-and-Regulations/Market-Regulations

rules for offshore wind farms if ordered by EN to perform downward regulation (reduce the production.

In the document Regulation F: EDI communication, [1], Appendix 1, part 7 – the Danish rules regarding EDI data communication: “This regulation sets the standard for data communication – i.e. exchange of notifications, metered time series, etc. – between Energinet and the players in the market and mutually between market players. Energinet supports the coordinated use and development of electronic data interchange (EDI) in the Danish energy sector for electricity and gas. The purpose of data interchange is to simplify and streamline business processes in the sector. This regulation provides a collection of principles and rules describing how to exchange EDI messages in the Danish electricity market. The regulation is primarily targeted at persons with an IT background and is relevant to both grid companies (DSO’s) and balance responsible parties (BRP’s).”

Regulation F includes several appendices’ as listed:

- Syntax and structure of EDI messages
- Principles and rules of acknowledgement
- The Danish role model
- Handling of notifications
- BT Document – Business transactions for submitting notifications and schedules.

Supplement is also:
Regulation F1: EDI communication with DataHub in the electricity market, [1], Appendix 1, part 7 – the Danish rules regarding EDI data communication with the DataHub: “This regulation sets out detailed requirements for the relevant market participants in the Danish electricity market as regards EDI communication with the DataHub and set-up of IT systems. The regulation primarily applies to grid companies and balance suppliers.”

In the document Regulation G: Discretionary policy and data protection, [1], Appendix 1, part 7 – the Danish rules regarding data confidentiality as described in the introduction of this document: “The purpose of this regulation is to ensure that confidential and commercial information received by Energinet is handled and safeguarded in a correct and proper manner. This regulation primarily applies to electricity market players who as a consequence of their obligation to submit data to Energinet require documentation to the effect that the data submitted is properly protected, including:
- metered data collectors who themselves are under a duty of confidentiality, and
- market players with commercial roles, i.e. the balance responsible players in particular.
This regulation describes the measures implemented by Energinet with a view ensuring data confidentiality.”

In the document Regulation I: Master data, [1], Appendix 1, part 7 – the Danish rules regarding general and specific requirements for creating and handling master data in the retail market for electricity. “This regulation lays down detailed requirements for the relevant market participants in the Danish electricity market as regards handling of master data. The regulation is aimed at all market participants in the market and specifies the rights and obligations of these market participants as regards the creation, processing and interchange of master data for metering points.”

3.6 Ancillary services to be delivered in Denmark – market requirements

The existing market rules have already been mentioned a couple of times in part 3.3 regarding the technical requirements of ancillary services – as the requirements regarding the market rules are closely linked to the specific reserve to be purchased; the market rules are described in the document: "Ancillary services to be delivered in Denmark tender conditions" in English[45] [12] and in Danish[46] version respectively. These rules currently apply; but as mentioned in part 3.1 new reserve markets (NBM, PICASSO, MARI) are planned and under development.

In the current existing markets locally in Denmark and at Nord Pool, EN purchases reserve capacity and reserve energy to balance the power system before the operating hours.

Instead of describing the market rules for each of the reserve types purchased, the specific market rules are inserted into tables – refer to:

- Appendix 4 Table 4 Market requirements procurement, deadlines and communication for ancillary services used in Denmark.
- Appendix 4 Table 5 Market requirements regarding bids and volumes for ancillary services used in Denmark.
- Appendix 4 Table 6 Market requirements regarding bids and prices for ancillary services used in Denmark.
- Appendix 4 Table 7 Market requirements regarding acceptance of bids for ancillary services used in Denmark.
- Appendix 4 Table 8 Market rules for payment, closing and activation for the ancillary services used in Denmark.
- Appendix 4 Table 9 Market rules regarding obligations of the players for ancillary services used in Denmark.
- Appendix 4 Table 10 Market rules – player's planning for delivery of ancillary services in Denmark.

In Appendix 4, Table 4 to Table 10, references are made to Regulation C1, C2 and C3; these regulations objectives are described in short here:

In the document Regulation C1: Terms of balance responsibility, [1], Appendix 1, part 7 – this Danish regulation sets out rules on and terms of balance responsibility. The regulation is primarily aimed at market participants that have already signed or want to sign an agreement with Energinet.dk in order to become a balance responsible party (BRP). The regulation is also aimed at all parties which are basically qualified to become BRPs, e.g. balance suppliers, grid companies and electricity generators, as well as balance suppliers in general. Finally, the regulation also defines which information is required in order for Energinet to carry out its tasks in relation to balance responsibility and which the market participants are therefore obliged to provide to Energinet on request acc. to the Danish Electricity Act [1].

In the document Regulation C2: Balancing market, [1], Appendix 1, part 7 – this regulation is aimed at balance responsible parties (BRP's). A BRP handles balance responsibility to Energinet for a given production plant, consumption or trade. The BRP's are committed to submitting a notification to Energinet for every 24-hour period and to settling imbalances, if any, pursuant to the rules for settlement applicable at the time in question. BRP's for production or adjustable consumption must furthermore submit operational schedules to Energinet. This regulation describes Energinet's organisation of the balancing market and specifies the rules for settlement

[45] https://en.energinet.dk/Electricity/Rules-and-Regulations#AncillaryServicesSupplierRequirements
[46] https://energinet.dk/El/Systemydelser/indkob-og-udbud/Krav-til-systemydelser

of regulating power and balancing power. The information communicated in notifications and power schedules is described in detail in Regulation C3, and the determination of actual consumption/production in the form of settlement metering etc. is carried out according to the rules laid down in Regulation D1.

In the document Regulation C3: Handling of notifications and schedules, [1], Appendix 1, part 7 - this regulation deals with the general and commercial rules for the daily handling of notifications between Energinet and BRP's. The regulation specifies the elements of this communication and is thus closely related to Energinet's communication requirements described in Regulation F. The daily notification is the central theme of the regulation. The regulation is aimed at BRPs in Denmark, i.e. players having entered into or wanting to enter into an agreement with Energinet on balance responsibility. The regulation is effective within the framework of the Danish Electricity Supply Act [1].

Viewed from a technical perspective on the market rules as listed above; references also as listed in Appendix 1 part 7, "The Danish rules and regulations for electricity markets participation", refer to above listed C1, C2 and C3 and the settlement and technical requirements for metering, IT communication etc. in part 3.5; these several set of rules are comprehensive and acquires a BRP or aggregator familiar with the market integration process to be involved if a provider wants to supply any type of reserves.

In December 2018, DUR published a report [5], which described EN's purchase of reserves to the electricity system and analysed the state of competition, described roles and responsibilities in the development of the electricity market for reserves. This analysis found that the supply side in the reserve markets is characterised by a high concentration with few participating market players. Following this, DUR recommended among other things, that EN publishes a report on potentials from new technologies with the involvement of new actors – which led to this report assignment of: "Publishing a report on potentials from new technologies with the involvement of new actors".

There are future further intensions in the Nordic countries to strengthen the cooperation regarding reserve markets (capacity and energy). The Nordic TSO's joint development plans for the electricity system and electricity market has been reported in a report named "The Way forward - Solutions for a changing Nordic power system" from March 2018 [18]; which with the established regional security coordination (RSC) office in Copenhagen and the planned implementation of the NBM have been important solutions. In the long term the development of balance markets harmonised across Europe will be an achievement for the market players. The Nordic reserve energy market will then be connected to the European markets, while the reserve capacity markets can only be created voluntarily according to EBGL.

In the overall over-view of all technical requirements of frequency ancillary services in Appendix 4, the FFR technical requirements are not included, while the market preparation is still in progress and as so cannot be defined in this report (market model expected in the summer of 2020).

Latest news regarding FFR delivery in DK2:
Here close to deadline of Ramboll's report, Energinet has announced on the 13th of December the stakeholder's public consultation regarding "Methodology for technical requirements for and new procurement method of fast frequency reserve (FFR) in DK2" – consultation period from the 13th of December 2019 until the 23rd of January 2020. Refer to Energinet's website:
https://energinet.dk/El/Systemydelser/Nyheder-om-systemydelser/Horing-af-FFR-metode

The justification report of 13th December 2019 for the introduction of FFR in DK2 is titled "Fast Frequency Reserve – Solution to the Nordic inertia challenge" can also be downloaded.[47]

The consultation documents, in Danish and English, can be downloaded in Energinet's website: https://energinet.dk/El/Nettilslutning-og-drift/Horinger/Hoeringer/Horing-af-FFR-metode
In addition to above stated; the test requirements delivering ancillary services has been updated including test requirements for FFR. The new version can be downloaded in the English document "Prequalification of units and aggregated portfolios" [13]:
https://en.energinet.dk/Electricity/Rules-and-Regulations/Approval-as-supplier-of-ancillary-services---requirements
and the Danish "Prækvalifikation af anlæg og aggregerede porteføljer" [13]:
https://energinet.dk/El/Systemydelser/indkob-og-udbud/Krav-til-systemydelser

The procurement model in DK2 for FFR capacity is stated in part 5. of the consultation documents, refer to: https://energinet.dk/El/Nettilslutning-og-drift/Horinger/Hoeringer/Horing-af-FFR-metode

Ramboll's report cannot reach to include the methodology description, test requirements and procurement model – due to the time constraints and the deadline for this report. Due to this fact, the part "Latest news regarding FFR delivery in DK2" will also be written in part 3.3.2 and in part 3.4.

[47] Same Energinet website: https://energinet.dk/El/Systemydelser/Nyheder-om-systemydelser/Horing-af-FFR-metode

4. ANCILLARY SERVICES FROM NEW TECHNOLOGIES

4.1 Introduction

The criteria for the selection of “a new technology”, which will be investigated for the technical potential of delivering ancillary services, is a production, demand, renewable fuels or storage energy technology having already to a small extent shown potential or is foreseen to show potential of delivering ancillary services in near future – 2-5 years from now – due to a technical potential of the technology in question.

The definition of a “new technology” is linked to a former work performed in a cooperation between DEA and EN publishing in five Technology Data catalogues [6]. The Technology Data features existing technologies, technologies in economic and technological development phase and technologies still at an experimental stage. In this report only existing technologies and technologies in development state will be considered and selected from the Technology Data catalogues.

The technology, which is identified from the Technology Data catalogues [6] will be selected as qualified for further description here in this report regarding delivery of ancillary services, if the technology summarising “Data sheets” gives information of some technical potential of delivering ancillary services. Figures showing the assessment of regulation ability of the technology is included as part of the evaluation in the technology Data sheets for each technology described in the catalogues. The four of the catalogues includes descriptions of technologies, these are:

1. Technology Data for Generation of Electricity and District Heating
2. Technology Data for Heating installations
3. Technology Data for Renewable Fuels
4. Technology Data for Energy Storage

Following the categorisation of the Technology Data catalogues are selected technology will be grouped as a:

- Generation technology – refer to Chapter 5.
- Demand technology – refer to Chapter 6.
- Renewable fuels technology – refer to Chapter 7.
- Energy storage technology – refer Chapter 8.

The technology’s suitability (potential) for delivering one or more ancillary service(s) is argued for in each of the chapters describing the technology selected to be reported here.

The parameters specified in the Technology Data catalogues to show regulation ability of the specific technology is specified different, dependent of in which of the catalogues the technology is described.

In the Technology Data catalogue of “Generation of Electricity and District heating”[48] [6] the parameters of regulation ability are the following:

- Primary regulation (% per 30 s)
- Secondary regulation (% per 1 min)
- Minimum load (% of full load)
- Warm start-up time (hours)
- Cold start-up time (hours)

[48] Part of reference [6], DEA website specific link: https://ens.dk/en/our-services/projections-and-models/technology-data/technology-data-generation-electricity-and

These parameters are perfect for evaluation and selection of the obvious candidates for further description regarding the technical potential for delivery of ancillary services; as it is not only the regulation ability criteria the selection will depends on, but also the seen trends – more of the technologies without data statements of regulation ability will also be chosen for description and be included in examples given in chapter 5, 6, 7 and 8.

In the Technology Data catalogue of “Heating installations” [6] the property of regulation ability is described: “Regulation abilities are particularly relevant for electricity generating and consuming technologies. This includes the part-load characteristics, start-up time and how quickly it is able to change its production or consumption when already online.”; regulation ability for heating plants, which also are demand units, will also depend on the entire mechanical system receiving the heat generated with the rate of change that supports the regulation of the energy input of electricity if frequency regulated. The parameters of regulation ability are the following:

- Change in capacity within 1 minute (%)
- Minimum load (% of full load)
- Warm start-up time (hours)
- Cold start-up time (hours)

In the Technology Data catalogue of “Renewable Fuels” [6] the property of regulation ability is described: “Mainly relevant for hydrogen technologies where electricity is used as main input. Description of the part-load characteristics, how fast can they start up and how fast are they able to respond to supply changes and does part-load or fast regulation lead to increased (or lower) wear and hence increased cost.” Renewable fuels production (or Power2X) are also demand units; which can be frequency regulated. There are no parameters defined for regulation ability.

In the Technology data catalogue of “Energy storage” [6], at page 19, the parameters of regulation ability are the following (only for electricity storage):

- Response time from idle to full-rated discharge (s)
- Response time from full-rated charge to full-rated discharge (s)

These two parameters are technically reviewed not fully comparable with the parameters as listed above given as data for technologies included in catalogue “Generation of electricity and District heating”.

With reference to the definition given in the catalogue “Energy storage” [6] at page 19, for electricity storage (=batteries): The first parameter tells the response time shifting from idle mode to full-rated discharging mode as the time, in seconds, the electricity storage takes to reach 100 % of the discharge capacity from idle condition (full availability time or ramping time for giving the 100 % power output). This time is assumed to be equal for the full-rated charging process (full availability time or ramping time from no-load condition to 100 % power input).

The second parameter tells the response time from full-rated charging input to full-rated discharging output as the time, in seconds, shifting from 100 % power input to 100 % power output or from 100 % power output to 100 % power input, as it is assumed the time is equal in both directions.

The two time parameters given in the Data sheets for electricity storage are both parameters, which specify the dead band for up- and downward regulation in respect to delivery of frequency activated reserves depending of the operational initial condition of the electricity storage (idle or full-rated charging/full-rated discharging to idle or full-rated charging to full-rated discharging

/full-rated discharging to full-rated charging) – expected is that the second response time defined is approximately twice the first – so the definitions are not quite obvious – and these time responses are expected not to be in “s” but in “ms”, depending of the technical features of the switchgear and charger/inverter-system. In revising this catalogue, these time data must be clarified for Battery Energy Storage Systems (BESS’s).

All new technologies described in the four catalogues are either a production unit or a consumption unit; that why the regulation ability due to their electrical energy supply or their load must be defined in same terms, as a suggestion, in all catalogues.

The fifth Technology data catalogues “Energy transport” gives the descriptions of the energy transport systems:

- Natural gas, included upgraded biogas
- District heating
- Electricity

The technologies to be described within this report, having a technical potential delivering ancillary services will be selected from the four first mentioned catalogues, caused by the fact that the “Energy Transport” technology catalogue describes transport systems for the energy transport – for electricity by the transmission and distribution grid (overhead lines, cables and HVDC lines/sea cables), for the natural gas by the distribution grid and for the district heating the transmission and distribution grid pipes.

In this report – a key premise for the delivery of ancillary services – is that all concerned energy transport systems involved can manage to exchange the energy conversion through all systems involved electrical as well as mechanical systems – including the transport roads.

4.2 Definitions and abbreviations

In this chapter there will be no definitions – the abbreviations giving as reference to the specific Technology data catalogue [6] and “technology”, will be stated mentioned the “Technology name” and a number in a bracket “(X; YZV)”; the number stated in the bracket is referring to the specific “Technology Data” catalogue and the “Table of contents” number system stated in this catalogue.

The numbering of the “Technology Data”-catalogues assigned here in this report are:

1. Technology Data for Generation of Electricity and District Heating.
2. Technology Data for Heating installations.
3. Technology Data for Renewable Fuels.
4. Technology Data for Energy Storage.

Then the reference of a specific technology is stated referring to its description and data sheet contained in one of the Technology Data catalogues stated – given as an example:

Catalogue “1. Technology Data for Generation of Electricity and District Heating” file contains the technology “Wind Turbines onshore”, which in the catalogues numbering system has number 20 in this catalogue’s “Table of contents”, this gives the number (1; 20) to be stated as reference.

4.3 New technologies screened for further description

During the evaluation process of the “new technologies” chosen for the descriptions and examples given chapter 5, 6, 7 and 8 – and as agreed with Energinet – the following technologies were chosen:

- New Technology – Generation Plants or Units:
    - Part 5.3 Technology: Wind Turbines and Wind Power Plant.
        - ✓ Example 1: Trial at Burbo Bank Wind Farm (UK).
        - ✓ Example 2: Australian wind farm tests with frequency control.
        - ✓ Example 3: Energinet’s pilot project - Voltage regulation.
        - ✓ Example 4: New Energinet’s pilot project – Reserves from RE.
        - ✓ Example 5: New Energinet pilot project – Congestion management.
- New Technology – Generation Plants or Units:
    - Technology: Photovoltaic plants and household/industrial units.
        - ✓ Example 1: Mind4Energy MINT® PV data Acquisition and Control.
- New Technology – Demand Plants or Units:
    - Technology: Household, industrial or heating sector equipment.
        - ✓ Example 1: FlexHeat Heat Pump – EnergyLab Nordhavn.
        - ✓ Example 2: Flexibility from household/industry heat pumps.
        - ✓ Example 3: Flexible demand industrial consumers – Energi Danmark.
        - ✓ Example 4: COOP Danmark A/S – FCR Data analysis DK1.
- New Technology – Renewable Fuels or Power2X Technology:
    - Technology: Biogas Plants.
        - ✓ Example 1: Nature Energy statement regarding ancillary services.
    - Technology: Solid Oxide Electrolyser Cell.
    - Technology: Methanol from Power.
        - ✓ Example 1: Electrolysers in the electricity markets in Denmark.
        - ✓ Example 2: Haldor Topsoe – Electrical driven hydrogen and synthesis gas generation.
- New Technology – Energy Storage:
    - Technology: Battery Energy Storage Systems (BESS).
        - ✓ Example 1: BESS installed as part of the EnergyLab Nordhavn.
        - ✓ Example 2: Automotive Battery Systems – Electrical Vehicles (EV).
        - ✓ Example 3: UPS-Systems with battery back-up.
    - Technology: Hybrid Power Plants.
        - ✓ Regulation ability of hybrid plants – control strategy.
        - ✓ Example 1: Vattenfall – Ancillary services from converter-based renewables.

The chosen new technologies described in the technical chapters 5, 6, 7 and 8 are supplemented with examples received from developer’s, producer’s or BRP’s– all stakeholders of the subject “ancillary services from new technologies”; together with the results from research work and underway or completed development projects in the subjects field.

5. NEW TECHNOLOGY – GENERATION PLANTS OR UNITS

5.1 Introduction

The analysis assumptions (AF19) for EN from DEA 2019 [2] and the political Energy Agreement July 2018 state, that the wind power capacity for onshore and coastal will in the short term be based on technology neutral supply[49], in the longer term the expectations are increasing the expansion at market conditions and as a part of larger municipalities' climate and energy planning; offshore wind will be based on politically determined supply conditions – the first new Danish call for offshore wind farm tenders has been published October 2019 – for the Thor Wind farm[50] (800 – 1000 MW) in the North Sea – this with new conditions.[51]

The expected development in wind power production is shown in Figure 20.

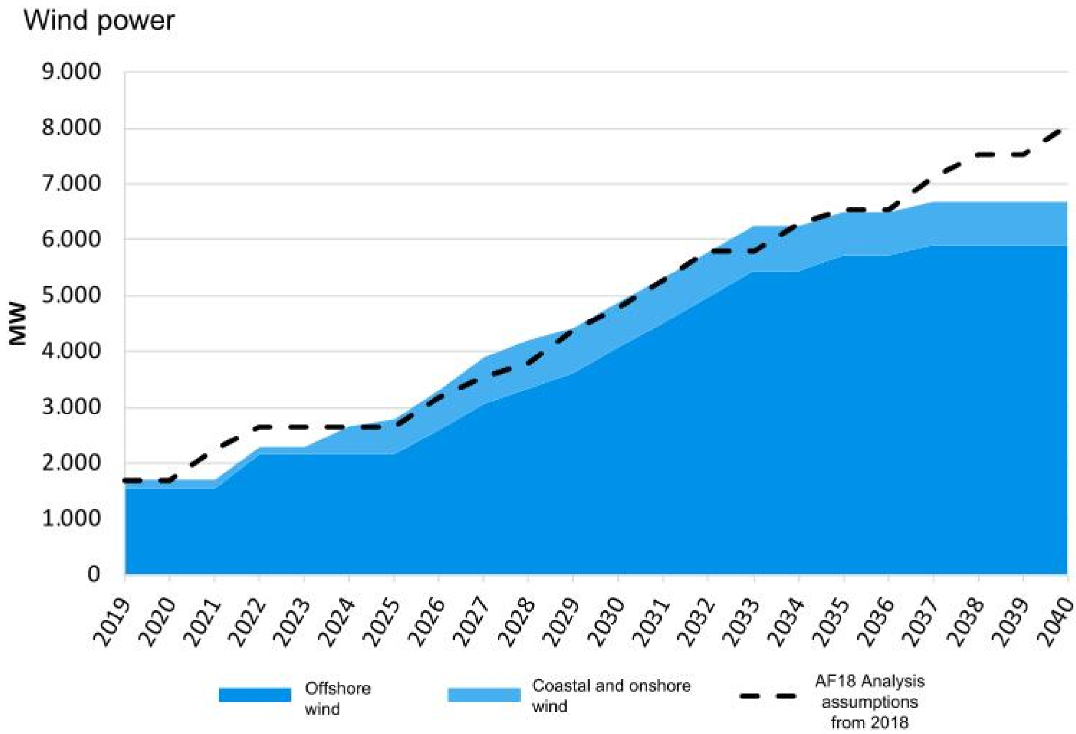


Figure 20 Expected development of wind power capacity regarding offshore, coastal and onshore wind power.[52]

The German Energy Agency (dena) has published a report "dena Innnovation Report Ancillary Services" [19]; in the report the needs for instantaneous reserves and reactive power are highlighted. "Decentralised power generation plant are becoming increasingly responsible for stability in the electricity grid. These plants are almost all connected to the distribution grid."

In Denmark compared with Germany the decentralisation of power generation has a long tradition with combined heat and power production, production from onshore wind turbines as stand-alone or smaller wind farms and photovoltaic (PV) production both on large scale with PV farms and on household level with limited production per unit (6 kW). Centralised production with renewables

[49]The technology neutral tender 2019 determined the 6th of December 2019, refer to: https://en-press.ens.dk/pressreleases/technology-neutral-tender-2019-determined-2951039

[50]More information refer to: https://ens.dk/sites/ens.dk/files/Vindenergi/brief_tender_for_thor_offshore_wind_farm_30march2019.pdf

[51]Tender conditions for Thor Wind Farm: https://ens.dk/sites/ens.dk/files/Vindenergi/offshore_wind_tendet_thor_marketing.pdf

[52]Source [2] "Figure 27" reproduced.

has primarily been with the expansions of offshore wind (Anholt Offshore Wind Farm in 2013 and Horns Rev 3 in 2015).

The decentralised power generation established in the last few years, as mentioned above, primarily from wind power and sun power generation. In Denmark the largest production unit, category D production unit, is defined as >25 MW (with reference to the RfG limits to be defined acc. to Article 5, Table 1), these category D units can be grid connected either in the distribution grid or in the transmission grid – depending on the local grid structure where the specific plant is planned to be established. The development with integration of more and more wind and PV power generation in the distribution grid will demand for the continuing development of the interfaces between the TSO, the DSO's and plant operators, as the larger amount of power production is feed into the distribution grid, this might cause local bottlenecks and result in need of balancing power estimation and control with shorter time span closer to the moment of production. Controlling the balance between production and demand needs features and estimation tools, which gives reliable data for tendering and provision of the reserves needed.

Regarding the state and lookout, these renewables power production units are feeding into the grid supplied through frequency converters; in the future setup of balancing production and consumption, their deliveries of power in-feed into the grid must also include delivery of ancillary services as supplement to or even substituting reserves today delivered by conventional power plants.

Today EN's rules in the tender conditions of ancillary services [12] delivered by wind turbines are as follows (page 4/44 in [12]): "Furthermore, a group of wind turbines cannot submit bids on their own in the different ancillary services markets. Wind turbines may be included along with other production to guarantee supply in the event that the wind turbines are unable to deliver the required performance due to failing wind."

Above rule is, of cause, justified because the balancing process must be performed securely, reliable, efficiently and with enough quantity and quality; but the rule provides challenges - as more and more developers/producers of power do not have a mix of power plants in their portfolio, then the mixing of reserves of security reasons must be performed elsewhere in the organisation of the market – this question has to be solved in the auspices of new market solution and rules combined with risk assessment. "The rules in the tender conditions [12] quoted above must be changed considering this issue."

The work regarding implementation of the rules from EBGL [9], EU Regulation (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing, will mean that all TSO's shall harmonise the balancing energy gate closure time (Article 24) for standard products at the Union level, at least for each of the following processes:

- Replacement reserves (This process is by now either used in CE nor in Nordic synchronous area);
- Frequency restoration reserves with manual activation (mFRR);
- Frequency restoration reserves with automatic activation (aFRR);

The balancing energy gate closure times shall:

- Be as close as possible to real time;
- Not be before the intraday cross-zonal gate closure time;
- Ensure sufficient time for the necessary balancing processes.

After the balancing energy gate closure time, the balancing service providers shall no longer be permitted to submit or update their balancing energy bids.

This work – presumably – will include the revision of the applicable rules also including the todays achievements in forecasting of wind and PV power production with uncertainty within ± 10 % [20]; today's current forecasts by EN include as shown in Figure 21:

- Wind power production
- Local CHP power production
- Transmission losses
- Consumption
- Flow on tie-lines
- Solar power production
- Adequacy

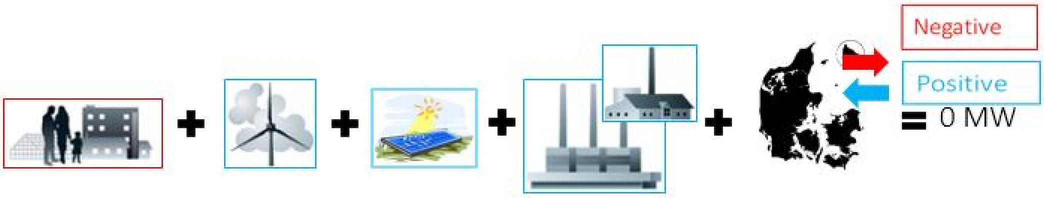


Figure 21 Picture illustrating forecasting actions taken by Energinet for balancing / procurement of reserves.[53]

Today the production from wind and PV provides only bits for downward regulation in the energy market or delivering special regulation directly agreed between EN and the provider; which should be changed – if possible – with regards to the technical requirements delivering reserves. In part 5.3 the prospects for wind production delivering ancillary services will be described – and for photovoltaic production the prospects delivering ancillary services are described in part 5.4.

In general wind power producers express, justified in progress in performing forecasting, that: A capacity reserves market should use a gate closure time as close as possible to delivery time, as to open the market for all participants by market risks – not by portfolio of production type.

EN has the 4th of December 2019 published[54] an invitation to submit tenders for "Pilot project on the provision of reserves from RE" [21]. Quoted from the invitation to tender: "Energinet aims to inject as much flexibility as possible into the electricity system by making it possible for all generation and/or demand types to provide reserves to Energinet. Energinet aims for 100 % technology neutrality when buying reserves, while also offering similar conditions and fair competition. Reserves must provide security of supply, and the important thing is that a reserve is provided so that electricity is available at all times."
In this pilot project EN wants to test several of the technical properties from renewable technologies in relation to the requirements of delivering ancillary services acc. to [13], "Prequalification of units and aggregated portfolios" – refer to Example 4, part 5.3.6.

Regarding photovoltaic plants, household units and commercial units in industry on roofs etc. the analysis assumptions (AF19) for EN from DEA 2019 [2] is that the commercial units are expected

[53]Source Energinet as part of reference [20]: Workshop den 18. September 2019 titled: VE som leverandør af reserver; presentation by Lasse Diness Borup.
[54]Refer to Energinet's website: https://energinet.dk/El/Systemydelser/Nyheder-om-systemydelser/Pilotprojekt---Reserver-fra-VE

to raise caused by decreasing prices of solar cells and batteries together with more CSR spirit and meeting voluntary renewable goals. In 2018 the DEA's tender request of technology neutral renewable power from wind and PV units resulted in the three new PV parks, as:

- Solar Park Rødby Fjord ApS, 60 MW
- Solar Park Næssundsvej Aps, 30 MW
- Better Energy Frederikslund Estate Aps, 11.5 MW.

The 20th of September 2019 Google Denmark announced that they will establish five new PV parks with the total capacity of 160 MW – so adding with the three parks stated above – in the next few years total capacity planned is in the order of magnitude of 262 MW.

Above stated figures for photovoltaic plants are just for grid connection in the next couple of years – in the outlook, refer to Figure 32, GW's of photovoltaic plants are expected to be installed in Denmark.

The technology neutral tender round for 2019 was determined the 6th of December 2019; the result is stated in DEA's website: https://en-press.ens.dk/pressreleases/technology-neutral-tender-2019-determined-2951039

In total expected to be contracted by DEA is 135 MW onshore wind power and 136 MW solar PV installations – to be grid connected within two years from now (aid period is 20 years).

The Danish support schemes for electricity produced on renewable energy sources is described in a "memo"[55] - the memo gives in outline and refers more to the rules in the law of "Promotion of renewable Energy Act", refer to Appendix 1 part 3, and to the law the Danish Electricity Supply Act, refer to Appendix 1 part 1.

From this "memo":
Types of support schemes in Denmark:
Price supplements for renewable energy and other environmentally friendly energy supply is provided in Denmark as a price supplement, a fixed settlement price, contract for difference, basic amount or as plant support.

Price supplement is a fixed supplement provided in addition to the market price. This type of supplement can be given with or without a limit, in which the supplement will decrease if the market price reaches a predetermined level. If this price limit is reached the supplement will accordingly be fully repealed.

Fixed settlement price indicates a varying support cost in proportion to the market price. The settlement price is calculated by deducting the electricity market price from a fixed settlement price.

Contract for difference is the support scheme covering the procurement of offshore wind turbines. This means that the companies are responsible for the allocation of the electricity on the market and the subsidy is provided as the difference on the spot market price and the sale price.

Basic amount is a subsidy given as a fixed yearly amount.

[55] Memo form DEA can be downloaded in its full contents here:
https://ens.dk/sites/ens.dk/files/contents/service/file/memo_on_the_danish_support_scheme_for_electricity_generation_based_on_re.pdf

Plant support typically covers a certain percentage of the plant expenditures.

For more details regarding amount of subsidy and rules, readers can refer to the memo.

For the new planned Thor Wind Farm mentioned in the start of this chapter; DEA has revealed that the concession owner for the project will be selected through a Contract for difference system, which is like the system used in UK. The contracted applicant will receive aid in the form of a price premium from the Danish State for a 20-years period, commencing at the time of grid connection. Once the wind farm supplies the first kWh to the collective grid, subsidy will be granted in accordance with the Contract for difference principle outlined above.

5.2 Definitions and abbreviations

Active power control: The automatic change in active power output from a generating unit in response to an active power control set-point received via a signal.

Active power control set-point: The maximum amount of active power in MW, set by TSO, which the WPP or PVP is permitted to export.

AF18 (”Analyse Forudsætninger 2018”): The analysis assumptions for 2018.

AF19 (”Analyse Forudsætninger 2019”): The analysis assumptions for EN from DEA 2019 [2].

CAPEX: Capital expense is an expense a business incurs to create a benefit in the future (construction and implementation costs) – unlike OPEX is an expense required for service and maintenance of the day-to-day functioning of the business.

CHP: Combined Heat and Power.

CSR: Corporate Social Responsibility.

dena: The German Energy Agency.

IR: Inertial Response.

RE: Renewable (generation or technology).

ReGen: Renewable Generation plants; abbreviation used in the RePlan-project [25], [30] and [31].

POC: Point of Connection, the point in which the wind turbines, wind farm’s or photovoltaics’ electrical system is connected to the public electricity transmission, distribution (or low-voltage) grid.

PPC: Power Park Controller (same as WFC: Wind Farm Controller), the management system that implements the control strategies and coordinates the operation of several wind turbines.

Power Park Module or PPM: A unit or ensemble of units generating electricity, which is either non-synchronously connected to the network or connected through power electronics, and that also has a single connection point to a transmission system, distribution system including closed distribution system or HVDC system.

PV: Photovoltaics (power generation); consisting of one or several inverters as collection system connected to the point of common coupling (PCC) via a collection grid or more POC.

PVP: Photovoltaics Plant.

PVU: Photovoltaics Unit (on household level).

WF: Wind Farm (Wind Power Plant), defines the aggregation of a number of WT's connected to the same substation and controlled by one PPM.

WPP: Wind Power Plant (or wind farm); a wind power plant consists of several wind turbines, which have been grouped – including a collection cable grid with one (or more) main transformers for the connected to the transmission grid (or distribution grid).

WT: Wind Turbine.

5.3 Technology: Wind Turbines and Wind Power Plant

In this part a wind power plant (WPP) or a wind farm are considered as several wind turbines connected to a single connection point in a transmission system or distribution system by means of a power park module (PPM) acc. to the RfG [10].

5.3.1 General Technology Data for Wind Turbines

The technology data for Wind Turbines Onshore (1; 20) and Wind Turbines Offshore (1; 21) are given in Technology Data for Generation of Electricity and District Heating" [6], stated in their data sheets with no regulation ability for primary regulation and secondary regulation.

Supplementary for onshore wind turbines is stated [6], page 168/338, as quoted:
"Electricity from wind turbines is highly variable because it depends on the actual wind resource available. Therefore, the regulation capability depends on the weather situation. In periods with calm winds (wind speed less than 4-6 m/s) wind turbines cannot offer regulation, with the possible exception of voltage regulation.
With sufficient wind resource available (wind speed higher than 4-6 m/s and lower than 25-30 m/s) wind turbines can always provide down regulation, and in many cases also up regulation, provided the turbine is running in power-curtailed mode (i.e. with an output which is deliberately set below the possible power based on the available wind).
In general, a wind turbine will run at maximum power according to the power curve and up regulation is only possible if the turbine is operated at a power level below the power actually available. This mode of operation is technically possible and, in many countries, turbines are required to have this feature. However, it is rarely used, since the system operator will typically be required to compensate the owner for the reduced revenue.
Wind turbine generation can be regulated down quickly, and this feature is regularly used for grid balancing. The start-up time from no production to full operation depends on the wind resource available.
New types of wind turbines (DFIG and converter based) also have the ability to provide supplementary ancillary services to the grid such as reactive power control, spinning reserve, inertial response, etc. However, these supplementary ancillary services from wind turbines are seldom utilized in Denmark, due to a lack of economic incentives. Older types of wind turbines typically deployed in Denmark before 2008 consume reactive power and can have a negative influence on voltage stability."

Supplementary for offshore wind turbines is stated [6], page 189/338, as quoted:
"Offshore wind turbines have similar regulation and ancillary service capabilities to onshore turbines. See the descriptions in the chapter about onshore wind turbine.
Offshore wind turbines have a disadvantage for regulation of voltage and reactive power in the main power grid, because of the large distances between the wind farm and the point of connection to the power grid. A larger distance will result in an increased impedance and loss. An offshore wind farm will be able to compensate for reactive power created by itself, however their contribution to further compensation of reactive power in the main grid is limited depending on the distance to point of connection. Onshore wind turbines, which in general are closer to the grid, have better possibilities for contributing to regulation of voltage and reactive power."

When deciding the update of the Technology Data catalogue regarding the wind turbines regulation ability – and in general with regards to the Danish implementation of the requirements stated in the RfG for all production power plants and for power park modules (PPM's) – a more nuanced picture is recommended to be developed.

5.3.2 Technical capabilities for providing ancillary services from wind power plants

In this next part the primary reference used is the report: "Capabilities and cost for ancillary services provision by wind power plants" [22]. This paper follows the wind turbine conversion topology according to standard IEC 61400-27: Types 1,2, 3 and 4.

The report states that in their request to the wind turbine industry the answers were regarding wind turbine types – 62 % are of Type 3 and 38 % are of Type 4 wind turbines – of cause this distribution in percentage has changed during the last five years; presumably a higher percentage of Type 4 wind turbines by now. The Type 3 WT respectively the Type 4 WT is shown below in Figure 22 and Figure 23.

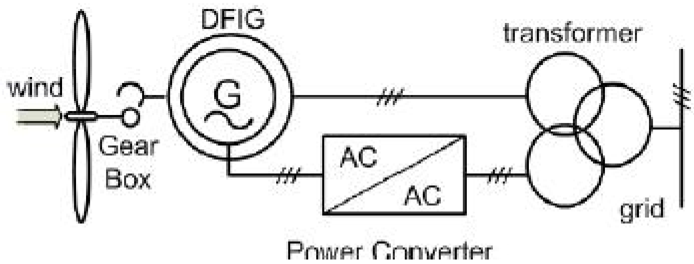


Figure 22 Diagram of Type 3 wind turbine.[56]

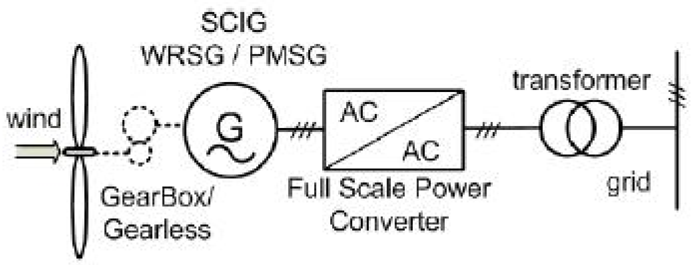


Figure 23 Diagram of a Type 4 wind turbine.[57]

The below descriptions is based on that the wind turbines are the Type 3 or Type 4 WT.

5.3.2.1 Technical capabilities – regulation ability

In the following text the reference used is [22] and the order of appearance of the respective ancillary services will follow this paper.

Frequency support:

Active power control – probably the most important functionality the wind power turbine/plant need in order to deliver frequency support is active power control, commonly used controls are:

- Active Power Delta Control Mode (sometimes referred as spinning reserve): Delta control implies the ability to reduce its power output by desired power offset or percentage value compared to the possible production under present wind conditions, creating a power output reserve. Delta control is shown in Figure 24.
- Active Power Limitation Control Mode (also known as Absolute Production Constraint): It limits the current power production at the connection point to a maximum value. This constraint may be necessary to avoid overloading the grid.

[56]Figure 22 reproduces "Figure 1" from reference [22].
[57]Figure 23 reproduces "Figure 2" from [22].

- Active Power Gradient Control Mode (also known as Power Gradient Constraint): It limits the maximum speed at which the power output of a wind power plant changes independently from wind speed variations. The definition of power gradient constraint is given in Figure 24

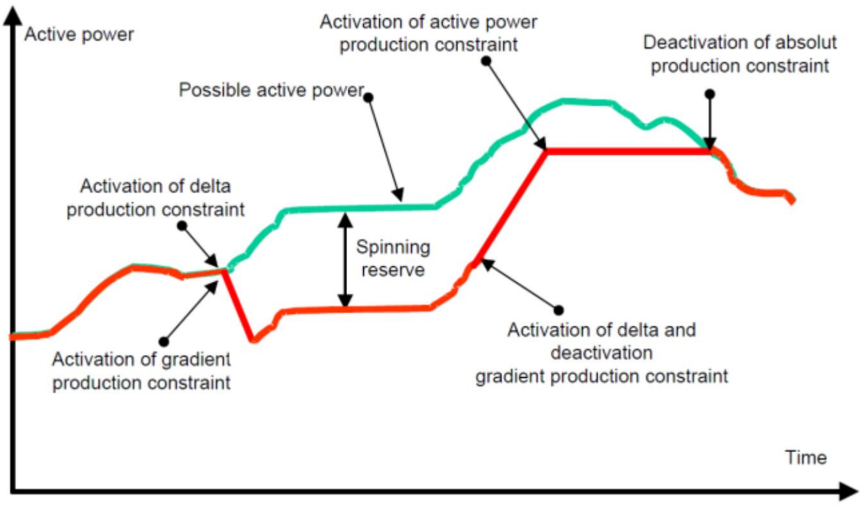


Figure 24 Delta control mode.[58]

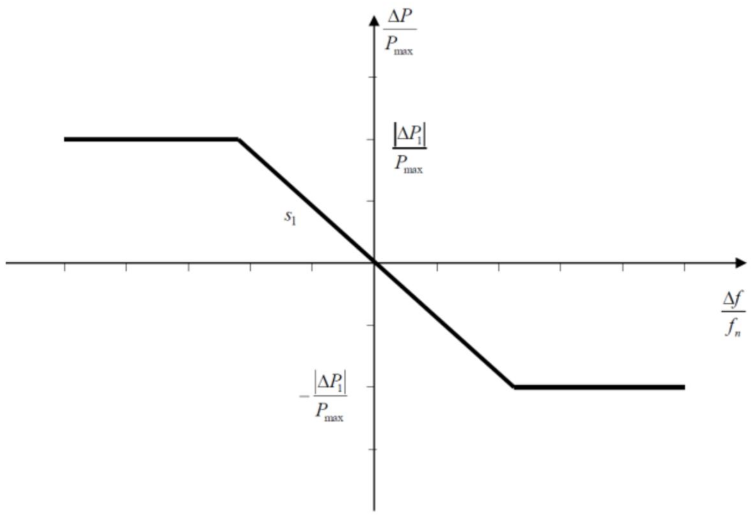


Figure 25 Active power setpoint as a function of frequency deviation (Droop control).[59]

The functionality "frequency sensitivity mode (FSM)" (or droop control) is required for WT/WPP's to automatically modify the active power output depending on the frequency, as shown in Figure 25, which are the same control function as conventional power plants typically uses. Active power control is available in all modern WT's (Type 3 and 4) equipped with blade pitch control. Modern WT's can go from the lowest power level to full rated power in a maximum response time of 6-10 s, providing that the wind resource is available. Consulted manufacturers in [22] has answered response times 1-2 s to 4-6 s for up- and downward regulation. At WPP level, active power control capability is generally available and have very fast ramping times (between 10-20 s) can be achieved, which must be added the possible delay, setting and communication times.

[58] Figure 24 reproduces "Figure 12" from [22] (original source Energinet.dk, 2010).
[59] Figure 25 reproduces "Figure 13" in from [22] (original source ENTSO-E, 2012).

Constraints from [22] regarding frequency control: “At WT level, there are challenges for Delta Active Power Control related to the calculation of available power. These challenges come from the distortions on the measurements due to turbulence and the unequal distribution of the wind resource across the rotor. Reliability of measurements depends significantly on the site wind conditions.
At WF and WPP level, the unequal distribution of wind gusts and the complex behaviour of the WT wakes create and extra challenge to derive the available or possible active power to calculate the correct value for Active Power Delta Control Mode.
The response time of the entire WF may depend on how much active power was curtailed. If the active power has to be raised from 10 % to 100 % it may take up to 30 seconds according to one WF operator. This value seems to be too high considering the response time of the modern WT and the state of the art in communication technology. Nevertheless, this time might be necessary considering an already installed WF using older and outdated technology.”

Due to shortage of time for this report – this task has not been investigated; which must be done for update of the technology data catalogue and present stage of development of the technologies of communication etc.

Never the less – modern WT’s can perform frequency droop control and switch between different settings or modes (under and over frequency operation mode acc. to the RfG) – the maximum initial delay to provide FCR at WT level is less than 1 s acc. to the responses from questionnaires acc. to [22] and it is also possible with a dead band acc. to Figure 6. At WPP level FCR is also available; but there is an extra delay of control response between 500 ms and 2 s on top of the WT level (1 s), as mentioned above.

Inertia support (FFR):
Several wind turbine manufacturers can today offer inertia response or Fast Frequency reserve (FFR). The stated WT manufacturer in the paper [22] must be updated regarding which manufacturers, who actual can offer this feature today – refer to Example 1 given as part 5.3.3.

This inertial response is possible either via a very fast control of the blades (pitch control) or the ability to extract the kinetic energy from the rotor. For the latter option, additional controls are necessary for the rotor to artificially emulate the effect of inertial response and to participate in the damping of frequency changes in a power system (Seman, 2011)” and “Using the stored kinetic energy from the rotor causes it to decelerate. At the same time the active power supplied to the grid is increased. After a time about 10 to 20 seconds the rotor has to be accelerated again, which lowers the output active power (Wachtel, 2009)” and acc. to [22].

Constraints from [22] regarding inertia response:” Inertial response using only pitch control requires the previous curtailment (as mentioned above). However, at decent wind conditions the additional active power can be maintained for a longer time. The response time in those cases are proportional to those provided for active power regulation using pitch system and reduced power operation.
The power converter, the electric generator, and the mechanical components of the WT must be designed to withstand the overloading condition created once the energy is extracted from the aero dynamical components.
As already depicted, the inertial response capability implemented by generator control is limited by the minimal rotor speed. Therefore, it can only be kept up to 10-20 s. It influences the technical capabilities of the droop control within its dedicated time frame. A combination of pitching control and the extracting kinetic energy from the rotor could improve this behaviour

(Erlich & Wilch, 2010). For bigger wind farms a spreading of the ending time of the FFR could reduce this effect (Morren, de Haan, Kling, & Ferreira, 2006).
Another limitation according to the literature could be the (low) speed of SCADA control systems (Seman, 2011)."

More papers describes investigating and modelling of inertia response from wind power plants, refer to [23], [24] and [25].

Voltage and reactive power support:
Quoted from [22] in summary:
The capability acc. to the RfG demands must be fulfilled is a prerequisite.
"If the farm or turbine is performing a steady-state voltage control, the dynamic is affected by the given impedance of the connected grid. The grid influences highly the possible response time, so no general answer of settling times can be given for that option; but the timing issues in this case are not seen as a critical for wind turbines.
Reactive power can be supplied up to a certain value. The range is normally defined by PQ diagrams. Using converters with self-commutated switching device, independent supply of active and reactive power is possible.
In order to keep the voltage at the POC within a tolerance band, the adjustment of reactive power with the grid has to be controlled by a specific mode.
There are three different modes to control the transfer of reactive power to the POC:

- Fixed power factor;
- Reactive power commitment;
- Steady-state voltage control by Q(U) characteristic (Erlich, Fortmann, Engelhardt, & Kretschmann, 2009).

The term Steady-State Voltage Control (also used in National Grid Electricity Transmission plc, 2013), is used to address the difference in time scale of this functionality to the possibilities coming with the "Fast Reactive Current Injection" functionality reacting on transient voltage deviations. The steady-state voltage control scheme by Q(U) characteristic is shown in Figure 26.

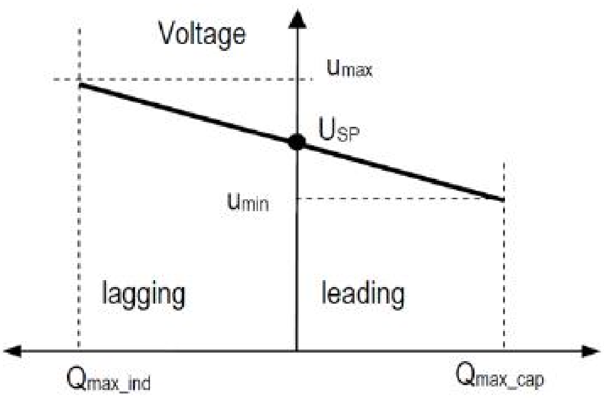


Figure 26 Steady-stage voltage control scheme by Q(U) characteristic.[60]

Voltage control would be the normal operation mode when connected to the transmission grid; but when connected in the distribution grid the common mode will be the reactive power mode.

[60]Figure 26 reproduces "Figure 27" from [22].

5.3.3 Example 1: Trial at Burbo Bank Wind Farm (UK)[61]

The Danish and UK grid codes interpretations of the demands and rules acc. to the RfG are different – here in this report it is not possible to explain the differences in detail. As an example, the FFR (Fast Frequency Reserve), which can be compared with the "Firm Frequency Reserve" (a primary reserve) in UK – the times defined isn't the same as in Nordic area with reference to part 3.3.2 neither is the test requirements[62] – but the outcome of the reactions of the trial performed at Burbo Bank Wind Farm can, besides from this fact, give some information regarding wind turbine/farm reactions of frequency deviation tests performed.

In a publicly available presentation [26] information is given of a trial performed at Burbo Bank Wind Farm – 25 SGRE-3.6 MW Siemens Gamesa wind turbines – the frequency control functions have been shown, refer to Figure 27 and Figure 28.

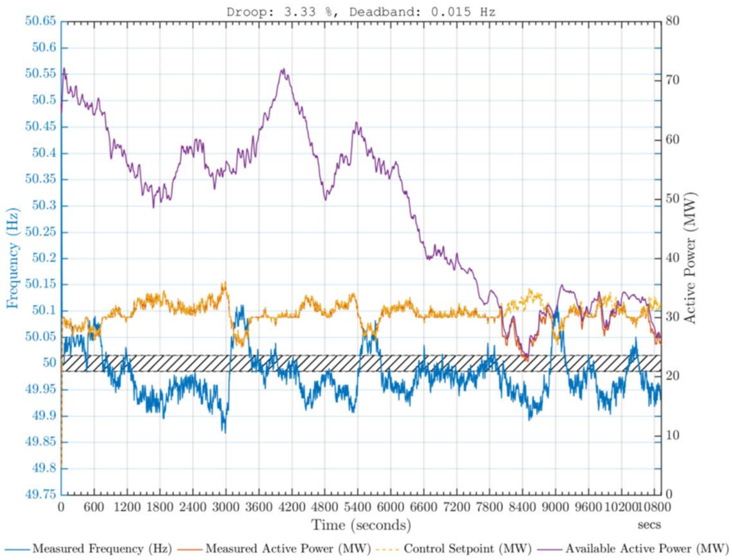


Figure 27 Droop control example 1 from trial at Burbo Banks Wind Farm UK [26].

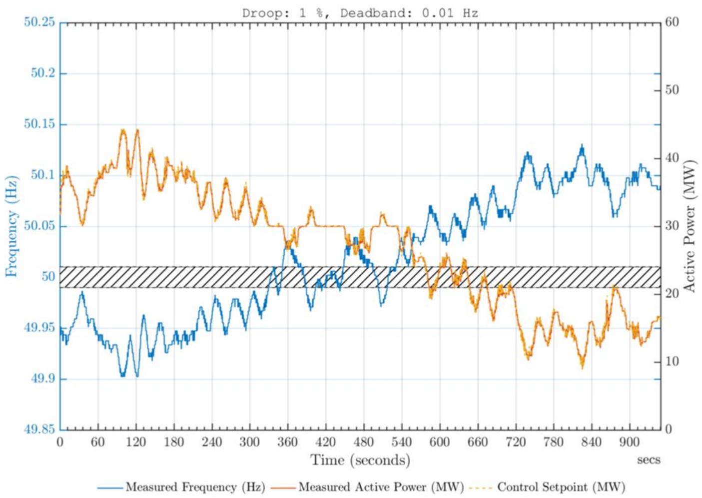


Figure 28 Droop control example 2 from trial at Burbo Banks Wind Farm UK [26].

[61] Presentation nationalgrid "Wind power Plant Capabilities and Trials": https://www.nationalgrideso.com/document/111511/download

[62] UK test requirements for Firm Frequency Reserves: https://www.nationalgrideso.com/document/148721/download

As stated in the presentation [26], reproduced here:

- Compliance with current grid code[63] requirements and more.
- Sub second response times – 150 ms – 1000 ms.
    - Downregulation 0.2 pu/s, upregulation 0.1 pu/s for 40 % of rated power and 0.05 pu/s of the remaining capacity.
- Droop of 1 % or less combined with a small dead band was promising for fast acting proportional frequency support.
- Droops lower than 1 % can have a small impact on asset integrity due to frequent and high magnitude activation.

"No curtailment no upward response, no wind – no response at all."

Regarding to "Used energy stored in the mechanical parts of the system for a short burst of additional energy" (FFR), or Inertial Response (IR) functionality (not virtual inertia), which is shown as Figure 29 - the result from the tests are stated: 10 % power for 10 s (IR ramp up) for one single turbine and 25 % recovery drop (IR ramp down). Test pictures are shown in the presentation. The results stated in the conclusion:

- "Fast acting upwards response is possible at no curtailment.
- "A recovery period of similar or higher energy than the injected."
- "Close loop control of IR can mitigate recovery."
- "Compromise between maximum dip, recovery time and energy injected."

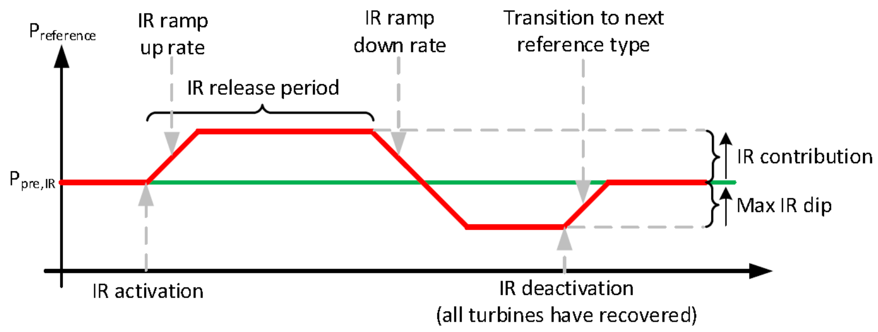


Figure 29 Inertial response curve.[64]

As this example shows – referring to the presentation [26] – frequency control and FFR reaction can be performed by wind turbines/farms.

In dialogue with Oersted[65] some general remarks was expressed by Jes Smed:

- "The barriers delivering ancillary services from wind power are markets requirements. (The wind power producer will lose production, which gives energy payment acc. to the subsidy scheme).
- The energy payment is relatively too high – compared with the payment for ancillary services.
- There is an "unknown penalty" for non-delivery of the reserve.
- The technical implementation of the facilities delivering ancillary services is relatively complex and having a high CAPEX; thus, a long payback time (frequency control functions, measurements, SCADA & IT-communication – including prioritising of resources as an example the IT staff)."

[63] UK Grid Code

[64] Picture from slide 12 in the presentation [26].

[65] Mail correspondence between Oersted/Jes Smed & Christian Tarning-Andersen and Ramboll/HEKN dated 2019-12-09

5.3.4 Example 2: Australian wind farm tests with frequency control

With reference to the 168 MW Tasmania Musselroe[66] project comprising 56 Vestas V90 3 MW turbines providing roughly 5 % of Tasmania's electrical supply – Australia performed a trial of frequency response from a wind farm – unfortunately it has not been possible to get some results from this test – but as the news told at that time (8. Marts 2018): "Australian Renewable Energy Agency (ARENA) is partly funding, with the project owner, a A$1 million project to investigate, if the project can provide grid stability services in a financially viable way."

From an Energinet Workshop, held the 18th of September, Vestas did give some input with reference to their presentation at the workshop [27], quoted here as:

- "Wind power pants today deliver both FCR and FRR in a reliable manner;
- When the energy prices are low, the marginal cost of providing up regulating reserves is low;
- To make the bids as efficient as possible, small block sizes and the possibility for intraday trading would be advantageous;
- A pilot project could be a way forward" (to be initiated between EN and Vestas).

Continued reference to Australian tests for ancillary services:

The Australian Energy Market Operator (AEMO) and ARENA did make a cooperation in Maj 2017 to facilitate collaboration between the organisations in areas of mutual interest such as power system security and reliability. In this respect – The Hornsdale Wind farm 2 (HWF2) was tested in a trial in market technical demonstration of wind or solar farm providing frequency control ancillary services. HWF2 have a registered capacity of 32 WTG's – 102.4 MW of provider/model Siemens SWT-3.2-113.
The concept and scope for the trial described in [28] were developed in 2017 by AEMO, ARENA, the Essential Services Commission of South Australia (ESCOSA), and NEOEN, developer of Hornsdale Wind Farm (HWF). Here in this report only one figure is extracted from chapter 2, Results and outcomes, showing again the frequency control can be performed
Delivery of raise and lower regulation providing frequency control ancillary services (FCAS) with Automatic generation Control (AGC) - the output of HWF" follows, to a high level of precision, the AGC set point in the direction to correct frequency – refer to Figure 30.

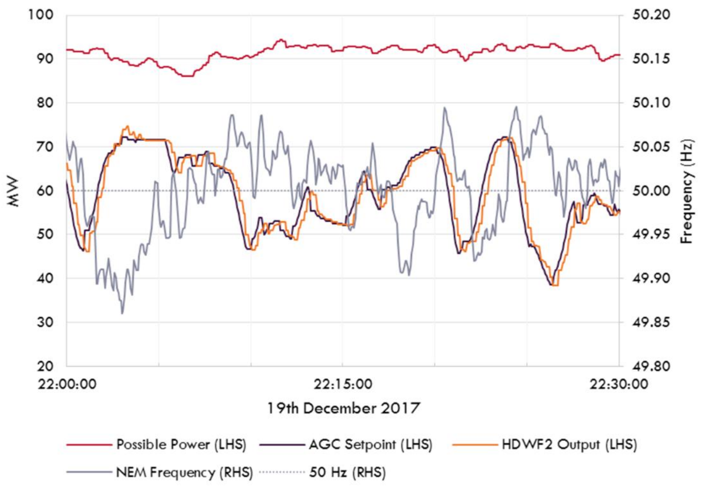


Figure 30 HWF2 regulation frequency control performance.[67]

Refer to the reference [28] for more test's and results. This reference also gives the "Market Trial Plan" for readers interest.

[66]Refer to website: https://www.windpowermonthly.com/article/1459032/tasmania-site-frequency-control-test
[67]Figure 30 is a reproduction of "Figure 8" from [28].

5.3.5 Example 3: Energinet's pilot project - Voltage regulation

EN has performed a pilot project for tendering of continuous voltage regulation during normal operation conditions. The tendering for this pilot project, which concerns a specific local area in Lolland, has been submitted for answering the 1st of April 2019, which were prolonged until the 30th of August 2019 – due to the requirements of a delivery of up to 40 Mvar reactive power locally supplied directly in the transmission grid.

E.ON Wind Services A/S and SEAS-NVE, owners 20/80 % of Rødsand 2 wind farm, offered the required amount of 40 Mvar reactive power – and was contracted by Energinet in this pilot project, which are expected to give input for the markets modelling of the process for implementing the delivery of voltage regulation.

EN has in the document "Behovsvurdering for systemydelser 2020" [4] given their latest descriptions of their plans regarding obtaining continuous voltage regulation in the future, refer to part 3.3.3.1.

5.3.6 Example 4: New Energinet's pilot project – Reserves from RE

This pilot project [21] was announced the 4th of December 2019[68]; EN invites interested parties to participate in a pilot project aimed at testing the supply security from renewable facilities, production units or plants. The present framework and requirements (page 4/44 in [12]), as mentioned in part 5.1, exclude renewable technology from participating in the capacity markets, and there is limited experience with the provision of aFRR, which will again starting from the 1st of January 2020 be purchased in DK1 – and also will be implemented in DK2 as part of a Nordic market in 2020. In this pilot project, EN wants to test the following [21]:

- The technical properties of RE technologies in relation to requirements for the delivery of ancillary services.
    - FCR, aFRR and mFRR in DK1.
    - FFR, FCR-D, FCR-N, aFRR and mFRR in DK2.
- Security and quality of forecasted generation of RE facilities.
    - Analysis of supply security of provision of reserves from RE.
    - Analysis of forecast of estimated generation.

"Interested parties are asked to submit a description of the facility/facility portfolio that they want to test in the market. This description must include the selected ancillary service(s) to be tested, descriptions of technology, physical units, control software, volume, bid sizes and expected time of testing of the reserves provision. Participation in the current market requires that bids are submitted via balance responsible parties."

"To safeguard security of supply and reduce the pilot project's impact in the market, the pilot project limits the permitted volume per participant per reserve to 1 MW for FFR, FCR, FCR-N and FCR-D, 3 MW for aFRR in both DK1 and DK2, as well as 5 MW for mFRR in both DK1 and DK2, respectively. Moreover, all reserves must be prequalified before being approved for participation in the pilot project. Frequent updates of forecasts will also be required as will regular participant validation of the forecasting method."

The test period is expected to be maximum six months, starting on 1 April 2020 for the pilot project. Regarding the commercial conditions of participation in this pilot project, refer to [21]. Deadline for market participants to send an application for this pilot project is 1st of February 2020.

[68] https://energinet.dk/El/Systemydelser/Nyheder-om-systemydelser/Pilotprojekt---Reserver-fra-VE

5.3.7 Example 5: New Energinet pilot project – Congestion management

Besides the project mentioned above in Example 3, part 5.3.5 - the congestion management challenge in balancing of production and consumption in the same area of Lolland, as mentioned in Example 2 part 5.3.5, during high production from renewables, wind and photovoltaic, has resulted in a new tendering process announced the 9th of December 2019 for a pilot project[69]; which has the following background [29]:

“Energinet currently sees congestion problems in the transmission grid in Lolland and South Zealand during hours of high wind power generation and wants to use the existing market for local downward regulation of generation or upward regulation of demand. Adding a specific geographical location to bids in the existing regulating power market offers the option to regulate upwards or downwards locally. The specific geographical locations are the nearest substations in the transmission grid. In the electricity market, downward regulation is a reduction of energy in the grid, meaning either reduced generation or increased consumption.”

For more information refer to Energinet’s website [29]; where the “Invitation to submit tender” can be downloaded; deadline for submitting of offer is the 15th of February 2020.

[69]Refer to Energinet’s website: https://energinet.dk/El/Systemydelser/Nyheder-om-systemydelser/Pilotprojekt---Handel-med-lokal-fleksibilitet

5.4 Technology: Photovoltaic plants and household/industrial units

The total picture of expectations from photovoltaic plants (PVP's) and household unit's (PVU's) establishment can be reviewed in [3] – and Figure 32; for the next couple of years the planning of plants to be established is stated in part 5.1.

The technology data for "Photovoltaics" (1; 22) are given in Technology Data for Generation of Electricity and District Heating" [6], stated in their sheets with no regulation ability for primary and secondary regulation.

Supplementary regarding the regulation ability is stated [6], page 210/338, as quoted:
"The production from a PV system reflects the yearly and daily variation in solar irradiation. Modern PV inverters may be remotely controlled by grid-operators and can deliver grid-stabilisation in form of reactive power, variable voltage and power fault ride-through functionality, but the most currently installed PV systems will supply the full amount of available energy to the consumer/grid.
However, without appropriate grid regulation in place, high penetration of PV can also lead to unwanted increase in voltage and other issues."

The advantages of PV to be mentioned are: Electricity is produced from PV in the daytime when demand is high – and as so it helps balancing of production and demand; PV can also complement the production from wind power – on sunny days without any wind; and PV can offer grid-stabilisation features (voltage regulation/reactive power).

One particularly disadvantage to notice is, that the weather in Denmark usually can have large variations during the day with fast moving cloud conditions, which can give a fluctuating PV production. If having large energy fluctuations, this will also result in large voltage fluctuations in the point of connection (POC), which is shown in Figure 31 .

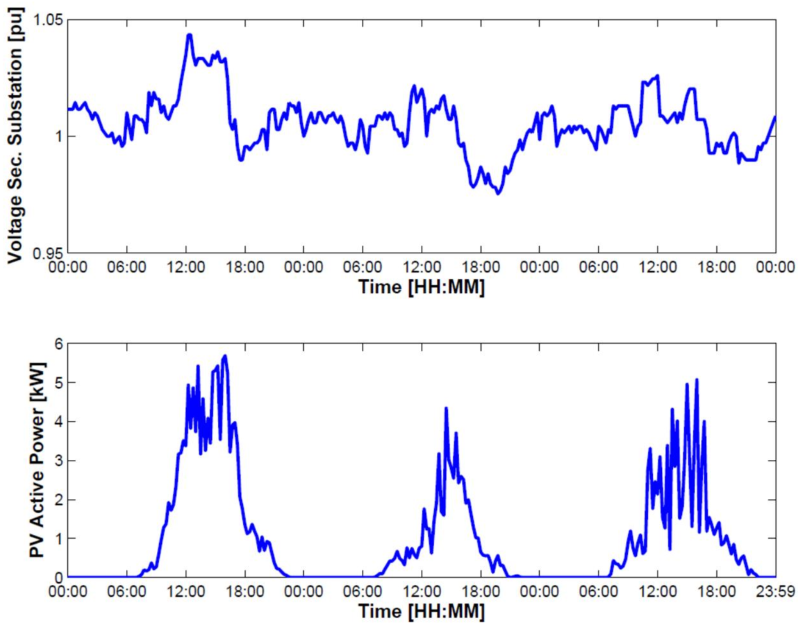


Figure 31 Voltage profile of a secondary substation (MV/LV) and power profile of one PV system (15 min values).[70]

[70]Figure 31 is a reproduction of "Figure 1" from [30].

Solar PV are used in different purpose, scales and purposes:

- Residential application
- Community application
- Industrial application

The three above mentioned are all for self-supply and must in delivering any type of ancillary services be aggregated; none examples are found in the scientific literature to describe the use of above mentioned three categories of PVU's delivering ancillary services. These plants are typically installed of climate reasons and to save electricity supplied from the residential low-voltage grid in Denmark – in the future possibly also supplemented with batteries for storing energy for use in the dark hours of the day.

Centralised PVP's of MW's size on land (field constructions) in Denmark has been implemented during the last years and the expansion will continue acc. to the outlook expectations, refer to Figure 32, with around 1000 MW in 2020. The grid connection of the PVP's is typically performed in the distribution grid.

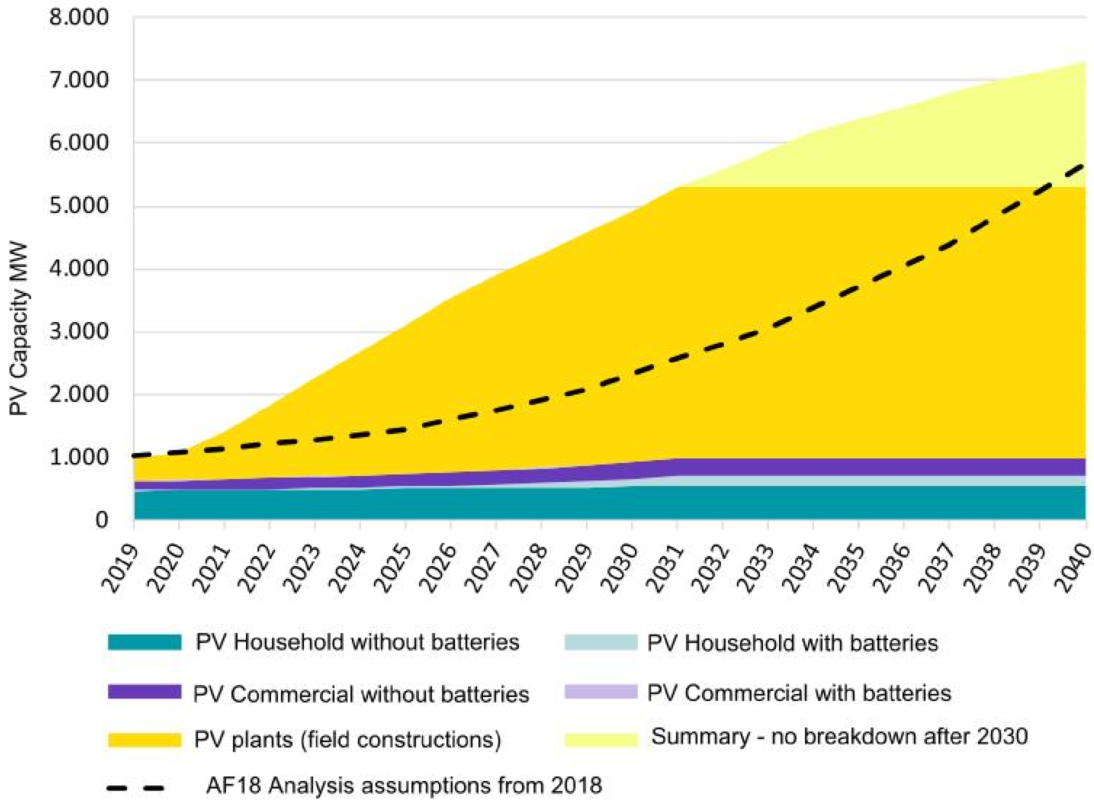


Figure 32 Expected development of the total PV capacity (measured at inverter) in MW for 2019-2040.[71]

With the outlook of more PV power production and wind respectively the sector coupling to the production of renewable fuels (Power2X technologies) is present and must be expected.

[71]Source [2] "Figure 28" reproduced.

5.4.1 Technical capabilities for providing ancillary services from PVP

In most literature found regarding PVP's delivering ancillary services the focus is on voltage stability and voltage regulation, as mentioned in part 5.4.

In reference [25], the RePlan-project, some results regarding both wind and PV are given, which will be the background for some highlight's here. In the RePlan-project's verification of ancillary services in large power system is conducted using the Laboratory facilities available at AAU-ET partner, a Smart Energy Systems Laboratory – refer to Figure 33.

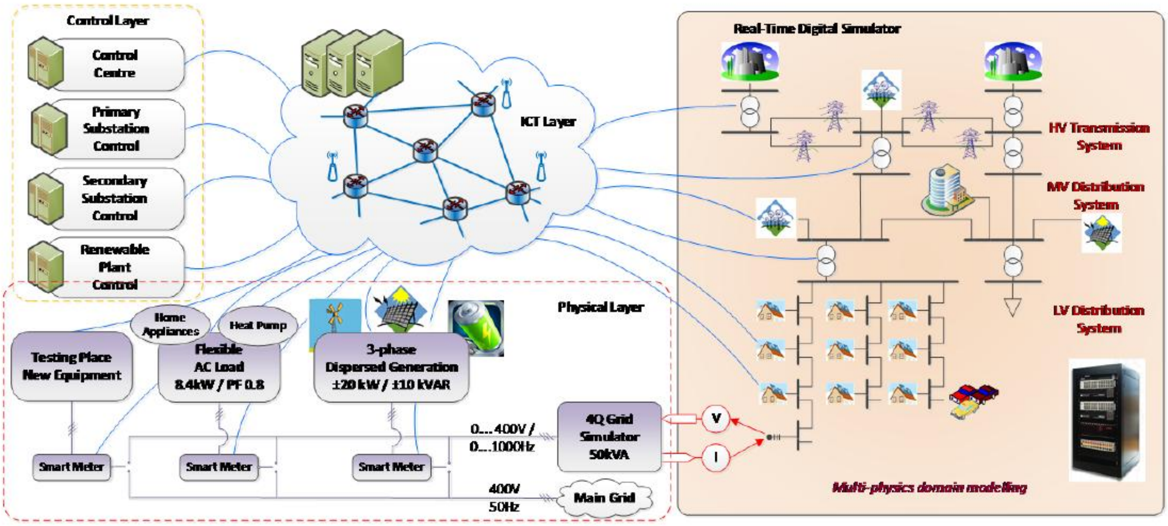


Figure 33 The architecture of "Smart Energy Systems Laboratory" in AAU-ET.[72]

For the regulation ability of PVP's connected in the distribution or transmission grid the findings regarding frequency-controlled deliveries of reserves in the above stated reference [25] is limited; the findings regarding WT/WPP's confirms the findings stated in part 5.3.2 and subsections.

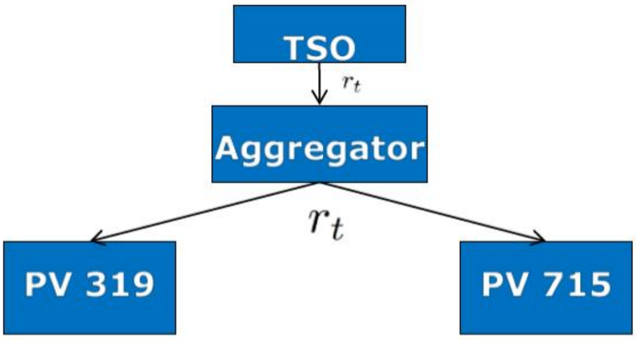
In the final report from the RePlan-project [25] is highlighted: "In the context of ancillary services delivery from PV's, more efforts have been still needed to fil the knowledge gab and to develop improved methods and solutions regarding available power estimation, faster and reliable communication and control within the plants and improved strategies."

One finding connected with the RePlan-projects objectives of developing "models of the controllers" together with the control concept developed to deliver FRR from WPP and PVP's power plants. "The main goal has been to experimentally investigate and underpin the control concept developed to deliver FRR from the renewable generation plants (ReGen). The objective of the control is to ensure the quality of the FRR service is according to the requirements while maximizing the utilisation of the available energy. The concept, described in [30][73], is how to ensure that the portfolio of ReGen power plants are meeting the power request from the TSO during operation in accordance with the reserve that has been contracted."

Testing of the controller has been implemented in the research facility SYSLAB, which is part of PowerLab.dk facilities. Two PV plants are part of the experiment performed. The control setup was performed with a hierarchical system, as illustrated in Figure 34, with an aggregator, who is situated between the TSO and the PV plants. "The aggregator receives the required control signal as a fraction of the total reserve and then distributes this signal to the ReGen Plants. Further, the

[72]Figure 33 is "Figure 1" reproduced from [25].
[73]Reference [30] here is the reference [10] in the final report from RePlan-project [25].

aggregator forecasts the generation based on input from the ReGen plants and determines the optimal base set point of the individual ReGen plants to ensure the delivery of the service while minimizing the potential production."



$$P^i_{\mathrm{ref},t} = P^i_{\mathrm{sch}} + r_t \; P^i_{\mathrm{res}}$$

Figure 34 Controller setup for tests in SYSLAB of PV plants.[74]

The result from the test:
"In the majority of the time the system is able to deliver the expected service. There are two instances where the expected output and expected control signal made it impossible to track the reference. The controller is also monitoring this and calculating the error in delivery of the service as seen in the lower part of the figure[75]. Since the error is higher than allowed the controller will in the next timeframe be more conservative i.e. lower the base line set point and by this improve the quality of service for that timeframe."

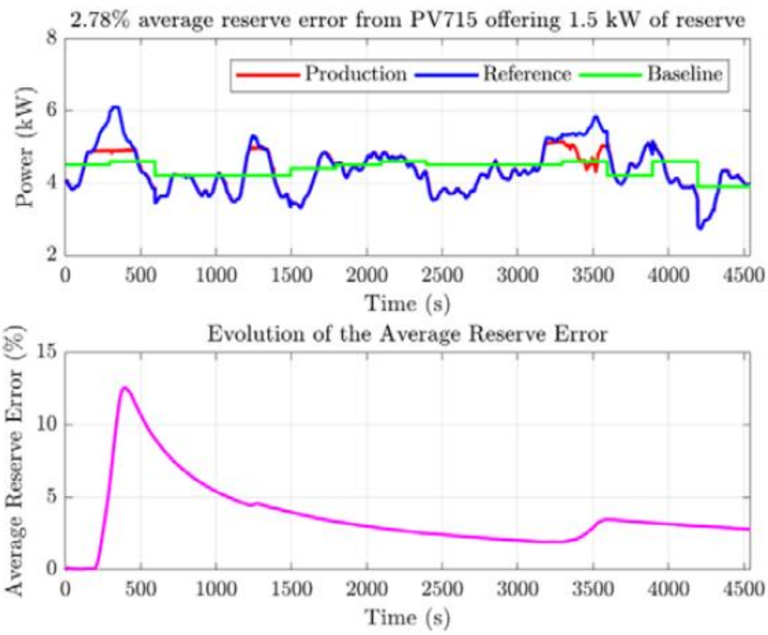


Figure 35 Test results from 04 Dec. 2018 in SYSLAB with PV plants delivery of FRR.[76]

[74]Figure 34 is "Figure 43" reproduced from [25]
[75]"figure" is here Figure 35, which is "Figure 44" reproduced from [25].
[76]Figure 35 is as stated "Figure 44" reproduced from [25].

The RePlan-project the work has shown – in general and with reference to the result shown in Figure 35 – quoted here from [25]:

- The forecast of the production is essential for the method;
- The forecast becomes more complicated when the output is being manipulated due to lack of real reference of the potential;
- Even for hardware that has not been developed to supply this type of service the approach can be done with relatively good performance;
- It is important that the system operators agree on this type of service delivery
- That the base for calculating the reserve is updated with short intervals e.g. 5-10 min;
- That a statistical measure is introduced to allow improved profitability by increasing the utilisation of the potential RE (renewable) production."

The PVP's established in the distribution grid will typically be a type C (> 3MW) or type D (> 25 MW) power generating module of acc. to the Danish implementation[77] of the RfG rules; besides this the "small scale experiment" reported is a result, which can support the further research and development.

Despite of above statement – a commercial company in Belgium - Mind4Energy NV developed a technology, Mind4Energy MINT®, for PV Data Acquisition and Power Plant Control (PPC) based on industrial quality PLC hardware – refer to Example 1 part 5.4.2.

Active power control of the PVP is possible; the PVP controller shall be able to reduce or increase its output to a MW setpoint between 0 MW and the available active power of the PVP due to the RfG. In addition, the PVP must stay connected to the transmission gird during frequency deviations event from 50 Hz acc. to the RfG.

Reactive power control of the PVP is also possible; and voltage regulation can be performed – but as most PVP's are grid connected in the distribution grid, they will most certainly be operated in Q-regulation mode as the TSO will decide the voltage set-point.

[77]Refer to Energinet's website: https://energinet.dk/El/Nettilslutning-og-drift/Regler-for-nye-anlaeg

5.4.2 Example 1: Mind4Energy MINT® PV data Acquisition and Control

The company Mind4Energy NV, Buchtenstraat 14, 9051 Gent, Belgium with the website: https://www.mind4energy.com/ - "offers a PV Data Acquisition and Power Plant Control (PPC) based on industrial quality PLC hardware. It allows to dynamically control the output of the PV plant based on control commands from grid operators, energy traders, flexibility aggregators or as part of a Virtual Power Plant. With the PPC, the solar plant is ready to participate in the energy market of the future." [32]

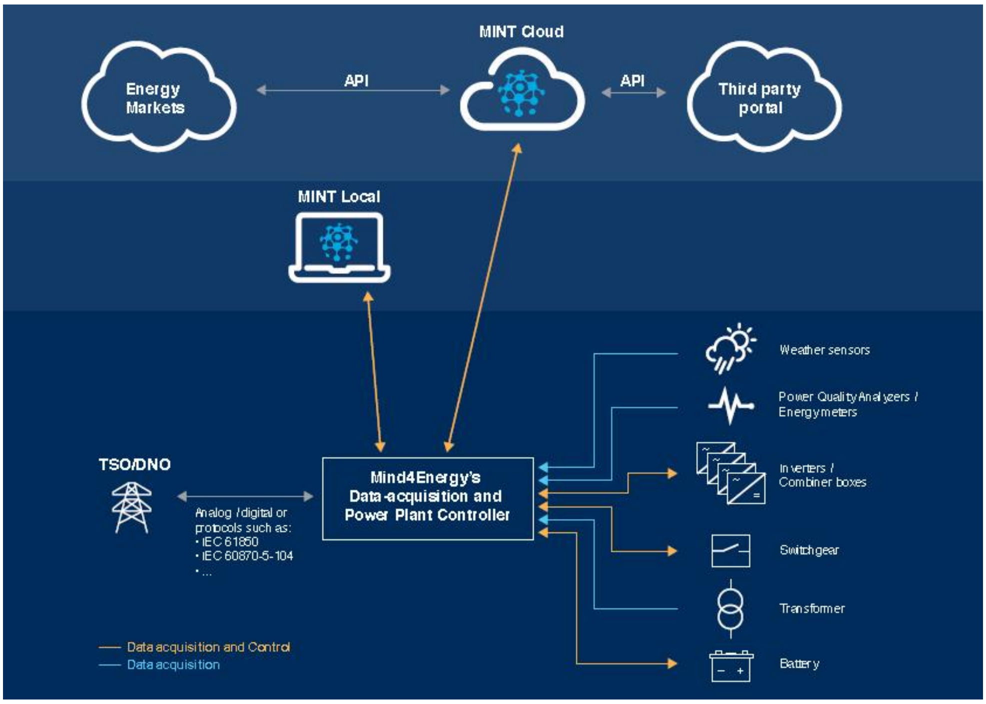


Figure 36 Concept solution Mind4Energy MINT® from the company Mind4Energy NV[78]

Quoted from the Flyer [32]:

"The PPC acts on the inverters to remotely control active and reactive power of the facility and on the switchgear for coupling or decoupling the plant. Response times of less than a second can be reached. The closed-loop control by means of a power quality analyzer at the grid connection point, assures a high accuracy of the output.

The Mind4Energy PPC can process a wide range of commands in multiple protocols, such as analog and digital signals, but also protocols specific to the power industry as IEC 61850.

The Mind4Energy PPC is fully integrated with MINT, Mind4Energy's new real-time monitoring and control platform. This platform assures effective real-time monitoring of the facility from string level to grid connection point."

And continuing quoted [32] – the available features are:

- "Real-time monitoring and real-time control of your PV plant.
- Control of the PV plant based on dynamic signals like real-time or forecasted energy prices.
- Control of active and reactive power with or without ramp rate.
- Frequency support (via active power).
- Voltage support (via reactive power).
- Cos φ-control (even at night, with specific inverters).
- Export limitation.

[78]Figure 36 is reproduced from reference [32].

- Battery management.
- Soft start and soft stop of the facility.
- Compliance with DNO (=DSO)/TSO communication requirements.
- Flexible interfaces and secure connections with third parties."

And the following options are available for large utility-scale plants – quoted [32]:

- "MINT Local: Local real-time SCADA.
- Managed fibre optic switches for a redundant ring network.
- The industrial hardware used by Mind4Energy allows for a redundant data acquisition setup.
- High security VPN router."

References for projects with Mind4Energy NV solution and more brochures can be downloaded in the company's website, refer to: https://www.mind4energy.com/downloads/

Dirk Eeraerts, representing Mind4Energy, had a presentation in the conference European Utility Week from the 12th of November to the 14th of November 2019 in Paris. From this presentation Dirk Earaerts has allowed Ramboll to show the pictures of slide 12, 18, 19, 20, 21, 22 and 25, which gives more information of the set-up and use of Mind4Energy's system:

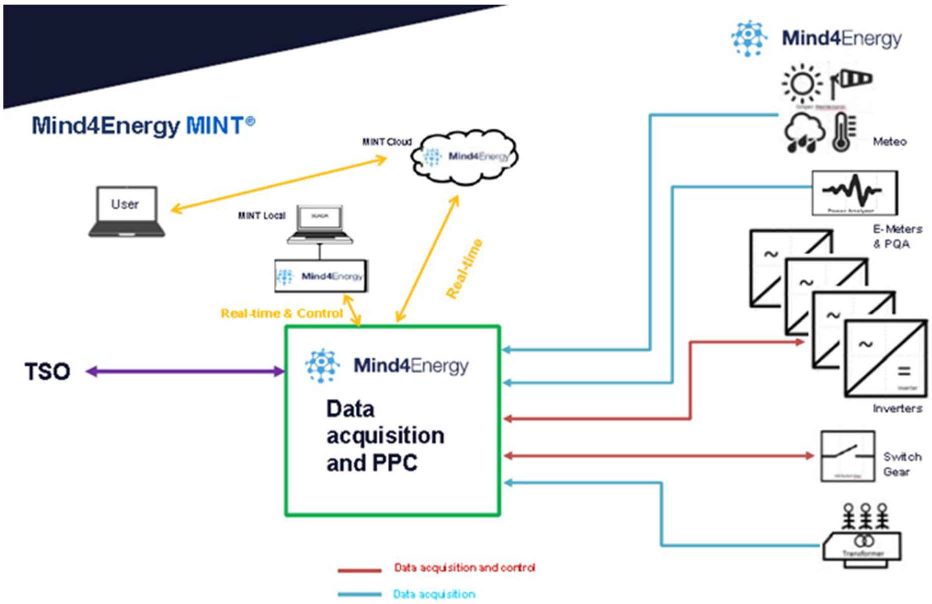


Figure 37 The generic schematic of Mind4Energy's system (slide 12).

The Data acquisition unit and the Power Plant Control (PPC), in Figure 37, manage to control the PVP from input and signal exchange with the TSO (purple line), which gives a voltage set-point and demands the operating set-point regarding active and reactive power. The Data acquisition unit collects weather data (radiation, temperature, wind) and measurements from the grid (voltage, current, active and reactive power), which are showed as the blue input signals. The red lines shown are the exchanges of orders and status of on/off- switching of the circuit-breaker and the PV inverters control, which also will correct the power set-point due to the actual state in the grid. Due to collection and exchange with the MINT Cloud, the PVP can be controlled in real-time from a local user on site, from a local control room or from a central control room.

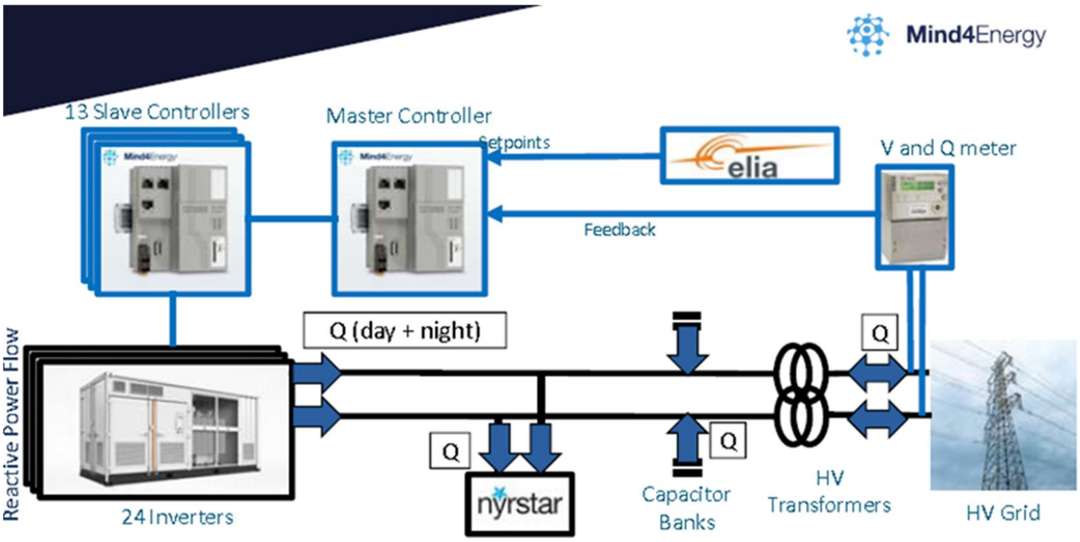


Figure 38 A specific site in Belgium with a 100 MW PV Plant suppling an industril plant (nystar) – a typical closed loop control (slide 18).

The Figure 38 shows the flow and control of the reactive power – measurements, control and feedback signals doing the corrections due to the reactive power components (capacitor banks, transformer and grid), reactive loading from the industrial plant and the output of the PV inverters in controlling the voltage and reactive power flow via the master controller, which have a voltage set-point as input from the TSO.

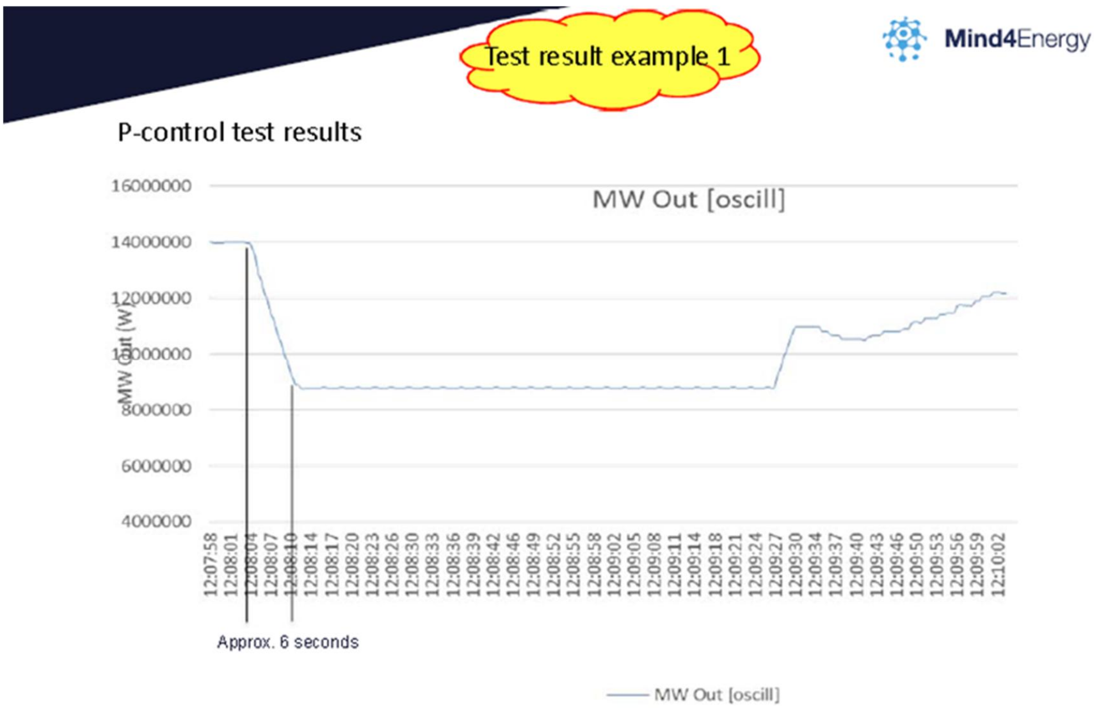


Figure 39 Set-point for active power – ramping and maintaining the power (slide 19).

Active power control is shown in the Figure 39; the selected active power control set-point can be maintained, if the solar irradiation does not drop below the level corresponding to the set-point.

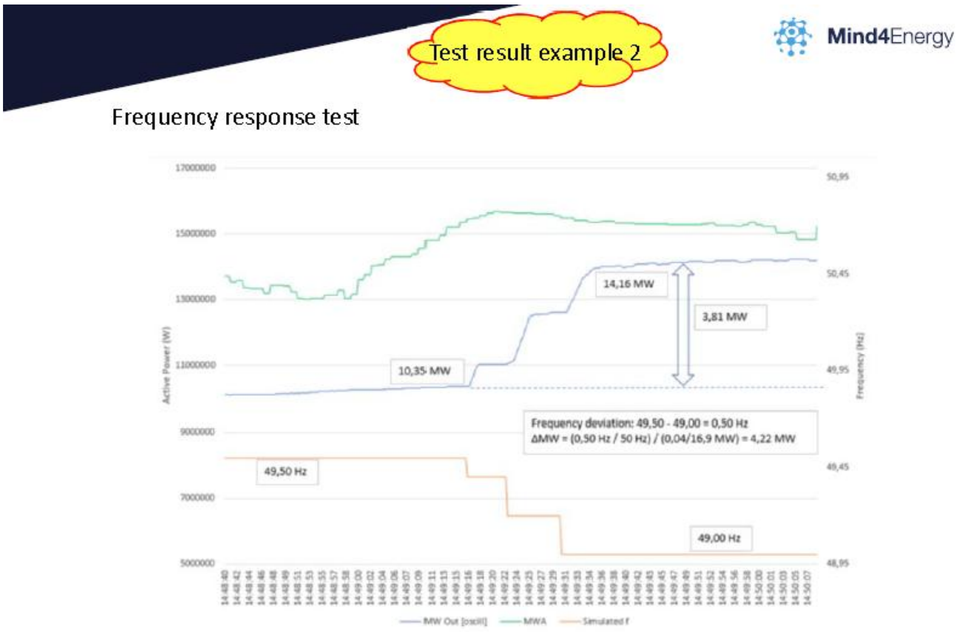


Figure 40 Frequency controlling the active power (slide 20).

In Figure 40 the curves show frequency controlled active power output from a PVP with the following explanation:
The green line in top: The active power potential of the PV facility based on the instant irradiation measurement considering the inverters availability.
The orange line in the bottom: Frequency signal, which are the input signal testing the active power being controlled due to the frequency drop.
The blue line in the middle: Frequency controlled active power due to the frequency drop.
This reaction from the PVP requires that the active power set-point is held below actual power possible due to the sun radiation (is scaled down).

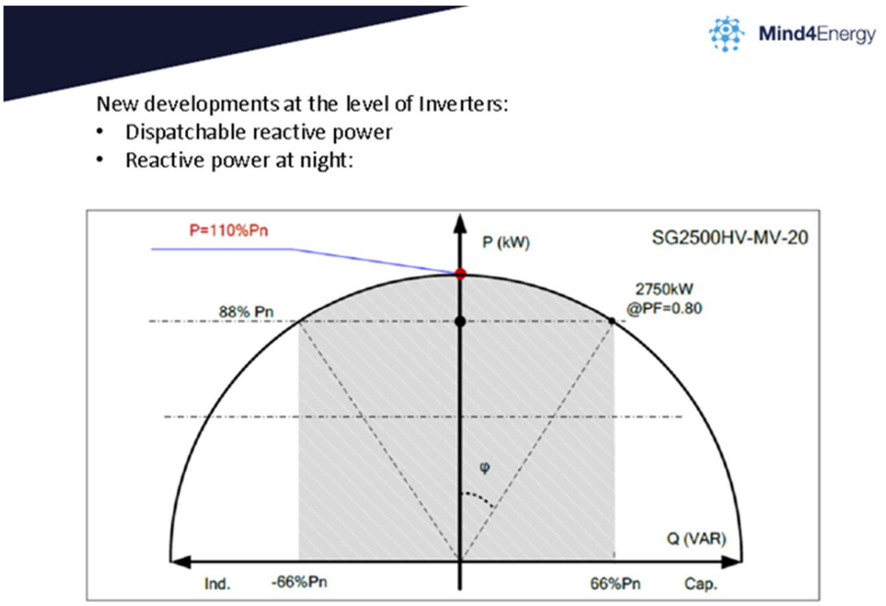


Figure 41 Inverter providers specification sheet of the P/Q-diagram (slide 21).

Figure 41 shows the working range of reactive power versus active power of a specific PV inverter.

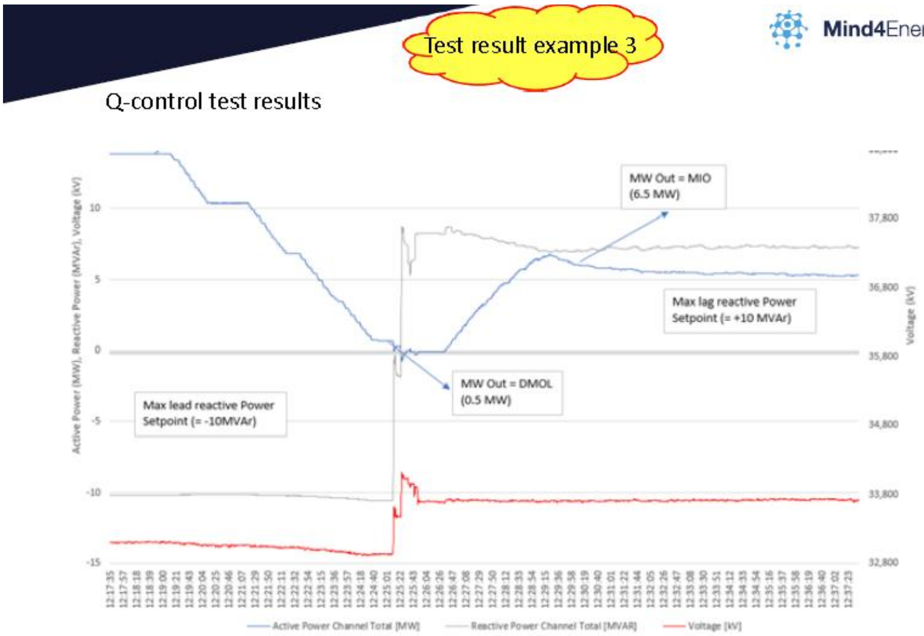


Figure 42 Verification of the inverter specification regarding voltage control (slide 22).

Explanation to Figure 42:

The red curve: Voltage in kV

The blue curve: Active power in MW

The gray curve: Reactive power in Mvar

When the voltage new set-point is given, due to maximum lead reactive power, the voltage control gives the changes in active and reactive power flow.

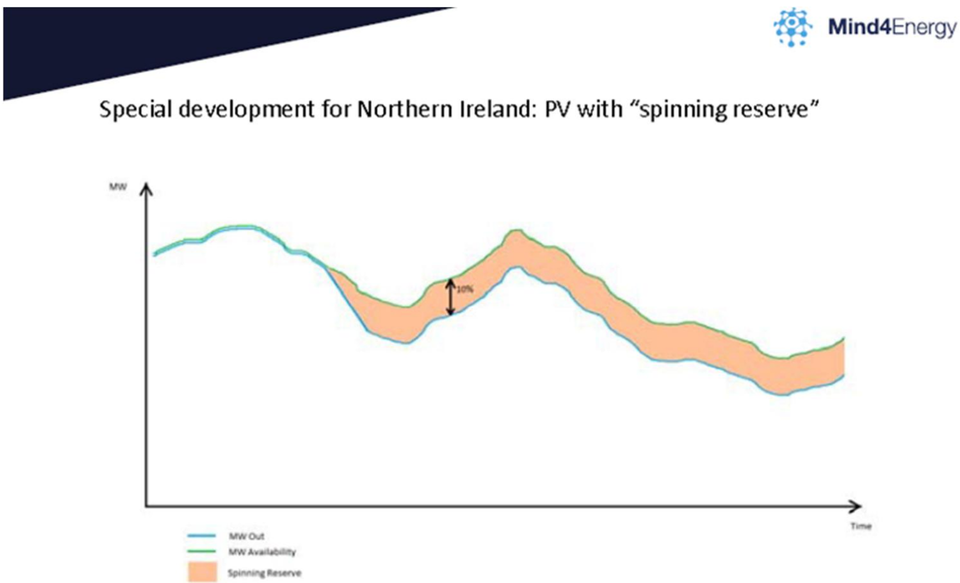


Figure 43 Simulated graph showing the "Spinning reserve" readiness of delivering reserve (slide 25).

The output active power from the PVP are controlled with a constant margin; the measurement of the radiation controls the active set-point having, as shown in the figure, a 10 % margin of power reserved as "spinning reserve". In Northern Ireland this feature is part of the TSO requirements for PVP's with compensation for the lost income.

6. NEW TECHNOLOGY – DEMAND PLANTS OR UNITS

6.1 Introduction

The analysis assumptions for EN from DEA 2019 issue [2] gives a picture of the increase of consumption (demand) for the coming years – with a substantial uncertainty – especially caused by little or non-experience with projecting the new technologies (Large heat pumps, EV's in the transport sector and large data centre). Figure 44 shows the DEA's expectation of the consumption development in the DEA 2019 issue [2]:

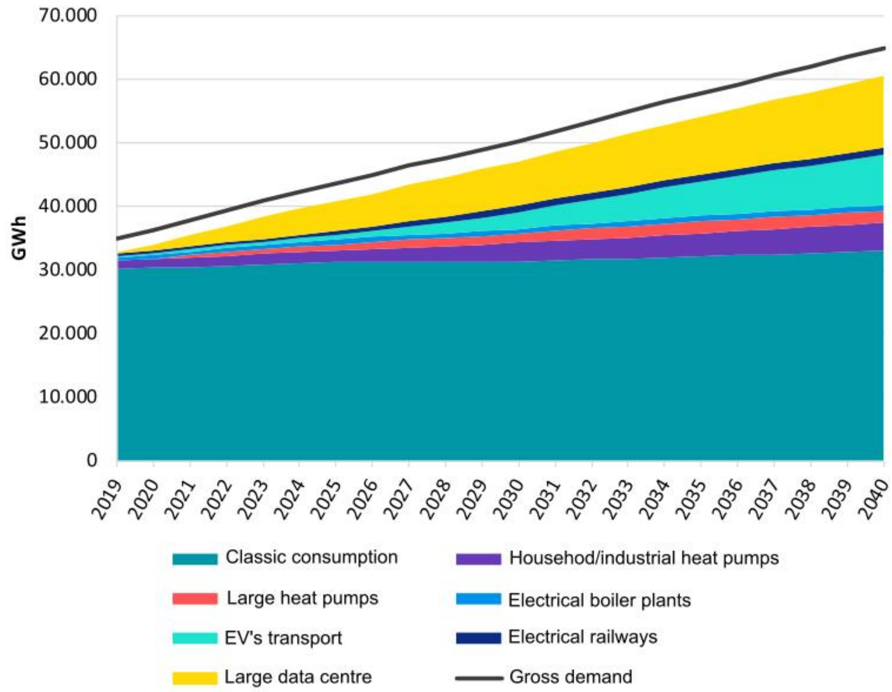


Figure 44 Expected development in the total Danish electricity consumption for the projection period.[79]

In Denmark the heat and power sectors have a long tradition of cooperation due to combined heat & power production facilities – on the demand side all the district heating areas are in the larger cities of Denmark. According to the heating supply law [1], Appendix 1, part 8, the city councils in cooperation with utility companies and other stakeholders, have the responsibility to carry out heating planning for the municipal area. The overall objective of the heating planning are[80]:

- to promote the heating form with most net benefits to society;
- to promote the most environmentally friendly heating form (including promotion of cogeneration of heat and electricity) and
- to reduce the energy supply's dependency of oil and other fossil fuels.

In the catalogue "Technology Data for Heating installations" [6] one of the consumers whose consumption of energy is shown in Figure 44 are described: Electrical heat pumps (2; 207); another of the consumers shown in Figure 44 is described in Technology Data catalogue "Generation of Electricity and District heating": Heat Pumps (1; 40); and the third one EV's in the transport sector (e.g. batteries) is described in Technology Data catalogue "Energy storage"

[79] Source [2] "Figure 28" reproduced.

[80] Regulation and planning of district heating in Denmark: https://ens.dk/sites/ens.dk/files/contents/material/file/regulation_and_planning_of_district_heating_in_denmark.pdf

(more types of batteries) – that's why this chapter have got the main headline "Demand plants and units", as this chapter describes the chosen technologies, which in agreement with EN could be the technologies showing possible near future technical potential of delivering ancillary services.

The new technology "EV's transport" is covered in 8. Chapter.

Here in this chapter the descriptions will cover: Large heat pumps, small scale heat pumps, cooling equipment and other industrials consumption, which can be designated flexible demand.

In the late 2015 EN asked stakeholders and BRP's to participate and submit application to join in pilot projects of delivering ancillary services from flexible electricity demand, energy storage and more – this with the purpose to address whether the current markets requirement was giving rise to any barriers for new technologies to participate in the ancillary service markets.
EN subsequently published a summary report [33] of the conducted pilot projects carried out. Some of these pilot projects will also be described here in this report with the aim of spreading awareness of the possibilities of delivering ancillary services from flexible consumption plants and units, refer to Example 2 part 6.3.2 with small scale heat pumps and Example 3 with different kinds of flexible demand in part 6.3.3.

The trends seen in the district heating sector is that several heating plants or combined heat and power plants are installing heat pumps or are planning to install, this also in combination with electrical boiler plants or larger heat storages. Electrical boiler plants already has shown their technical potential delivering ancillary services.

All these district heating plants have installed heat storage tanks in combination with the combined heat and power plants (CHP). Thereby an increasing number of plants has a combination of heat storage gas fuelled CHP's, electric boilers and large heat pumps, enabling them to offer huge demand response in the market and having the potential for delivering ancillary services in an efficient way due to economy of scale. Seen from the power system, the district heating acts like a huge battery, a virtual battery, which can store heat generated by electricity for later use and use back-up capacity in case of capacity constrains in the grid. Thereby a substantial part of the district heating sector could shift from gas based on to the available capacity in the grid. More over the electric boiler plants could unload the grid in case of overloading from wind or photovoltaic production.

In the larger cities district cooling is in progress and the trend is that the district cooling will be provided by heat pumps for combined heating and cooling in combination with a chilled water storage and in many cases also ground source cooling, a so-called ATES system.

This thermal inertia in the district heating and cooling in large scale is an opportunity to develop new technologies for faster regulation and communication compared to small scale appliances in households.

For having potential delivering ancillary services it is an advantage to have inertia in the system; heating and cooling systems do have natural temperature inertia in their system.

As mentioned above the district heating and cooling sector has a huge potential due to the storages and back-up from the gas system. More over this potential is huge compared to the potential in small end-user installations and the cost of installing equipment for regulation and communication is relatively small compared to end-user installations.

At the end-users: If turning off the electrical heating radiator or domestic heat pump, it will not be chilly before after some time – or turning off the refrigerator or freezer the food will at least after some time be heated to ambient temperature or melt if frozen from the start, however this regulation has much lower potential.

Starting to deliver ancillary services from large consumers or aggregation of minor consumers of household, industrial or heating sector equipment, have been chosen, as mentioned above to be described in several examples in this chapter, which shows their possibilities of delivering ancillary services.

6.2 Definitions and abbreviations

ATES: Aquifer Thermal Energy Storage

LED: Light-Emitting Diodes.

CHP: Combined Heat and Power plant.

COP: Coefficient of performance; for compression heat pumps, the practical heat output is usually 3 to 5 times the drive energy.

6.3 Technology: Household, industrial or heating sector equipment

Due to each type of equipment's characteristics they will have different capabilities to be regulated regarding their energy consumption – and different capacity of powering on/off, ramping etc.

Equipment, which typically have one or another regulating ability, are:

- Pumps
- Fans
- Compressors
- Large lighting installations (floodlight etc. – and not LED's lights, with low consumption)
- Melting furnaces
- Industrial stoves
- Large electrical boilers for district heating combined with storages
- Large heat pumps for district heating combined with storages
- Large compressors and heat pumps for district cooling with chilled water storages
- ...and several other types of industrial power consuming components and equipment.

A large part of the mentioned types of equipment are either supplied by a motor equipped with frequency converter or supplied by soft starters or other controllable/regulated supply management units.

Due to the differences of regulation abilities and control signals (flow, temperature, level, light, etc.) – and to keep the technical descriptions short in this chapter – only examples of projects performed delivering ancillary services will be highlighted here – these four examples follow in part 6.3.1 through to part 6.3.4.

On the 13th of November 2019 the Danish government announced "Their partnership with companies" for the commitment and reach out for help with the implementation of the objective to achieve the 70 % goal of less CO_2 in 2030. Thirteen "demand" groups were constituted – these groups are also the relevant forums to consider the question as raised in this report: How to manage to deliver ancillary services in the future in the context of optimisation and planning the energy consumption in the thirteen sectors defined with the goal having less emissions of CO_2? The main headline for the thirteen groups constituted are[81]:

- Energy heavy industry
- Energy
- Transport sector, airline
- Food and agriculture
- IT, service and consultancy
- Transport sector, land
- Waste, water and circular economy
- "The Blue Denmark" – shipping transport sector.
- Trade
- Production companies
- Life Science and biotech
- Building and construction
- Financial sector

The following parts in this chapter will describe the examples of demand response delivering ancillary services and their considerations regarding the applicable rules and regulations.

[81] DI News Business website: https://www.danskindustri.dk/di-business/arkiv/nyheder/2019/11/regeringen-vil-na-klimamal-gennem-partnerskaber-med-virksomheder/

6.3.1 Example 1: FlexHeat Heat Pump – EnergyLab Nordhavn

The following text has been delivered by HOFOR/Tore Gad Kjeld allowed to be presented in this report:

"The FlexHeat heat pump is a two-stage ammonia heat pump with a thermal capacity of 800 kW delivered by Johnson Control and installed in the Nordhavn harbor area in Copenhagen, Denmark.

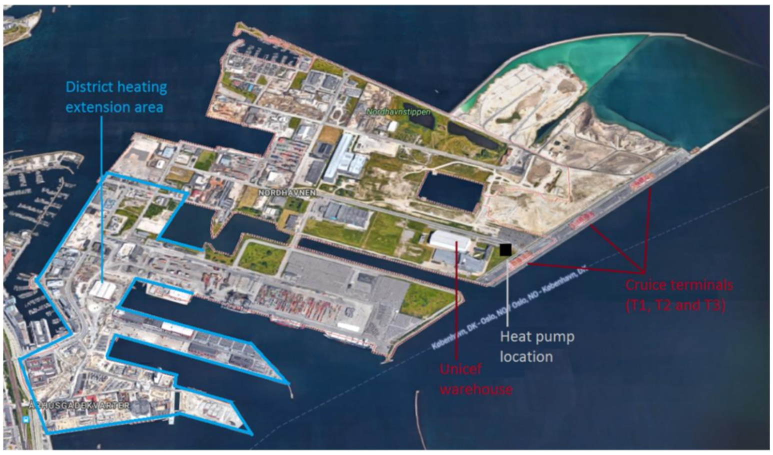


Figure 45 Location of heat pump, cruise ship terminals, and warehouse in Nordhavn, Copenhagen.[82]

It is owned and operated by HOFOR and was part of the EUDP research and development project EnergyLab Nordhavn. It uses groundwater at 10.5 °C as heat source and rejects the groundwater into the sea. The heat pump is the main supply unit of a small-scale district heating grid supplying three cruise ship terminals and a high bay warehouse. The heat pump can deliver district heating forward temperatures of 60 to 82 °C. The heat supply unit is further equipped with a storage tank with a volume of 100 m³ and two electric boilers with a capacity of 100 kW each downstream of the storage tank.

Figure 46 FlexHeat heat pump building and storage tank in front of cruise ship terminal building.[83]

The heat pump unit is comprised of the following main components: Flooded evaporator, separator, low- and high-stage piston compressor, open flash intercooler, desuperheater, condenser and sub-cooler and two throttling valves. The evaporator was a corrugated plate heat

[82]This figure's number now follows numbering of figures in this report – "Figure 1" in received document from HOFOR.
[83]This figure's number now follows numbering of figures in this report – "Figure 2" in received document from HOFOR.

exchanger and the other three heat exchangers were shell-and-plate heat exchangers. Both compressors are equipped with variable speed drive, thus enabling part-load operation.
The heat pump can operate in 7 different operation modes:

1. Default mode: Heat pump operation only; the heat pump runs at a given capacity and based on the consumption level the remaining heat is delivered into the tank.

2. Heat pump operation with electric boiler boost: The same as mode 1, but the temperature to the costumers is boosted to a higher level by the electric boilers if needed.

3. Test-mode for heat pump operation only: Same as in mode 1; but with different settings for the tank and heat pump. Mode 1 is used as a default mode, whilst mode 3 is used for testing.

4. Discharging of the storage tank: The heat pump is not running. The storage tank discharges heat to the costumers.

5. Discharging of the storage tank with boost from electric boilers: Same as in mode 4, but the temperature of the discharged heat from the tank is boosted by the electric boilers to a sufficient level.

6. Discharging of the tank while re-heating the tank with electric boilers: The heat pump is not running. The return water is circulated through the electric boiler to boost the temperature in the bottom of the tank, while discharging the tank.

7. Intelligent operation for fast regulation of the heat pump: Additional equipment is installed to pre-heat the system, and thus allowing faster ramping of the compressors without condensation.

An intelligent operation optimization was implemented to allow for an optimal bidding strategy including day-ahead and frequency regulation market. This allows for cost-optimal operation of the heat pump system.

For the seventh operation mode the control of the heat pump was rebuild in order to allow for fast ramping of the heat pump. Further measures to prevent condensation in the suction line were taken to allow for fast ramping. First tests after reconstruction of the system have shown that the heat pump is able to ramp up/down by 50 % in less than 150 seconds. This is the required ramping time for flexible assets providing frequency regulation normal operation (FCR-N), which is a primary regulation service in Eastern Denmark. Thereby, the operation may be operated fast enough to act on this market as stand-alone unit.

It was further shown; that the heat pump can support the BESS based frequency regulation (as described in part 8.3.3) by offsetting the energy content of the frequency deviations. This may also allow heat pumps to take part in primary frequency regulation markets (together with fast regulating units), even if these require lower ramping times.

It was demonstrated that the heat pump may also help the local DSO in assisting the load – both in case of an overload and a deficit of load. In cases of overload, for example a high in-feed from wind turbines or PV production units, the heat pump was called upon to consume maximum electricity to assist the local grid. In another case, a deficit of load, the heat pump was called upon to decrease or shut down to help. This was possible due to the high amount of flexibility in the district heating system, the storage tank, grid and at the consumers."

Together with above content Ramboll/Henny K. Nielsen received a Memo from HOFOR, “Plan-Fjernvarme Bygas & Kraftvarme”, Tore Gad Kjeld (+45 2795 4341 /e-mail: tgkj@hofor.dk) and Wiebke Meesenburg (e-mail: wmeese@mek.dtu.dk); this Memo translated to English is reproduced here below:

Memo

Date:	12.11.2019
Task:	Heat pumps, refrigeration machines and electric boilers in the future electric system
Sender:	Tore Gad Kjeld & Wiebke Meesenburg
Receiver:	Henny K. Nielsen, Ramboll, on behalf of Energinet

Heat pumps, cooling machines and electric boilers in the future electric system

Preface

HOFOR A/S has in connection with EnergyLab Nordhavn and in close cooperation with DTU, Technical University of Denmark, Mechanics tested a flexible energy system consisting of a heat pump and an electric boiler. Here it is assessed how the heat pump can provide system services to the electricity grid. The plant supplies heat to customers in the Copenhagen urban development area Outer Nordhavn.

In this memo, inputs are provided to Ramboll, who, on behalf of Energinet, performs the following task for the Danish Utility Regulator:

> *“The Danish Utility Regulator will request Energinet to continue supporting the growth of new technologies in the development of market design, and to provide a better overview of the potential of these new technologies. In this context, the Danish Utility Regulator recommends that Energinet identifies and works to remove unnecessary entry barriers and challenges to make use of new technologies in the reserve capacity and energy activation markets. The Danish Utility Regulator recommends, that Energinet, with the involvement of market players and international experience, prepares and publishes a report of the potentials of new technologies based on the Technology Data catalogue before the end of 2019."*

This memo focuses on heat pumps and electric boilers, as well as perspectives for refrigeration machines. This memo is limited to highlighting the potential of these three technologies in the current system performance markets for primary, secondary, and tertiary reserves. The services provided are as follows:

- **FCR-D** (Primary reserve)
- **FCR-N** (Primary reserve)
- **aFRR** (Secondary reserve)
- **mFRR** (Tertiary /Manual reserve)

Therefore, the capability of the technologies in other markets such as non-frequency ancillary service or system stability properties markets is not considered. It is recommended to investigate this subject in another occasion.

Bid limits

The bid limit for some of the services will be advantageous to reduce in order to increase the supply of the facilities.

The recent legislative changes in terms of being able to deliver as a single portfolio, helps using the plants to a certain extent, but the size ratios between power plants, wind turbines, etc. will often limit the bid and the capacity of these. The following changes are proposed:

- **FCR-D:** 0.3 MW → 0.1 MW
- **FCR-N:** 0.3 MW → 0.1 MW
- **aFRR:** 1 MW → 0.5 MW
- **mFRR:** 5 MW → 1 MW

This would to a great extent allow for individual bids and portfolio optimised bids.

Heat pumps

HOFOR has tested a 0.25 MWe ammonia two-stage heat pump from Johnson Controls. This heat pump is purchased under normal conditions, i.e. no requirements for rapid upwards- and downwards regulation have been specified. A standard heat pump regulation is thus tested.

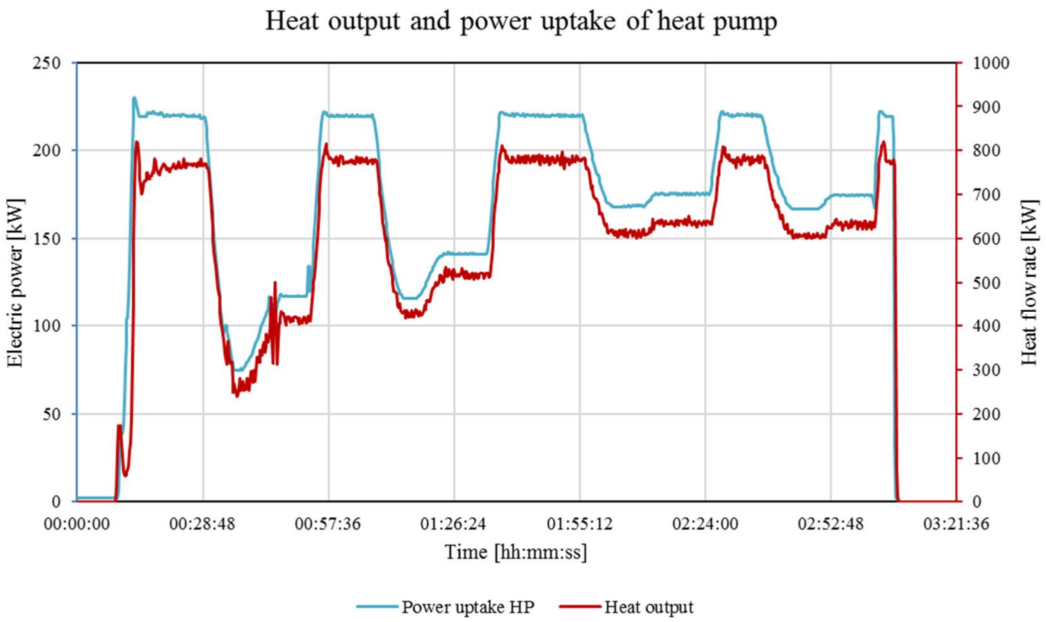


Figure 1: Test run for the heat pump. Start-up, shutdown and partial load control are shown here.

Figure 1 shows a test sequence in which the start-up is shown, then partial control for respectively. 40, 60 and 80 % capacity, and finally a shutdown. Wiebke Meesenburg from DTU Mechanics has summarized the current potential in Figure 2:

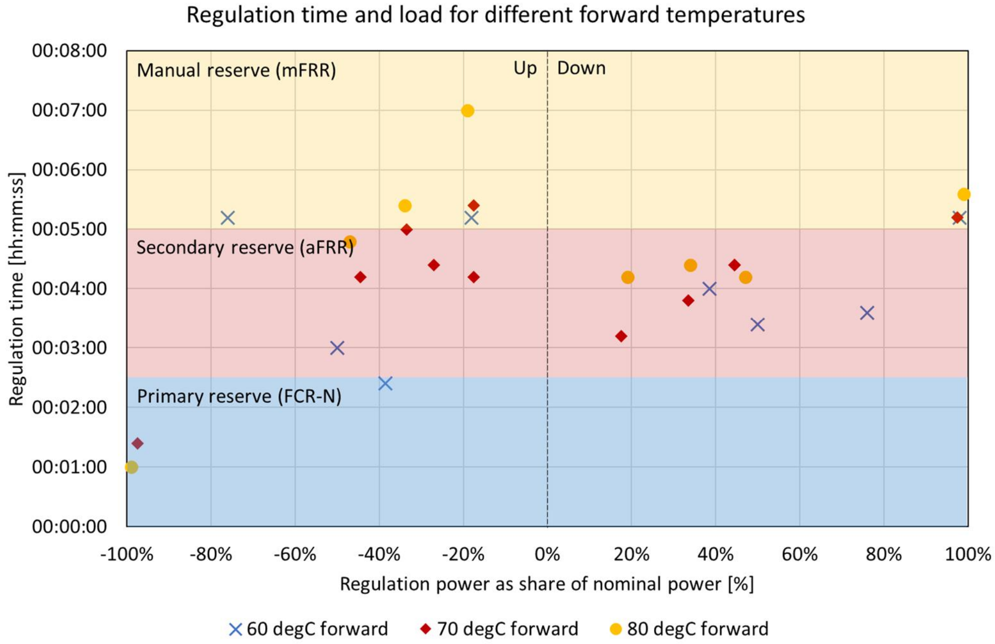
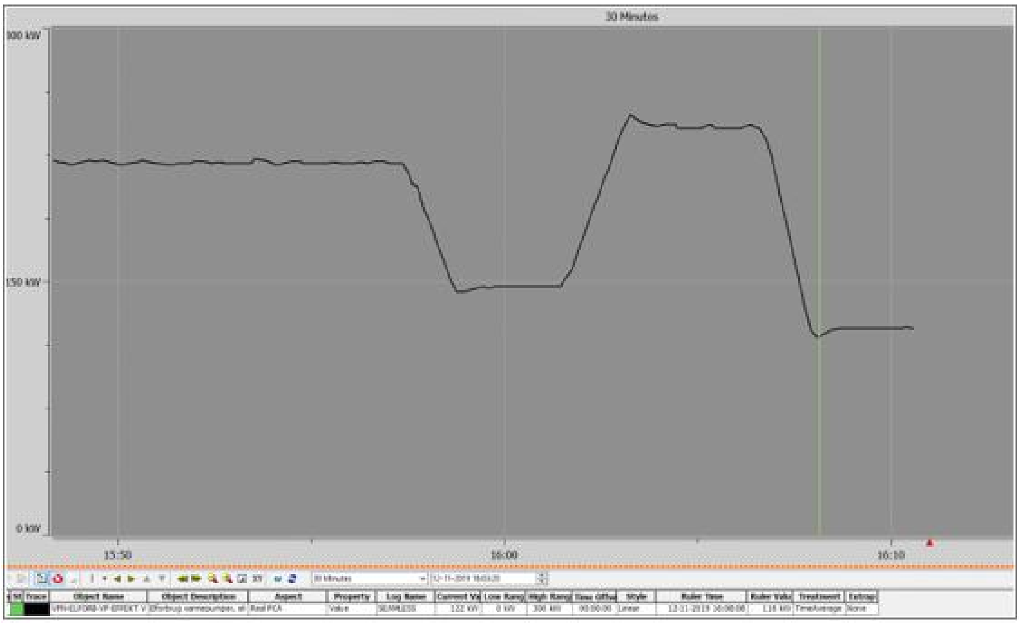


Figure 2: Summary of the times of regulation for the heat pump without undershoot.

Here it is seen, that with the current heat pump, it will be most compatible with the secondary and tertiary reserves under current conditions both regarding markets as well as technical requirements.

The regulation shown above is focusing on the heat side and not the electricity side. The test plant has since this test been reconstructed, where it is preheated to achieve a suitable thermal balance allowing faster regulation. For this purpose, here the plant is also controlled by the electricity side, i.e. the regulation follows the compressors instead of the evaporator outlet temperature. This gives the following preliminary results for adjustment:



This can be adjusted from 100 % to 50 % within 90 s. This, however, comes with a small loss in COP, but the control is designed in a way as only to perform preheated when frequency ancillary services are needed and in the remaining hours the heat pump runs with normal COP.

The following is a further close look at the service-by-service compatibility:

FCR-D:

Present situation: The heat pump can shut down momentarily and thus provide a service within approx. 30 s. However, the requirements cannot be maintained by 50 % within the first 5 s and then the remaining within 25 s - but the total amount of reserve can be delivered within 30 s. In addition, the challenge is that the heat pump is stationary for approx. 20 min, and it takes another 6 min to start the system - therefore it cannot be restored within the 15 min demand.

Suggestions for restructuring of FCR-D reserve requirements: Based on the testing experience, 100 % capacity is required within 30 s, and recovery can take place after 30-45 min, depending on the size of the heat pump. Then heat pumps could play a role.

FCR-N:

Present situation: The heat pump can deliver partial load regulation within 3-5 min in most cases without being optimised for it. The preliminary results regarding intelligent control, where the system is preheated to be able to deliver faster regulation, tell that the system will be able to deliver this within 1.5 min. Future heat pumps could be designed more appropriately in relation to providing this service based on the same principles.

Suggestions for reconstruction of the FCR-N reserve requirements: With the new measures, it is expected that the heat pump will be able to deliver part of the capacity within 2.5 min (≤ 150 s) as specified for the FCR-N service. A possibility of securing heat pumps as a player in this market could be increasing the time to 3-3.5 min, in order to deliver a higher capacity. For this purpose, heat pumps are preferred to provide an up-regulation service, and therefore it would be less advantageous to retain capacity to deliver FCR-N symmetrically. Asymmetric services would therefore make it more attractive to deliver into this market.

aFRR and mFRR:

Present situation: The heat pump can deliver this to a large extent due to demand of delivery within 5 min, even without the intelligent conversion. Here, a significantly higher capacity in part load regulation can be delivered from larger heat pumps than it appears regarding delivery of FCR-N.

Suggestions for restructuring of the FRR reserve requirements: The heat pump could provide significant capacity in this market. Requirements for the 15 min's recovery time can prevent full shutdown and startup operations, but since this is hardly appropriate anyway, it is only a minor obstacle.

The total delivery profile

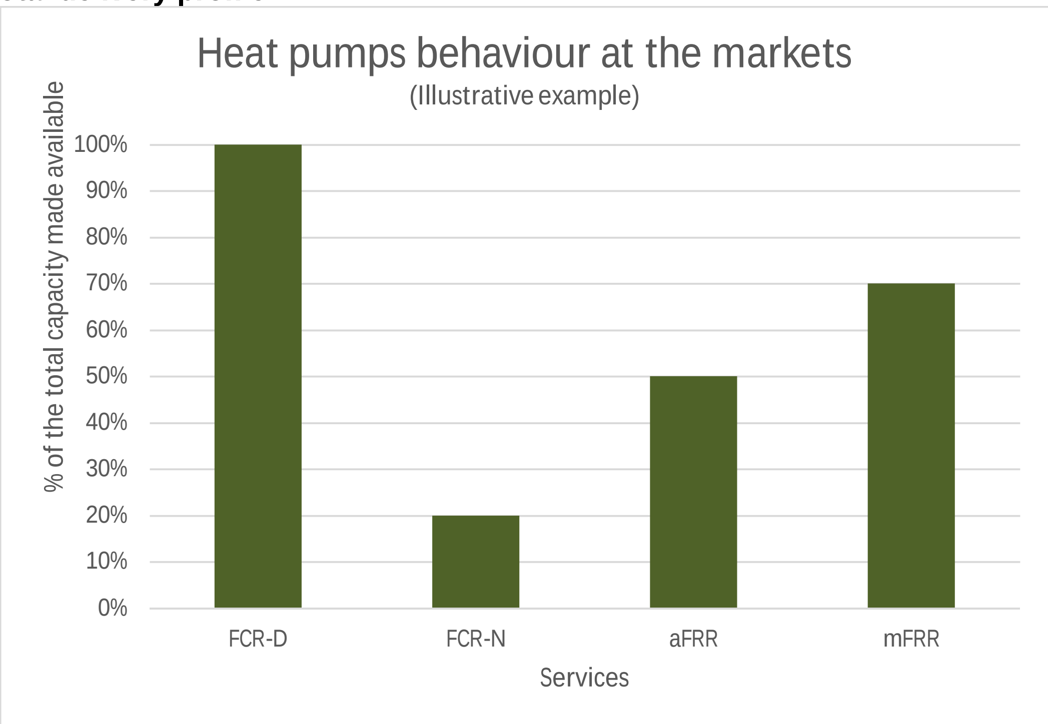


Figure 3: Illustrative example of a delivery profile for heat pumps for ancillary services

Here, Figure 3 shows an indication of how heat pumps could offer themselves in the ancillary service markets if the proposed initiatives are established. It is most appropriate for heat pumps to provide an up-regulation service, as the plants are most often in operation and would be able to downsize to meet a need, and start-up of the plant to provide a service is less advantageous.

Electric boilers

The plant also has two electric boilers, which together with the heat pump deliver heat to the customers in the Outer Nordhavn. Here again we look at the compatibility of the electric boiler technology with the ancillary service markets service-by-service. No specific electric boilers have been tested here, but it is estimated that the plant can be in the current markets with all ancillary services as it is a very simple technology.

FCR-D:

Present situation: The boilers will be able to shut down in 30 s - the system could also be challenged to deliver high capacity in 5 s as in the situation for the heat pump.

Suggestions for restructuring of FCR-D reserve requirements: In order to ensure that the boilers will be able to supply as much capacity as possible, it is proposed that 100 % capacity can be delivered within 30 s, just as with the heat pump. Recovery time is not a challenge for the electric boilers.

FCR-N and aFRR:

Present situation: The electric boilers will be able to provide these services without major technical challenges.

Suggestions and aFRR reserve requirements: The electric boilers are most often used at peak load with very low start-up costs – therefore, they are ideal for down-regulation services. Here, asymmetric services would be needed to ensure that an electric boiler can provide the service, which it is most economically suitable for the electrical boiler a predominant part of the time.

mFRR:

Present situation: The electric boilers will be able to provide these services without major technical challenges.

Suggestions for restructuring of mFRR: It would be advantageous to introduce a market solution for manual down-regulation reserves, as the boilers would be able to bid on this market in most part of the year. It may be relevant rather than down-regulating wind turbines in situations where it is more optimal to get electricity converted to heat.

The total delivery profile

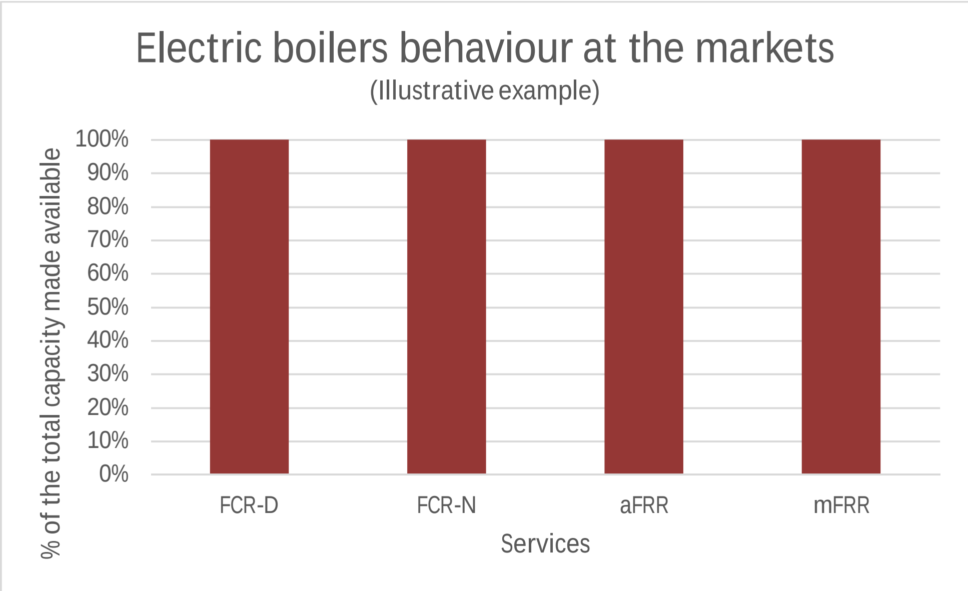


Figure 4: Illustrative example of a delivery profile for electrical boilers for ancillary services.

Figure 4 shows how electric boilers can deliver to the market if the conditions are changed to those proposed. Here, it is preferred that the boilers provide down-regulation services.

Refrigeration machines

No tests have been conducted with refrigeration machines in relation to delivery of system services. It is assessed that the technology is comparable to the heat pumps according to technical specifications - however, there is considerably less flexibility in the cooling system than in the heating system, which means that the plants can offer less than heat pumps.

6.3.2 Example 2: Flexibility from household/industry heat pumps

One of the parties, who was participating in the pilot project concepts [33] EN announced in 2015 was Insero Energy and Neogrid Technologies based on aggregation of flexibility of a pool of totally 315 kW small scale heat pumps. The two companies got a waiver regarding the delivery of up- and downward regulation on time basis without having online measurements on each single heat pump.

The process for aggregation was developed, and their model is reproduced in Figure 47.

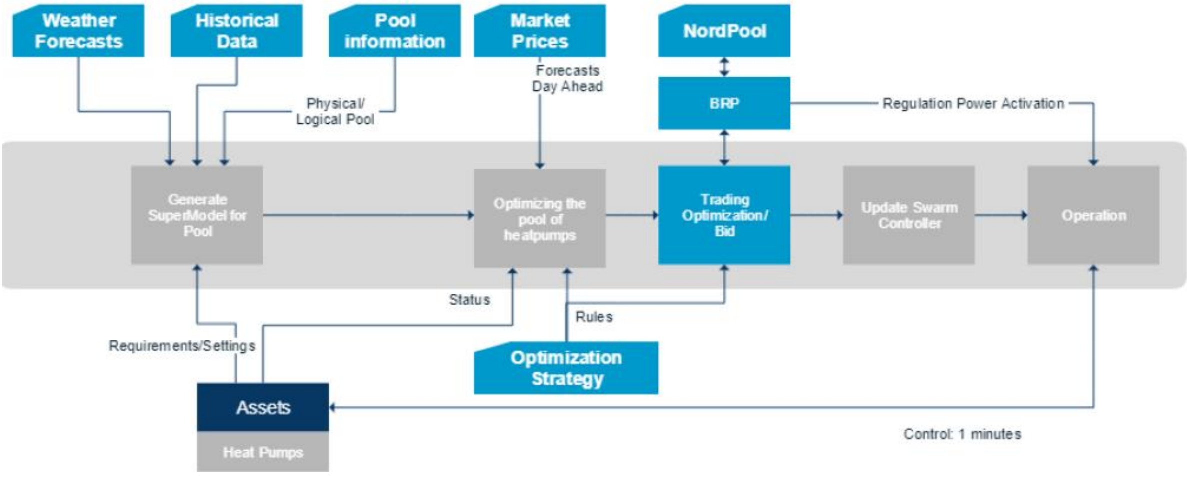


Figure 47 Process of aggregation; the aggregation-engine (the grey beam in the middle), input and output.[84]

Input data for their model was:

- Weather forecasts
- Historical data for the operation of the heat pumps concerned
- Pool information
- Market prices
- Assets (heat pumps) knowledge.

The output aggregation-engine gave the following output:

- Price optimised baseline for the pool in the coming 24 hours' time.
- The amount of power, which can be activated as up-or downward regulation in the next hour.
- Dispatch control signal to the heat pump, which should start and stop to comply with the baseline.

The aggregator did bid one bid into the capacity market and was activated.

Pool of heat pumps for intra-day actions is settled by a SWARM controller, which "decides" which heat pump(s) must start and stop as it also activates the pool for the total amount of bid to the day-ahead market. This process is shown as a block diagram in Figure 48.

The aggregator concept was original developed and tested in a ForskEL-project "READY - Smart Grid Ready VPP Controller for Heat Pumps", where the concept back in 2014 were tested with approx. 70-100 heat pumps. The aggregator was tested and activated against the BRP Neas A/S.

[84]Figure 47 is reproduced with permission from Neogrid Technologies and Insero Energy.

The Neogrid aggregator was again tested in January 2018, where it worked with a limited number of heat pumps (< 10). In this testing no BRP was involved and as so the estimated availability of power calculated was not enrolled and tested against the market.

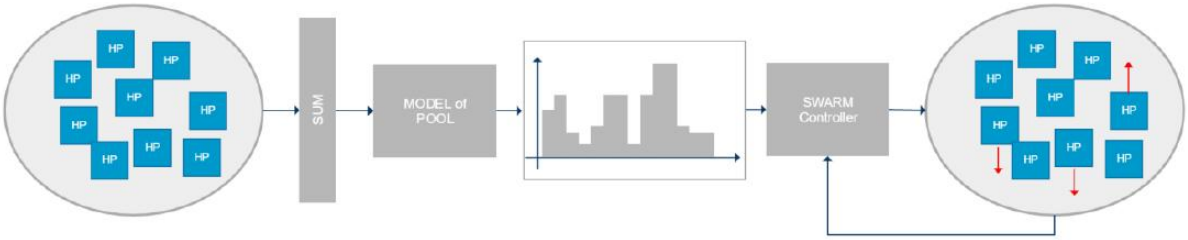


Figure 48 Block diagram for SWARM controller.[85]

Insero Energy and Neogrid plans to cooperate further with this project for offering flexibility for the ancillary service markets with the aggregation of small heat pumps having more capacity added to the portfolio.

Input from Claus Weber/Insero Energy[86]:
In our point of view, there are no significant technical barriers to participation in the markets - the barriers are all due to the market's nature – the economical achievement delivering ancillary services by aggregating multiple plants does not meet the cost of establishing the technical solutions.

[85] Figure 48 is reproduced with permission from Neogrid Technologies and Insero Energy.
[86] Mail correspondence Insero Energy/Claus Weber with Ramboll/HEKN dated 2019-12-09.

6.3.3 Example 3: Flexible demand industrial consumers – Energi Danmark

Energi Danmark participated with a pilot project [33] based on flexible demand from industrial consumers for delivery of capacity to the regulation power market. Four consumers did take part in the pilot project: A horticulture company, a wastewater treatment plant, a cold store and a shopping centre – with a summarised capacity around 7 MW. I the project Energi Denmark cooperated with KIWI Power, who did the development of hard- and software for the control and optimisation of the consumer units related to the delivery of balancing services.

Energi Danmark got a waiver to differ from several of the market's requirements. The waiver's concern included among others the opportunity to pool consumption and production, and the possibility to fail the requirement to maintain activation of energy throughout the full bid time period. The outcome of this was that the aggregated bids from one of each of the consumer units gave a total bid, which was submitted as a production bid in the capacity regulation market, as it was not possible to find sufficiently similar consumption to aggregate. To have some activity Energi Danmark needed to lower the prices to a level where the units would not otherwise have been operated.

The experiences and conclusion of Energi Danmark of this project was that it succeeded to have activations by two of the consumers – but very few activations. The integration of the control in existing systems is expensive and time-consuming – and as expected the consumers primary focus is on their core activities and not on optimising their system delivering ancillary services and flexibility for the market.

Still during 2019, Energi Danmark has continued with an agreement with EN testing pilots regarding flexible consumers contribution of delivering ancillary services.

During telephone interview the 2nd of December 2019 with Aslak Jacobi Kristensen/Energi Danmark and follow-up by mail correspondence the following input was summarised in general regarding barriers from the technical and market requirement of Energinet's rules and respectively summarised some barriers from the stakeholders/flexible consumers:

"Barriers from the rules and regulations/Energinet:

- The rule from [12] regarding "back-up capacity from other production units is a demand if production from renewables (wind) are submitted as bids to the capacity reserve market".
- The demand of full activation time periods of demand products of ancillary services – for FCR 4 hours' time blocks and for mFRR 1 hour of activation.
- Minimum bids of 0.3 MW of FCR-N to be lowered to 0.1 MW – most important for demand bids (Svenska Kraftnät allows this).
- Minimum bid of 5 MW of mFRR - most important regarding demand bids – lowering to 1 MW will presumable result in faster introduction of demand bids.
- Also, to allow asymmetrical bids of FCR-N, FCR-D and aFRR in DK1 (and in DK2 expected Q3/2020).
- Time settlement of auctions the-day-before-operation is a challenge for demand units and their planning of operation.
- Uncertainties regarding future more restrictive requirements of on-line measurements and control, IT-security and more signal exchange with EN.
- The pool of production and demand is not allowed – more demand units, besides electrical boiler plants, can participate if they become allowed pooled with production units.
- Costs and demands of grid connection and energy measurement requirements (measurement responsibility is now located at the DSO's).

- Static price tariffs of electricity, which follow a daily profile and not the market prices. The tariffs of electricity must support consumers to act flexible.

Barriers seen from the owners of the demand units:

- A widespread understanding of showing flexibility but the operation of the company's business always comes first in line.
- Implementing the technical features in the demand units' given the control- and activation potential delivering ancillary services shows long pay-back times. Long pay-back times cause projects implementation to die…
- The flexible consumers are not familiar submitting planning schedules of their operation possibilities to give the baseline of capacity bidding.
- Fear of being unable to deliver in the operation hour and thus receiving financial punishment of no delivery (the risk must stay at the company not at the BRP)

And for the last subject: What is it that drive the stakeholders to go for the ancillary market:

- The stakeholders want to make a difference, be climate friendly, optimise their processes and plan for saving energy costs etc.
- The revenue from the sales of ancillary services is secondary – but it matters anyway."

6.3.4 Example 4: COOP Danmark A/S – FCR Data analysis DK1

In 2018 an investigation[87] of Inopower A/S took place for COOP Danmark A/S to survey whether refrigeration units in DK1 could be qualified delivering FCR. The investigation was limited to a survey the FCR pool handling and regulation; and as so limited to not considering the limitations of the individual refrigerator, communication and regulations resolution.

Coop Danmark A/S wanted to investigate whether existing refrigeration units were able to participate in the FCR regulation (asymmetrical) – only reducing the load (consuming less) – and as so for upward regulation.

The three parts, which were investigated:

- How often and for how long time each refrigerator in average will be deactivated for delivery of FCR?
- What will be the context between the number of deactivations and frequency measurement accuracy?
- What will be the context between the number of deactivations and the volume of the aggregated pool?
- What will be the context between the number of deactivations and the number of pools?

One of the results of their investigation; which this report could mention[88]:
The frequency measurement accuracy – the applicable requirements says 10 mHz – so if using a frequency measurement accuracy much better than this (1 mHz) the deactivation number goes significant up; which means more wear of the refrigerators.

To conclude the dimensioning and sizing of the regulation circuit due to the applicable technical requirement must be carefully investigated as to give the best starting point for making the business case.

[87] Reference: Confidential report delivered by Inopower A/S to COOP Denmark A/S.
[88] Ramboll/HEKN mail correspondence with Coop Danmark A/S and Inopower A/S.

7. NEW TECHNOLOGY – RENEWABLE FUELS OR POWER2X TECHNOLOGY

7.1 Introduction

EN's report "PTX in Denmark before 2030, "Short term potential of PtX in Denmark from a system perspective" [34], which was published in April 2019, reports the outlook for the conversion of renewable electricity production via electrolysis into hydrogen and further processing into gaseous and liquid fuels before 2020 – and despite the PtX-report has a longer time perspective defined as "that PtX can complete with fossil fuels expected around 2035" – than this report – EN's PtX-report also states, "that a lot of development projects are underway already".

News on bioenergy, hydrogen and fuel cells research[89] – issue November 2019 – announced with the headline: "Biogas plays a key role in development of Power-to-X" – and as so today, where P2X still are under development – "It is first and foremost the CO_2-content in the biogas, which will be used to convert electricity to stable storages of the generated gasses or liquids".

Sixteen out of eighteen P2X-project, five of which are completed are using a combination of hydrogen and biogas, refer to Table 3 below.

Project	Maturity	Input	Product	Project management
MegaStoRE	Pilot	Biogas	Bio natural gas	DTU
Biocat	Demonstration	Biogas	Bio natural gas	Electrochaea
Electricity upgraded Biogas	Experiment	Biogas	Bio natural gas	Haldor Topsoe
SYMBIO	Experiment	Biogas	Bio natural gas	DTU
MegaBalance	Analysis	Biogas	Bio natural gas	NEL Hydrogen

Table 3 The overview of the five finalised P2X-projects.

All projects in Table 3 use water, electricity and biogas as input raw materials – and all projects end up with the product bio natural gas, which can replace fossil natural gas.[90]

In the DEA's website[91] - the historical and expected future biogas production and its use in Denmark 2012-2020 can be found – here reproduced as Figure 49. The columns in this figure show, that most of the gas is used for electricity generation and for distribution in the infrastructure gas grid.

Biogas production in Denmark is spread throughout the country. Most biogas plants are manure-based agricultural plants located near the livestock farms. Other biogas plants are part of waste

[89]The article from November 2019 in News on bioenergy, hydrogen and fuel cells research can be readhere: https://www.biopress.dk/PDF/biogas-indtager-en-noglerolle-i-udvikling-af-power-to-x-projekter

[90]Source: The Danish Energy Agency

[91]Reference: https://ens.dk/en/our-responsibilities/bioenergy/biogas-denmark

water treatment plants located in or near larger cities. A smaller number of biogas plants are industrial- or landfill plants treating organic wastes from these sites.

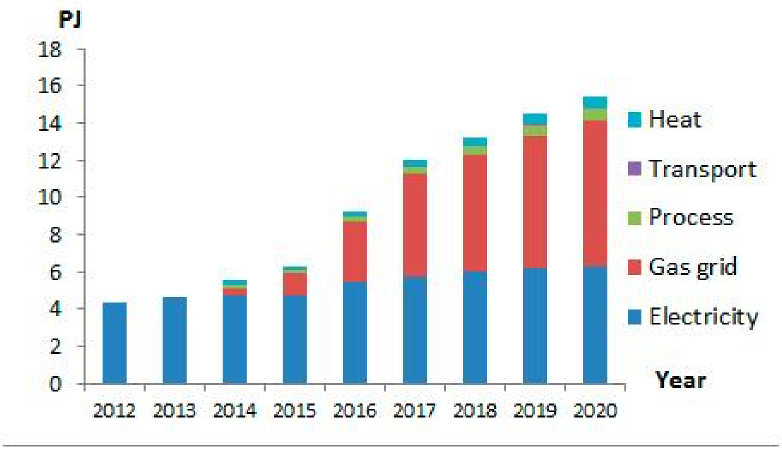


Figure 49 Historical and expected future biogas production and its use in Denmark 2012-2020.[92]

The 18th December 2019, DEA announced, which of the applied projects that have been awarded for energy storage development. The two projects granted financial support both deal with the conversion of electricity into hydrogen[93] (Power2X).

7.1 Definitions and abbreviations

GHG: Greenhouse gas; the primary greenhouse gases in the Earth's atmosphere are water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and ozone (O_3).

Nm^3/h: The unit stands for: Normal m^3 per hour for flow of gas at a pressure of 1 bar.

Power2X, P2X or PtX: Power to another kind of gas or liquid fuel or chemical substance, which can be used in the transport or industry sector instead of fossil fuels or liquids generated from oil.

SOEC: Solid Oxide Electrolysis Cell; which make synthesis gas hydrogen and nitrogen

[92]Reference: https://ens.dk/en/our-responsibilities/bioenergy/biogas-denmark
[93]Refer to the DEA's Danish website: https://kefm.dk/aktuelt/nyheder/2019/dec/128-mio-kr-til-udvikling-af-groenne-braendstoffer/

7.2 Technology: Biogas Plants

The technology description and data sheets for biogas plants are presented in “Technology Data Renewable fuels” [6] Biogas Plants (3; 81).

Advantages to highlight from the technology data catalogue are:

- Methane emission is mitigated, with relatively low CO_2 abatement costs fossil fuels are substituted.
- Saved expenses in slurry handling and storage.
- Environmentally critical nutrients, primarily nitrogen, phosphorus and potassium, can be redistributed from intense farmlands to other areas. The risk of leaching of nitrates is reduced.
- The fertilizer value of the digested biomass is better than the raw materials. The fertilizer value is also better known, and it is therefore easier to administer the right dose to the crops.
- Compared to other forms of waste handling such as incineration, biogas digestion of solid biomass has the advantage of recycling nutrients to the farmland – in an economically and environmentally sound way.
- Application of digestate reduces smell compared to application of raw slurry.

and disadvantages with reference to same source are:

- Use of straw and other solid biomass resources in biogas production yields a lower energy output than if the same feedstock was used for thermal gasification and/or combustion.
- The successful operation of biogas plants is relatively complex and requires large experience.
- The consumption of large quantities of biomass with low dry-matter content (manure) makes transport and sourcing radius a critical parameter.

The production of biogas in Denmark is promoted through public subsidies. The different support schemes for biogas include the following uses[94]:

- Production of electricity
- Upgraded biogas delivered to the natural gas grid or cleaned biogas delivered to town gas grid.
- Use of biogas as a transport fuel.
- Use of biogas for heating purposes.

The schemes for production of electricity and upgrading of biogas will be confined to plants that are operational before the 1st of January 2020. Regarding the schemes for use of biogas for processes, transport and heat, no new subsidy commitments will be issued after the 1st of January 2020.

The DEA is responsible for the rules and regulations regarding the different support schemes. The Danish Energy Agency is administering the payment of subsidies.

The regulation ability of biogas plants is not stated as information in the technology data catalogue.

Nature Energy, the largest producer in Denmark, has been asked regarding their plans for delivering ancillary services in the future – their statement refer to Example 1 following below in part 7.2.1.

[94] Source: https://ens.dk/en/our-responsibilities/bioenergy/biogas-denmark

7.2.1 Example 1: Nature Energy statement regarding ancillary services.

Figure 50 Nature Energy Korskro Biogas Plant.[95]

On Ramboll's request Nature Energy was asked, how far they were – thinking of perhaps delivering ancillary services to the grid in the future as a demand response from the power supply to the Nature Energy biogas plants established in Denmark; Nature Energy /Mette Smedegaard Hansen[96] mailed the following as an answer to the question:

"Nature Energy, as Denmark's absolute largest biogas producer, is a representative of the biogas industry in Denmark of answering the question - perhaps because, we as "big" are having more opportunities and muscles to deal with these kinds of issues than the smaller producers. Thus, we are likely to be the front-runner on these points as well. But no doubt the rest of the industry will follow.

So far, since our early start in 2015, we have been unilaterally focused on output from the plants, and how we get the most gas produced. Not least because the subsidy scheme is a significant part of the revenue base of a technology on an increasing maturity curve. We have also been focused on reselling the degassed biomass to the farmers as well as to additional horticulture producers etc.

Just now in December 2019, we started focusing further on the output raw material by separating some of the degassed material at one of our plants, with the aim of being able to deliver "designer" liquid manure in return to the farmers (with means a fertilizer adapted to the specific field, on which it shall be spread out).

[95]Picture reproduced with permission from Nature Energy.

[96]Mail correspondence between Nature Energy/Mette Smedegaard Hansen and Ramboll/HEKN dated 2019-12-09.

Our second major focus – not least in our storytelling - is that upgraded biogas sent into the gas grid, and thus makes us able to make use of gas storages, is the perfect mix for a fluctuating solar & wind electricity production. The gas is just ready to use, when required and can otherwise be stored in pre-existing and paid gas storages.

It has been a very important story, since just a few years ago, it was a predominant view that gas was not a part of the future fossil-free energy supply. This point of view is - thanks to biogas and Power-to-X options - fortunately turning.

The next issue we have focused on is our in-side. Here is the absolute biggest cost raw material in the form of biomasses (not agricultural biomasses, since we only borrow this material from the farmers - they get them returned in degassed condition). But industrial biomasses such as fat, glycerin products, food waste, molasses and several other residues that cannot be used for food or feed for animals.

We have not yet focused much on our energy consumption - and yet a little. Already in the design phase of the plants, it is determined that all tanks must be insulated (otherwise they are uninsulated at all others plants, considering a content that holds temperatures above 50 ° C it is really a lot of waste of heat), we have heat exchangers to use the heat from the degassed material to preheat new material, we do also look at surplus heat projects, where we are close to the district heating network and similar initiatives.

We have not yet worked specifically with our electricity consumption in the sense of adjusting consumption based on prices/grid charges, etc. Of course, we primarily buy low-consumption equipment; but to adapt our consumption of electricity for our production to the infeed of renewables production into the grid has not yet reached our focus area.

But it will certainly come into focus in the coming years. With the change in the “Act on Energy Consumption Audit” of major companies that was published a short time ago, Nature Energy will be involved and thus, we will have an energy consumption audit done by the end of 2021. So, at the latest, in this regard, it will be relevant to consider.

However, I do not know whether our plant's own consumption is so large that it will be able to change anything in the total grid load in a local area, as many processes must be operated unconcerned of electricity balancing of generation/load.”

7.3 Technology: Solid Oxide Electrolyser Cell

The technology description and data sheets for the SOEC are in “Technology Data Renewable fuels” [6] “Solid Oxide Electrolyzer cell” (3; 86).

The input is electricity, heat and water for having the reaction producing hydrogen (H_2).
“This technology has been demonstrated at a level of 50 kW during 2017 and developers expect it to be commercially available from around 2020 on a scale in the order of 300 Nm^3/h, corresponding to roughly 1 MW plant size.” [6]

The regulation ability with reference to the technology data stated [6]:
“The cells have fast regulation abilities (from 0 % to 100 % power in few seconds) if the cell temperature is kept at the operating temperature. If the SOEC is cold in idle state, the start-up time could be several hours depending on the design and fabrication of cell and stack. However, different operation and insulation strategies can be applied in the SOEC-plant to keep the plant close to operation temperature also when idle.”

Advantages/disadvantages [6], which are relevant to mention here:
Advantages include:

- High production rates, high efficiency.
- SOEC is modular technology, which allows for cost-effective manufacturing process through automated production
- The process is endothermic allowing joule heat or surplus heat from other processes to be used as energy input.
- Operation at high current densities at or above 0.8 A/cm^2.
- Possibility to produce synthesis gas including high purity CO in CO_2-electrolysis which can be used in chemical industries such as green fuel production.
- Ability for fast regulations to cope with transient variations. Possibility to operate in reverse mode as a fuel cell for grid balancing.

Disadvantages include:

- The technology has not yet been demonstrated at large scale and is not readily commercially available.
- Limited lifetime at stack level at high current densities.
- To date only available at modest capacity level (~50 kW level).”

The SOEC technology is categorised as a technology in the research and development phase.

In Example 2 part 7.4.2 the SOC4NH3 EUDP-project managed by Haldor Topsoe generates ammonia synthesis gas.

7.4 Technology: Methanol from Power

Methanol from power is a concept, which combines CO_2 with hydrogen produced by electrolysis to produce methanol. The technology description and data sheets for this technology are presented in “Technology Data Renewable fuels” [6] Methanol from Power (3; 98).

With reference to the technology data stated [6]:
“The regulation ability of the electrolysers have excellent load following capacity and can respond to large load changes within a fraction of second. The commercial natural gas methanol production process can take several days to reach operating capacity as both the natural gas reforming stage and the methanol synthesis stages operate at high temperature and pressure.
A power to methanol process won’t have the natural gas reforming stage but the methanol synthesis stage still operates at about 300 °C and 85 bar of pressure. If this stage is not operated at a continuous rate there will be significant loss of overall efficiency for the process.

Advantages/disadvantages:
With renewable power the GHG emissions for this pathway are extremely low. The technology will be limited in scale due to the supply of hydrogen and the availability of carbon dioxide.
The relatively small scale of the production systems will likely result in higher capital costs for the facilities. The methanol production process is not well suited to intermittent operation making it a poor match to wind and solar power generation without some storage capacity somewhere in the system prior to the methanol synthesis stage.

In Example 2 part 7.4.2 the E-SMR EUDP-project managed by Haldor Topsoe will produce methanol.

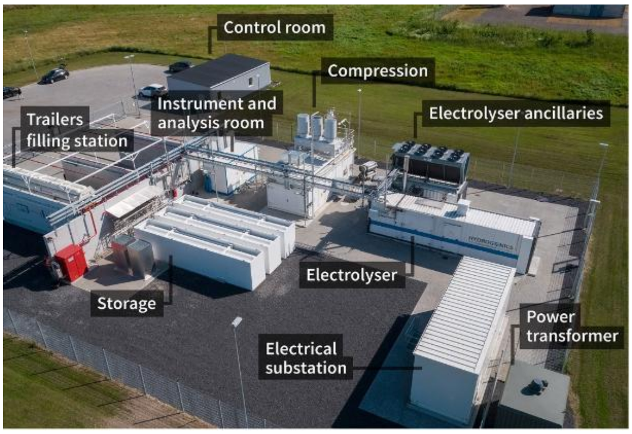
7.4.1 Example 1: Electrolysers in the electricity markets in Denmark

Centrica Energy Trading (former name Neas Energy) is the balance responsible party (BRP) for the first two MW scale electrolysers producing hydrogen in Denmark. HyBalance in Hobro is producing hydrogen for industrial purposes and the BioCat Avedøre electrolyser at the BioFos waste water treatment plant is producing hydrogen for power-to-gas (methane), which is injected into the gas grid. From Centrica Energy Trading/Lotte Holmberg Rasmussen[97]:

The electrolyser unit at the BioCat Avedøre has been approved by Energinet to participate in the DK2 FCR-N market. The unit can also participate in the spot market and the regulating power market with mFRR (aFRR is not relevant in DK2[98]). The electrolyser is an alkaline electrolyser of app. 0.6 MW. Refer to: http://biocat-project.com/

Foto: Biofos/Electrochaea

The HyBalance electrolyser in Hobro has been approved by Energinet to participate in the DK1 FCR frequency market. This unit can also participate in the spot market and the regulating power market mFRR as well as the automatic reserves aFRR. HyBalance is a PEM electrolyser of app. 1.2 MW. Refer to: www.hybalance.eu



Picture HyBalance[99]

Both the BioCat Avedøre and the HyBalance units are making bids though the Centrica Energy IT system called Neas Direct, where the plants can place bids in all the different markets and where they are informed about which bids, they have won. Signals are sent from Neas Direct to the plants when the electrolysers are to start or stop in the different markets.

As a balance responsible party Centrica Energy Trading had neither technical nor market challenges with connecting electrolysis plants or EV's, as these are flexible units like others.

[97]Reference: Mail correspondence Centrica Energy Trading/Lotte Holmberg Rasmussen and Ramboll/HEKN 2019-12-02.

[98]aFRR expected in Q3/2020 in DK2 - remark from Ramboll/HEKN.

[99] Reference for HyBalance picture: http://hybalance.eu/wp-content/uploads/2019/10/Production-of-hydrogen-from-wind.pdf

7.4.2 Example 2: Haldor Topsoe – Electrical driven hydrogen and synthesis gas generation

On Ramboll's request to Haldor Topsoe regarding their view concerning delivery of ancillary services to the grid with reference to their Power2X-projects, the following answer was received from John Boegild Hansen/Haldor Topsoe[100]:

"Haldor Topsoe has worked with electrical driven hydrogen and synthesis gas generation and its integration downstream chemical synthesis for more than a decade. The development has been brought to pilot/demonstration level in five main projects:

- eCOS[101]: Production of carbon monoxide, CO, from CO_2. This technology has been commercialised and a 680 kW unit producing 200 Nm^3/h CO is sold.
- El upgraded biogas EUDP project[102]: Upgrading of 10 Nm^3/h of raw biogas to pipeline quality gas based on a 50 kW SOEC for hydrogen production followed by a catalytic methanation unit converting the 40 % CO_2 in de-sulphurated biogas to more than 98 % methane.
- SOC4NH3 EUDP project[103]: Generating ammonia synthesis gas (3 H_2/N_2) in a 50 kW SOEC unit – shown in Figure 51 [35].
- Co-electrolysis project sponsored by Obel funding generating methanol synthesis gas ($CO/C_2/H_2$) by co-electrolysing CO_2 and steam.
- E-SMR EUDP project[104]: Using electricity to drive steam reforming of biogas plus SOEC steam electrolysis to produce methanol.

The extensive experiments carried out in the "El upgraded biogas"-project has demonstrated that the technology can deliver ancillary services to the electrical grid by being able to cut off the power supply within seconds as well as ramping up the power consumption within seconds as well. The preferred operation mode is, however, only to ramp down to 2-4 % of design load in order to keep the unit(s) hot for rapid ramping up.
It is expected that the other applications will have similar flexibility."

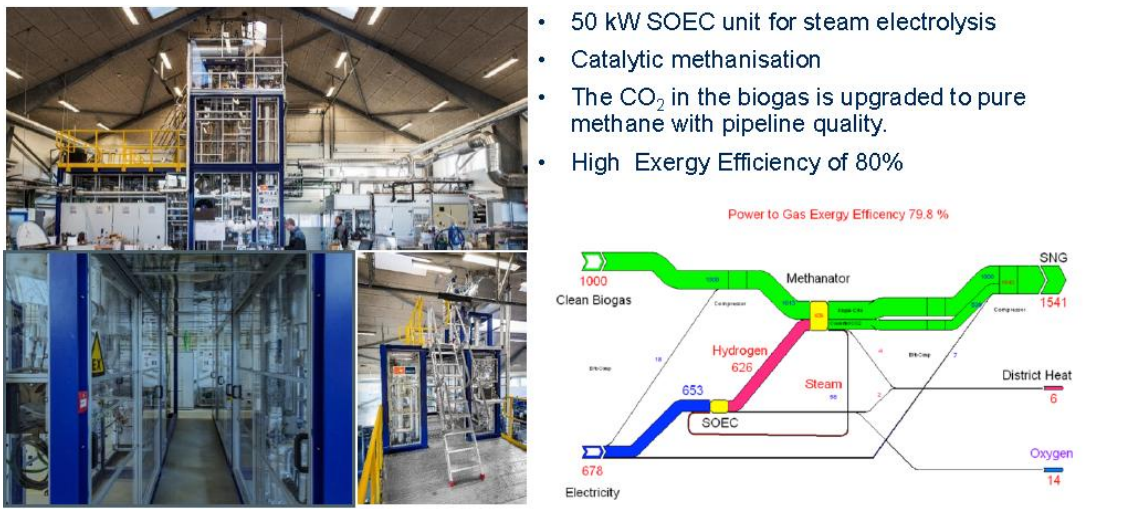


Figure 51 The biogas upgrading demonstration unit in Foulum, Denmark.[105]

[100] Mail correspondence John Boegild Hansen/Haldor Topsoe and ramboll/HEKN dated 12-12-2019.
[101] Refer to Haldor Topsoe website: https://www.topsoe.com/processes/carbon-monoxide/site-carbon-monoxide
[102] Refer to energiforskning.dk – website: https://energiforskning.dk/en/node/7155
[103] Refer to Haldor Topsoe website: https://blog.topsoe.com/ammonia-can-become-the-co2-free-fuel-of-the-future
[104] Refer to haldor Topsoe website: https://blog.topsoe.com/topsoe-to-build-demonstration-plant-to-produce-cost-competitive-co2-neutral-methanol-from-biogas-and-green-electricity
[105] Reference: https://nh3fuelassociation.org/wp-content/uploads/2017/11/NH3-Energy-2017-John-Hansen.pdf

8. NEW TECHNOLOGY – ENERGY STORAGE

8.1 Introduction

The analysis assumptions for EN from DEA 2019 issue [2] do not include the integration of electricity storage systems on a large scale.

In 2019 the Danish Energy Agency has announced that an amount of DKK 128 million has been allocated projects that develop and demonstrate new energy storage technologies on a larger scale. The amount is technology neutral and there is an application deadline on October 22nd of 2019. One of the major challenges for the energy system in the future is to integrate and utilize the increasing amount of fluctuating energy from, not least, wind and solar energy. Therefore, the Danish Energy Agency has offered the amount of DKK 128 million to contribute to the green transition as new storage technologies can increase the flexibility between energy production and consumption. The applicant's projects must contain new innovative technologies or new combinations of known technologies; the projects are expected to be significant and of considerable size. There was application deadline on October 22nd of 2019; just close to this report's deadline, the 18th December 2019, DEA announced, which of the applied projects that have been awarded. It can be assumed that this support will boost the development of energy storage systems in a larger scale – the two projects granted financial support both deal with the conversion of electricity into hydrogen[106] (Power2X).

There are today approximately 1.5 MW of stand-alone batteries and 0.5 MW of electric vehicles providing ancillary services to Energinet.[107]

[106] Refer to the DEA's Danish website: https://kefm.dk/aktuelt/nyheder/2019/dec/128-mio-kr-til-udvikling-af-groenne-braendstoffer/

[107] Reference: the_smarten_map_2018.pdf

8.2 Definitions and abbreviations

New definitions and abbreviations used in this chapter will be defined or explained below:

AEP: Annual Energy Production.

BESS: Battery Energy Storage System.

BMS: Battery Management System.

DoD: Depth of Discharge.

EMS: Energy Management System.

EV: Electrical Vehicles.

FRT: Fault-Ride-Through.

HyPP: Hybrid Power Plant.

LIB: Lithium-Ion Battery, can store electric energy as chemical energy.

Levelized Cost of Energy or LCOE: The levelized cost of energy (LCOE) is a measurement used to assess and compare alternative methods of energy production. The LCOE of an energy generating unit can be thought of as the average total cost of building and operating the asset, per unit of total electricity generated over an assumed lifetime.

PCS: Power Conversion System.

PGC: Point of Generator Connection.

PCC: Point of Common Coupling.

PCI: Point of Connection in Installation.

POC: Point of Connection; here for batteries – the point of connection of the batteries connection to the public electricity grid.

POP: Preferred Operation Point; abbreviation/notion defined by Nuvve/DTU during development of the system for delivering frequency reserve from electrical vehicles.

SoC: Battery's State of Charge.

STATCOM: A Static Synchronous Compensator (or static synchronous condenser) can continuously provide variable reactive power in response to voltage variations, supporting the stability of the grid with a fast response time. Technology for STATCOM's are based on Voltage-Source Converter (VSC) solutions.

TMS: Thermal Management System.

VRB: Vanadium Redox flow Battery.

VRLA: Valve-regulated lead-acid battery.

8.3 Technology: Battery Energy Storage Systems (BESS)

Due to their technical capabilities, Battery Energy Storage Systems (BESS) stand out among the various technologies currently available for the provision of Fast Frequency Reserve (FFR and FCR) and voltage support. BESS is regarded to be a technology, which can be integrated or already is approved by EN as supplier in reserve power and balance energy markets framework.

8.3.1 General Technology Data for batteries

The technology description and data information for batteries, LIB (4; 180), VRB (4; 181), Na-S (4; 182) and Na-$NiCl_2$ (4; 183) types of batteries, are given in "Technology Data for Energy Storage" [6].

The advantages/disadvantages high-lighted for batteries in comparison to other technologies for energy storage are:

Advantages	Disadvantages
Short response time	
Flexible installation size	Relatively short lifetime[108]
High energy efficiency	
Versatile application	Large investment cost
Relatively compact	
Low maintenance	

Table 4 Advantages/disadvantages high-lighted for batteries in catalogue "Energy Storage" [6].

The schematic configuration and grid connection over-view for BESS is shown in Figure 52.

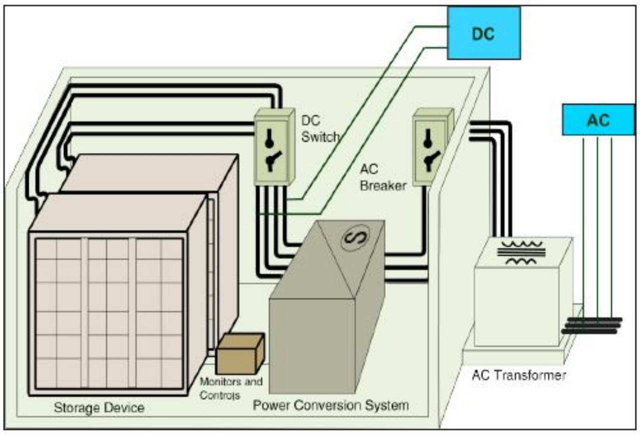


Figure 52 Schematic detailed layout of a Battery Energy Storage System (BESS)[109]

[108] Although some batteries have lifetimes as long as 20 years, battery lifetimes in general are shorter than Pumped Hydro Storage and Compressed Air Energy Storage.

[109] Source reference [36]: Sandia National Laboratories; as shown in "Electricity Storage Handbook in Collaboration with NRECA", download website: https://prod-ng.sandia.gov/techlib-noauth/access-control.cgi/2015/151002.pdf

Terms and conditions for grid connection of an electrical energy storage in Denmark must be according to “Technical regulation 3.3.1” [37] – the electrical energy storage grid code; which is currently in an update and public consultation phase, planned for release 18. December 2019. Examples of layouts and definitions of connection points are as shown in Figure 53 and Figure 54 below.

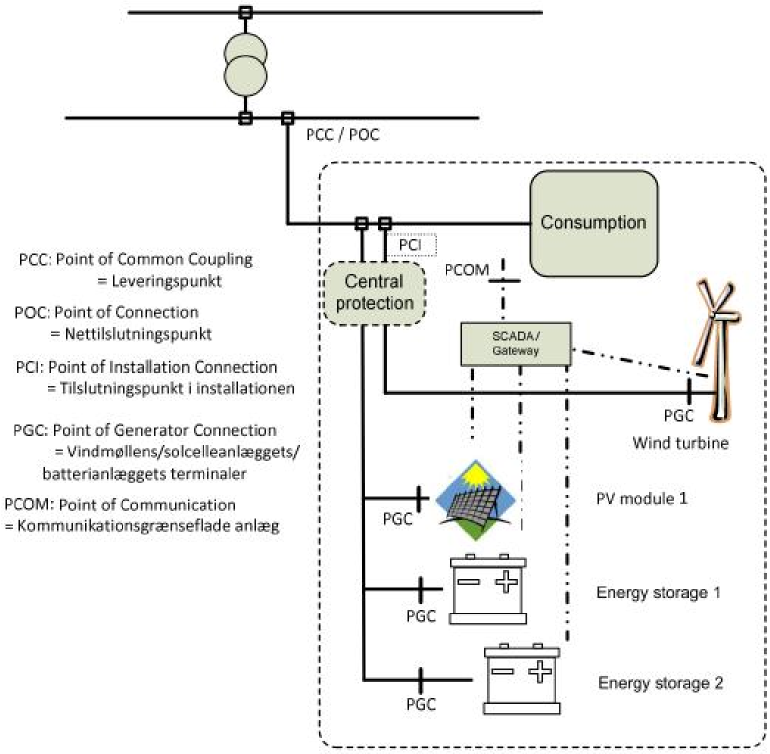


Figure 53 Example of installation connection of stand-alone energy storage batteries (PCC and POC is coincident)[110]

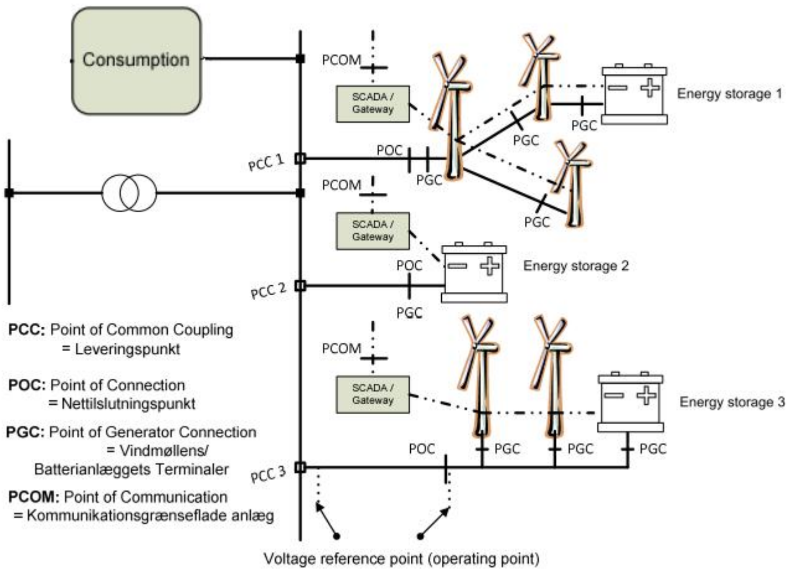


Figure 54 Example of grid connection of a stand-alone energy storage system (BESS) and energy storage system. as part wind power plants.[111]

[110]Source for Figure 53 is Technical regulation 3.3.1 [37].
[111]Source for Figure 53 is Technical regulation 3.3.1 [37]; modified with English text for “Consumption”.

8.3.2 Regulation ability BESS

Highlights from the "Technology Data for Energy Storage" [6] regarding regulation ability for LIB is: "Grid-connected LIB's can absorb and release electrical energy fast. The response time of grid-connected LIBs are strongly dependent on control components, EMS, BMS and TMS as well as the power conversion system (PCS). Applications are:

- Peak load shaving, where the BESS provides or receives energy to reduce peaking in the power system.
- Promote renewable integration with load shifting of photovoltaic power from day to night
- The BESS can provide transmission congestion relief, where locally deployed BESS reduces the load in the transmission and distribution system. In this way the BESS can help defer expensive upgrades of the transmission and distribution network.
- The fast response time enables the use of BESS for a broad range of primary control provisions.
- Today, frequency regulation is the main application of stationary BESS systems deployed worldwide.
- The BESS can also be used to improve network reliability by reacting immediately after a contingency. Here the BESS can help maintaining stability in the power system until the operator has re-dispatched generation.
- The BESS can effectively be used for black-starting distribution grids and LIB-BESS systems are suitable for enhancing the power quality and reducing voltage deviations in distribution networks.
- BESS can be used to provide spinning reserves and regulate active and reactive power thereby improving the network voltage profile. This can improve the integration of renewable energy.

In the following sections these highlights will be further elaborated regarding frequency reserve provision, voltage regulation and reactive power control.

8.3.2.1 Dynamic frequency reserve provision from BESS

BESS can offer dynamic frequency response as required by the "Ancillary services to be delivered in Denmark tender conditions" for all timescales required. The level of response, which is available depends on the size of the battery (storage MWh), the battery state of charge (SoC) and the rating of the power electronics (capacity MW). The capability for BESS is detailed below:

Delivery of primary reserves (FCR, FCR-N, FCR-D):
BESS can respond to a frequency change very quickly, within milliseconds and can ramp from 0 MW to full load in that time, much fast than the requirements set out in the "Ancillary services to be delivered in Denmark tender conditions" [12].

Delivery of secondary frequency control reserves (aFRR):
BESS can offer this reserve product but may be limited by the storage available in the battery, but large units will be able to offer this secondary reserve product as required by the "Ancillary services to be delivered in Denmark tender conditions" [12].

Delivery of tertiary frequency control reserves (mFRR):
Like the secondary reserve BESS can offer this reserve product but may be limited by the storage available in the battery, but large units will be able to offer this tertiary reserve product as required by the "Ancillary services to be delivered in Denmark tender conditions" [12].

Delivery of Fast Frequency Reserve (FFR):
In UK the Firm Frequency Reserve response has been used as type of reserve to replace inertia on the system.

Advantages/disadvantages in the frequency reserve market:
The major benefit of the BESS in the frequency reserve market is the speed at which they can operate, and the major disadvantage is the limit of the battery storage that is available, hence it can be seen that the BESS are best suited to operate in the FCR and future expected FFR markets, where their speed of operation is an advantage.

The strong fluctuation of the frequency in the Nordic synchronous area, which results in a high number of activations of FCR-N as well as provision of response energy, will cause the BESS to be exposed by many cycles and rapid changes in SoC, these operation conditions could potentially result in severe battery degradation, stated within [38]. The high demand of response energy could also deplete the battery, which could cause the battery to be unavailable several days a year. FCR-D shows the lowest response energy turnover in the Nordic synchronous system, which means the battery here will only complete few full-cycles per year. Regarding delivery of FFR the conclusion is that the envelope and power tolerance experienced for delivery of EFR (Enhanced Frequency Response) and FFR in UK (in UK “FFR” means Firm Frequency Reserve) are found to provide the greatest flexibility of the dynamically utilized degree of freedom to support SoC maintenance – hence, similar approaches could be beneficial for BESS providing FFR in other countries.

Highlights from the conclusion of the paper [38] are:
“The different conditions of the power systems from the selected countries (Germany, Great Britain and Sweden) increase complexity when considering BESS as FCR providers. Firstly, FCR products are fundamentally coupled with the frequency of each synchronized system and must be assessed accordingly. Secondly, since technical requirements are generally still focused on conventional providers, there is regulatory leeway, which provides flexibility when choosing an operation strategy. And thirdly, the diverse settlement regulation leads to other markets and processes, which are also unclear regarding applicability of BESS.
Integrating BESS as fast-responding control reserves is central to support power system stability in power systems with increasing shares of variable generation and decreasing inertia. Therefore, the regulatory framework must be revised to ease the introduction of BESS as FCR providers or in other fast-responding frequency regulation services, so that they rely not on regulatory leeway, but can instead take advantage of specifically designed regulation to improve their business case.”

8.3.2.2 Delivery of voltage support and reactive power from BESS

BESS are connected to the grid with power electronics, which offer the benefit of being able to offer reactive support even when the BESS is not producing or absorbing real power (MW) and because the power electronics have the ability of operating as a STATCOM, the reactive power available from the devices is greater at low load and no-load conditions.

The BESS can operate in the following mode:

1. Voltage Support Mode

The BESS can operate in voltage support mode and this will control the voltage at the point of connection to the grid. When operating in this mode, the BESS voltage control is in droop control mode. If the droop setting is 4 %, the reactive output will change unity power factor to full load reactive capability, if there is a 4 % change in system voltage at the point of connection. The speed of operation of the BESS is extremely fast (ms) as the operation is through power electronics. This would be the normal operating mode when connected to the transmission system.

2. Reactive Power Mode

In this mode the reactive output from the BESS is fixed at an agreed reactive output value but will not respond to a voltage variation. This mode of operation is not normally used in transmission systems, but it is a common mode of operation in distribution networks.

3. Power Factor Mode

In this mode the reactive output from the BESS is fixed at an agreed power factor value but will not respond to a voltage variation. This mode of operation is not normally used in transmission systems but is a common mode of operation in distribution networks.

The advantages of BESS for ancillary services agreements regarding voltage support are:

- Their ability to offer fast dynamic reactive power as required in support of the system voltage.
- They have a good reliability.
- They can offer reactive support even when the unit is not supplying active power.
- Control the system voltage with a droop setting, which can be adjusted in agreement with the system operator.
- Can operate in the voltage support mode and frequency support mode at the same time.

8.3.2.3 Technical challenges from BESS

Besides all the good technical potentials from BESS regarding fast response to frequency change, excellent voltage regulation and reactive power support, there are a few technical challenges regarding BESS integration in the grid:

- Power electronics produce harmonics in the grid and may have to be ameliorated using power quality filters.
- BESS may have issues with Fault-Ride-Through (FRT) regarding a solid fault and the requirements must be checked to confirm the grid code compliance.
- BESS units do not produce large amounts of electrical current at the time of a solid fault in the grid system, and this characteristic may result in the fault level of the system being reduced. This issue could cause problems with the operation of circuit protection.
- BESS will not be able to respond as expected if a frequency event is caused by fault on the transmission system (for example a busbar fault which trips a generator). The reserve from the BESS will be delivered slower than expected.

8.3.3 Example 1: BESS installed as part of the EnergyLab Nordhavn

The main data for the BESS delivered by ABB and installed in Nordhavn, Copenhagen are:

- Output: 630 kW
- Energi: 460 kWh
- Technology: Li-Ion
- Capacity to provide 200 apartments with electricity for 24 hours
- Commissioned: January 2017

A master thesis written by Camilla Lund, published June 2017, with the title: "Techno-economic analysis of operational strategies for a battery energy storage system installed in Nordhavn"[112] [39], describes and discuss a number of main subjects of application of BESS, the master thesis was submitted before the battery in Energylab Nordhavn was commissioned.

After installation and evaluation of test and performance of Energy Nordhavn BESS installation, the results and conclusions were drawn in the status report: "Delivery no.: D6.3.4 + D6.3.7 Results on Radius Elnet usage of Battery" issued 23-10-2019 of the Energylab Nordhavn WPL Group. This status report [40] will be used to highlight their gained experiences.

Below in Figure 55 is shown a schematic electrical lay-out of the BESS installed in Nordhavn.

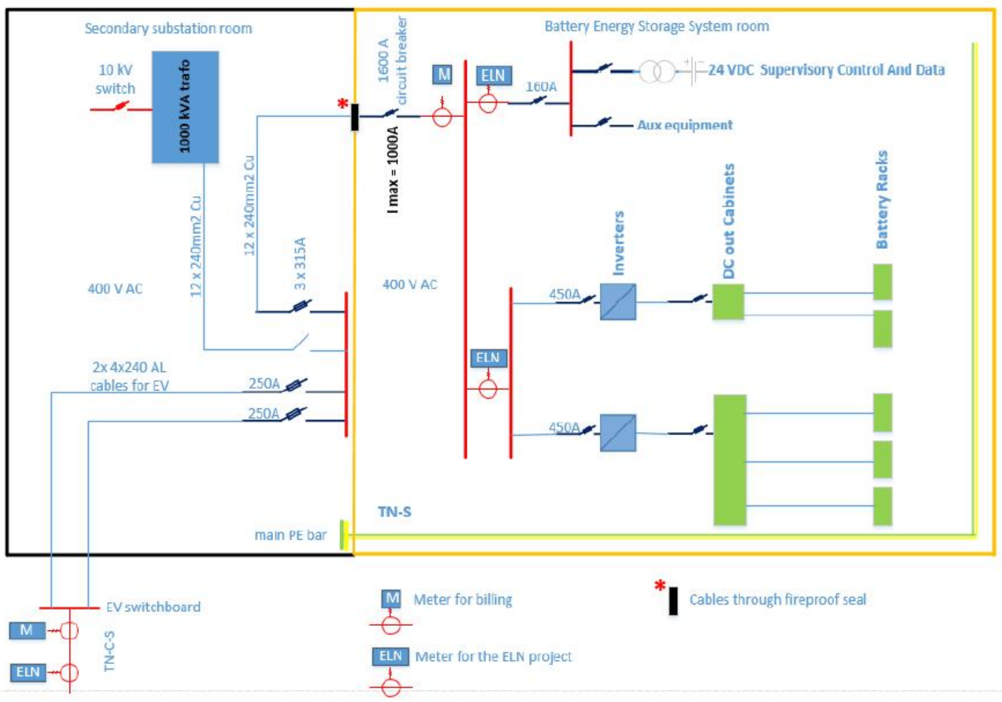


Figure 55 Schematic lay-out of the grid connection of the BESS of EnergyLab Nordhavn[113]

The main purpose of installing the BESS was for peak shaving, but it was also intended to be used delivering ancillary services to the reserve markets. The status report gives some results and conclusions to be highlighted:

[112]Reference [39]: http://www.energylabnordhavn.com/phd-and-master-theses.html

[113]Reference [40] the origin of Figure 55 is: Figure 23 page 40 of status report, which can be downloaded from the website: http://www.energylabnordhavn.com/uploads/3/9/5/5/39555879/d6.3.4_and_d.6.3.7_results_on_radius_elnet_usage_of_battery.pdf

- From a DSO point of view, the investment in batteries could provide a cost-effective solution/alternative to upgrading a distribution network feeder or temporary postpone the investments of establishing a new feeder if peak shaving services from a battery could be provided. The upgrading of an existing feeder with higher rating of the circuit-breaker, adjustments of protection, signals implementation and larger cross-section of the existing cable, if even possible due to main station layout and busbar rating, could be postponed especially if there are uncertainties regarding the sizing of the final load from the new consumer(s) - or if the demand of the feeder only gives peak loads during a day or season. Peak shavings are perhaps only needed in a very short time span over the year and a very short part of the day, which argues for, that the battery also could be used providing frequency regulation, voltage support, retail electricity energy time-shift and stabilisation of power and distribution quality, as stated in [40] page 10-11 and in part 4. The design criteria for provision of peak saving services from an owner of a BESS at a specific location must be handled very carefully in forecasting and design, as failures in delivery can have large consequences to the DSO if missing security of supply. The peak savings design criteria will not be further described here as the focus in this report is on delivery of ancillary services.
- Before investing in a Battery Energy Storage System (BESS), it is necessary to analyse the possible value-streams at different sizes of a battery systems, as batteries can supply several different services, dependent on the size of the battery. Therefore, it is important to assess, which products provide the highest positive value-stream, when choosing size both in terms of kW and kWh – more detailed advices regarding battery dimensioning are given in reference [40] page 12-16 – example: Considering to deliver FCR-D, which usually have a relatively low energy consumption (kWh), but a high, short term demand of power delivery (kW), one should consider increasing the power capacity (kW) of the battery. This requires mainly that the inverter must be specified with a higher DC/AC capacity. On the other hand, delivering FCR-D in case of a large disturbance, the battery must deliver full capacity (kW) for up to 15 min, which could require a significant amount of energy from the battery depending on the bid size. The sizing of the battery/inverter-system must be considered precise which services to deliver. The commissioning tests of FCR-D functionality tests of the BESS at Nordhavn acc. to EN's requirements were met.
- FCR-N reserve delivery was considered for the BESS in Nordhavn, but not implemented, [40] page 22-24 nevertheless, some considerations are given as the availability payment for FCR-N on average is 3-4 times higher than for FCR-D, but as FCR-N is continuously active in the frequency range 49.9 – 50.1 Hz, it will demand that the battery should both be able to produce and consume power, the SoC of the battery should start at approximately 50 % at every period of delivery and there could be a risk for that the bid size anyhow could empty the battery in short time. Forecasting of the charging and discharging pattern of the battery due to the frequency variation in the Nordic synchronous area was evaluated to be impossible. The charging strategy is further mentioned in part 3.4 – time-based or price-based charging can be performed. The bidding strategy for FCR-N was then considered only to submit bids every other hour; but this is not allowed acc. to the EN rules stated rules.
- The battery management system controlling the BESS to keep all functions running at a high safety level were programmed into the main RTU of the supplier ABB. A local screen gives detailed information from each battery cell. The BESS can be controlled on site and remotely. Applications can be controlled via web HMI from office PC with the proper access.
- Communication system setup communicates with Radius control room, Radius office pc, DTU MicroSCADA, the BSP Markedskraft MK Planner and the TSO Energinet. The Figure 56

shows the communication setup. Some minor problems showed up during commissioning using wireless GPRS communication, the problem were solved changing to ADSL.

- Part 7 and 8 of the status reporting are dedicated "The economics of the Nordhavn battery" – and "Wider economic perspectives of the batterries in the grid" – readers of this report are kindly referred to the source [40]. A commercial owner of a BESS must establish and connect the battery to the grid as any other customer that needs connection to the distribution grid or transmission grid.
- In the EnergyLab Nordhavn project the DSO, Radius Elnet, established the BESS. The Danish Electricity Act [1] (in Danish "Elforsyningsloven") do not restrict the DSO to own a BESS; but it is assigned that the DSO cannot own a battery with the primary purpose of peak shaving – and it is questionable whether the law support that the DSO is involved providing ancillary services under the applicable legislation Directive (EU) 2019/944, Article 36: "Distribution system operators shall not own, develop, manage or operate energy storage facilities." The fact is that: "Storage services should be traded in competitive markets as flexibility products that provide a market value reflecting the system benefits of storage. Owners of storage facilities should be independent from the grid operators, apart from clearly defined exceptions.

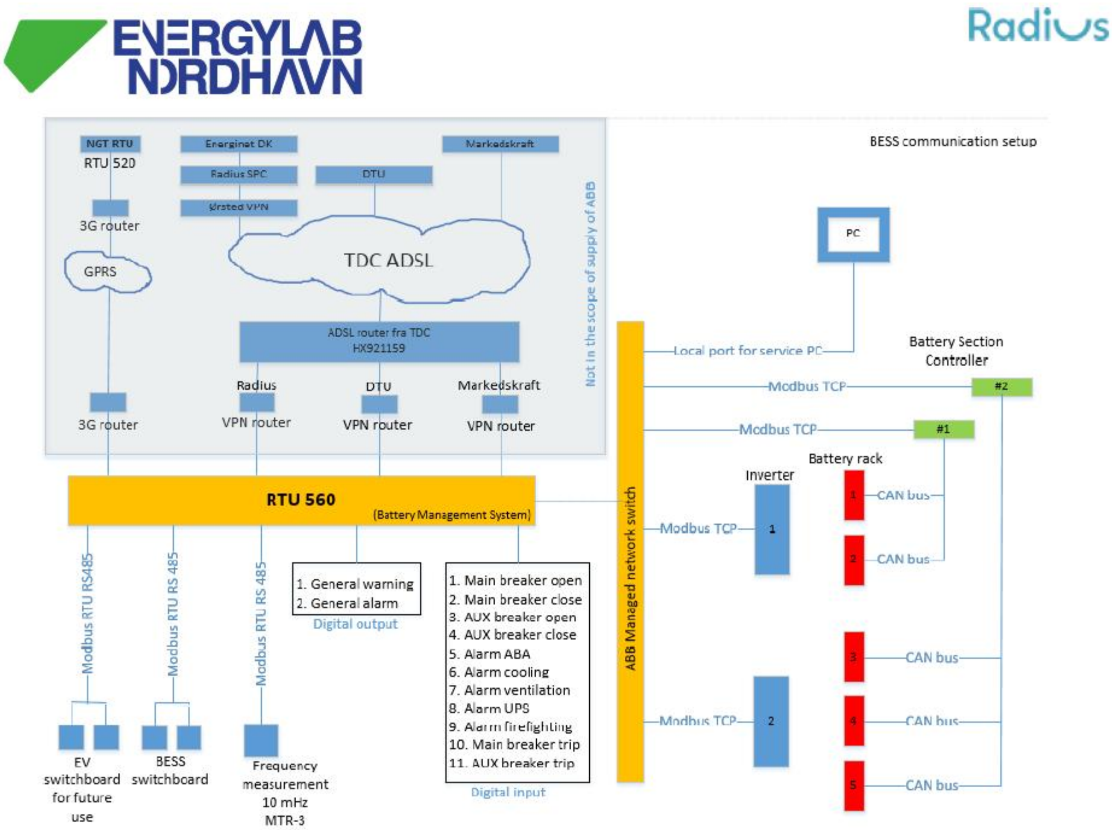


Figure 56 Sketch of the communication setup[114]

[114]Reference [40] the origin of Figure 56 is: Figure 25 page 44 of status report, which can be downloaded from the website: http://www.energylabnordhavn.com/uploads/3/9/5/5/39555879/d6.3.4_and_d.6.3.7_results_on_radius_elnet_usage_of_battery.pdf

8.3.4 Example 2: Automotive Battery Systems – Electrical Vehicles (EV)

Two different companies in Denmark True Energy ApS and Nuvve Corporation have made a business concept delivering FCR-N frequency reserves bases on the aggregation of charging/ discharging of several batteries of EV's through bidirectional charging stations for vehicles.

The concept from each of companies will in short be described as Example 2A and Example 2B.

Example 2A: True Energy ApS – Aggregation of EV batteries
The concept for delivering FCR-N aggregating the charging/discharging of electrical vehicles from True Energy, as approved by EN, consists of a description of the concept for aggregation and the communication. True Energy has developed an app controlling the charging of EV's. The owner of the EV connects the car to this app and specify at what time the car must be charged, maximum charging state of the car and more data needed for True Energy's Energy Management Server system (EMS) ensures subsequent to charge the car battery at the desired time setting during the day or typically during the night, where the power is cheapest and most climate-friendly.

With the app installed it is possible for True Energy to switch on and off the charging of the owners EV battery. Connected to many cars at the same time the summary of the power can be used for upwards or downwards frequency regulation.

True Energy manages due to historical data and forecast calculation algorithms to predict the amount of power available to contribute to the regulation market - including a safety margin to ensure having access to the energy (kWh) offered. True Energy operates with Energi Danmark as BRP. When confirmed to True Energy that their bid is chosen the frequency regulation is performed – in Figure 57 – the concept is shown.

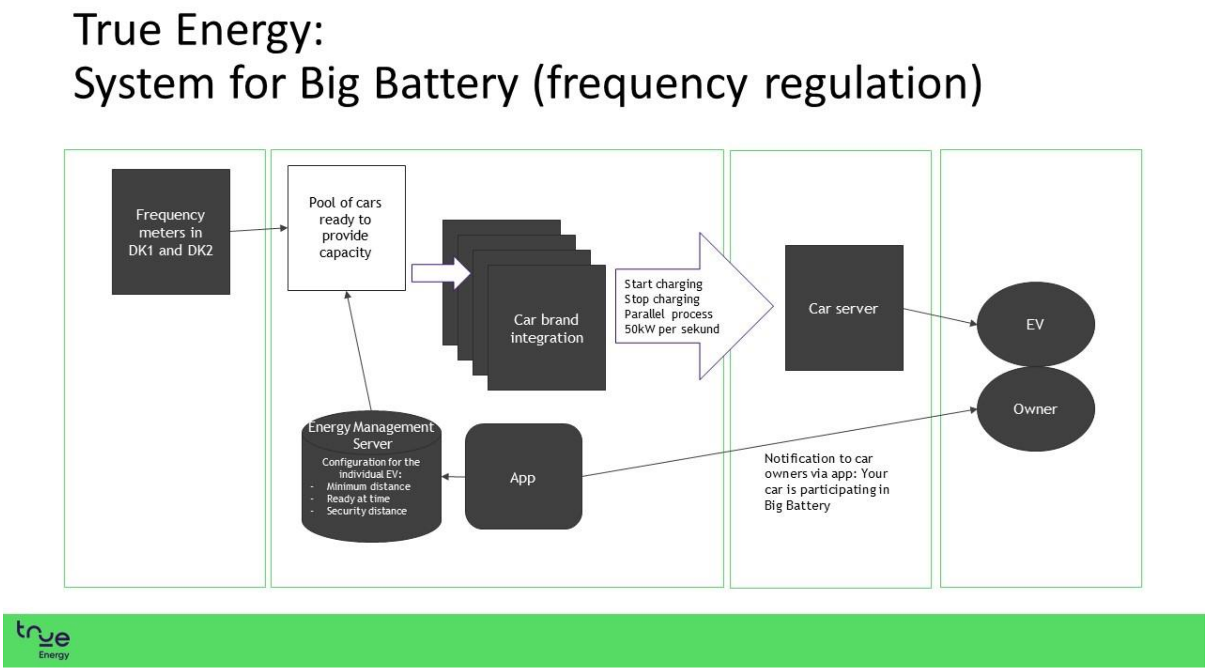


Figure 57 Aggregation of EV battery power for frequency regulation as performed by True Energy.[115]

[115]Figure 57 is reproduced with permission from True Energy Aps.

Based on the frequency measurement the reserve from the EV's can be activated when the limits (49.9 Hz < f < 50.1 Hz) for delivering FCR-N are reached. When the EMS receives signal for up- or downward regulation, the system already knows the cars to have signal for switching on or off. The activation of the reserves follows the pattern:

- When the activation period starts, several EV's corresponding to the offered reserve will start charging.
- If the frequency drops, (part of) the EV's charging are turned off until the frequency again is measured to be within the acceptable range.
- If the frequency increases, more EV's are turned on for charging until the frequency again is measured to be within the acceptable range.

A real-time overview of the activation can be followed on a dashboard.

All events are logged for each EV including the charging start and stop times in the EMS system. These data can be aggregated into aggregate data for the entire reserve's activation and forwarded to EN if needed for documentation.

Challenges connected with the establishment delivering FCR-N in DK2 input from True Energy[116]:
On the technical side True Energy's challenges included:

- "Getting responses from the EV's and servers, that were fast enough to provide frequency regulation within the time limits of the specific services True Energy delivers (FCR and FCR-N)
- The development of algorithms, that included the users' needs and behaviours, the demands from the TSO and the varieties of the EV's – and still produce a solid output (= frequency regulation) every time."

On the market side True Energy's challenges included:

- "Having enough EV's under management in order to be able to bid the minimum capacity."

True Energy's suggestions - What would make it even better than today:

- "Asymmetric regulation is much better for True Energy hence our services would benefit from new services being traded for DK2 (like asymmetric FCR).
- In DK2 we are paid as bid. Getting paid the maximum bid, as in DK1, would make it easier for us to bid in DK2 – so if Energinet wants to support the development of (new) services instead of trading skills, then more services should be paid as in DK1."

[116]Mail correspondence Charlotte Blou Sand/ True Energy ApS dated 2019-11-27.

Example 2B: Nuvve Corporation – Aggregation of EV batteries
Stated by Nuvve: "The concept from Nuvve Corporation designated Vehicle-to-Grid (V2G) bridges the gap between renewable energy and storage. The V2G chargers enables a two-way flow of electricity between V2G ready EV's and grid. Vehicle owners can charge their EV from the V2G chargers and the grid can benefit from the energy storage of the vehicle. The control is handled by Nuvve's GIVe™ platform based on parameters (from users, the building, the car, the grid, DSO's, TSO's, pricing etc.)."

Charging and storing energy at times where the price of electricity has low rates, selling energy back at peak rates or delivering ancillary service to the grid, when the battery has capacity are some of the services provided by the V2G technology. In Denmark Nuvve is approved by EN delivering FCR-N in DK2 and will at the same time provide "Time-of-Use" and tariff savings services to the EV owners.

The Nuvve GIVe™ platform aggregates and enables the control of the EV batteries that can match the frequency fluctuation for delivering FCR-N to the grid trigged by the input activation signal given from the frequency measurement from the grid – illustration as shown in Figure 58.

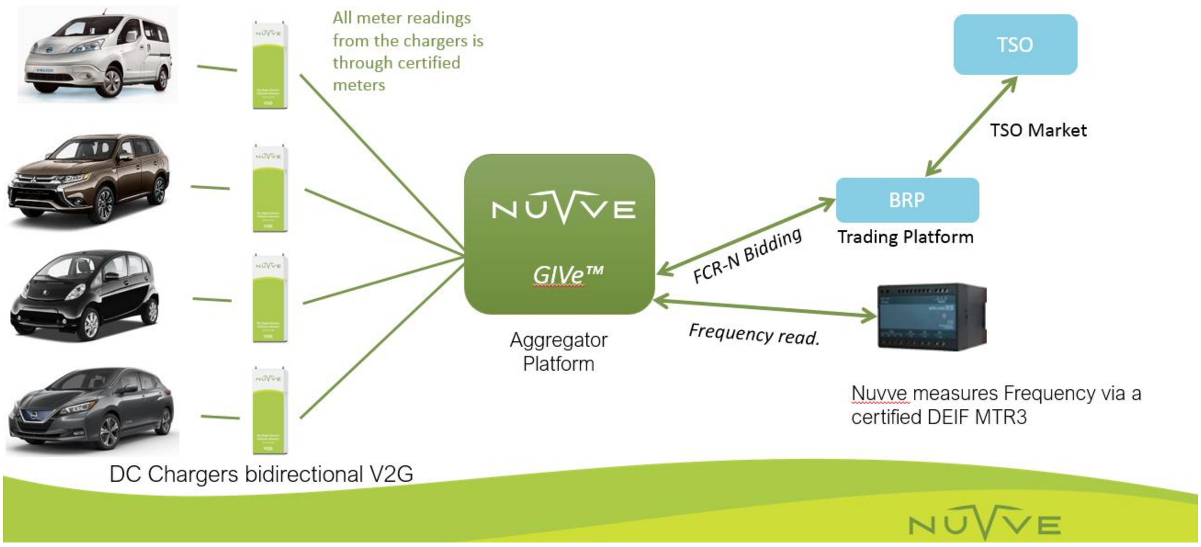


Figure 58 Aggregation of EV battery power for frequency regulation as performed by Nuvve.[117]

The GIVe™ platform controls the following services in Denmark:

- Frequency regulation requirements
- Time of charging with variable prices
- Demand for charging of the vehicles

The EV's, which are prepared for V2G, are the following makes and types:

- Nissan LEAF (2014MY and newer)
- Nissan e-NV200
- Mitsubishi iMieV
- Mitsubishi Outlander PHEV

For the owners of the EV's having reduced prices and income from delivering FCR-N, they need to tune their behaviour to plug in their vehicles as soon as they are parked by a charger station,

[117] Figure 58 is reproduced with permission from Nuvve Corporation Denmark.

rather than wait until their vehicles' batteries need to be recharged. The real-time response of a frequency regulation in the Nordic area – delivery of FCR-N – is shown in Figure 59.

Figure 59 FCR-N real-time response from EV provided reserve delivery.[118]

For the EV owners, using Nuvve V2G, reduced cost is not the only advantage. Fleet management options are available in a full overview and control platform. An additional free smartphone app let the fleet manager, or the user decide when the car must be charged or even fast charged (like emergency charging).

Challenges connected with the establishment delivering FCR-N in DK2 input from Nuvve[119]:
On the market side Nuvve's challenges included:
"V2G offers a radical change of turning the consumption (load) of EV's for the grid into an asset:

- The EV as an asset opens a number of opportunities for the grid companies (DSO's) and the TSO to gain flexibility and significant savings
- However, there are some challenges to get there:
    - Tariffs are paid twice, when the EV is performing services for the grid. This problem has to be eliminated and that can be done implementing a tariff-neutral re-export of power to the grid (a rather simple exercise on the technical side).
    - Since the V2G chargers has not yet reached mainstream and mass production they are expensive. To expand the infrastructure of V2G chargers an amount must be dedicated for V2G chargers and support for V2G ready vehicles for fleet owners across the country. We are happy to assist in calculating the needed amount.
    - Information of V2G technology is needed. Support to raise the awareness level is needed in terms of campaigns and education for the main markets."

[118] Figure 59 is reproduced with permission from Nuvve Corporation Denmark.
[119] Mail correspondence Mogens Løkke/True Energy ApS dated 2019-11-27.

8.3.4.1 EV charging infrastructure – eurelectric input

In a paper eurelectric[120] [41] writes their views on "EV charging infrastructure: Myths and reality".
In this paper the answers on some claims (as eurelectric designates as myths) among other the following four out of five myths are reproduced here:

"Myth #1: Electric vehicles use dirty electricity from coal. Switching to an electric vehicle will just mean that a similar amount of pollution comes from the electricity generation rather than from the tailpipe of my car."
eurelectric's short answer to this is: "58% of electricity generation across the EU is already carbon neutral. It is also possible in most Member States to choose charging points, which use renewable electricity. 93% of the EU population has the option of using 100% renewable electricity to charge their vehicle."

"Myth #2: Mass switch to electric vehicles will make the electricity grid collapse. Investments to make this grid stable would be way too expensive."
eurelectric's short answer to this is: "As the share of electric vehicles grows, it is possible to significantly limit the additional investments required in electricity distribution grids thanks to smart charging. Cars are parked 95 % of the time, which gives quite some flexibility, and EV batteries can be used to help stabilise the grid while their owners are remunerated for this service. That is a win-win!"

"Myth #3: We are still facing a chicken or the egg debate. The charging infrastructure must be built before people adopt EVs."
eurelectric's short answer to this is: "There is no chicken and egg debate any longer. The charging infrastructure is already developed and available in countries where the EV market develops fast. At the end of 2018, there were 150,000 publicly available charging points across Europe.[121] Looking at EV customer behaviour, we see that early adopters rely largely on home and office charging[122]. This trend will continue in the future, as we expect that 85 % of charging will happen at work place and at home as millions of EV's hit the roads in the next decades."

"Myth #4: Charging an electric vehicle takes too long."
eurelectric's short answer to this is: "EV charging speeds depend on the performance of the charging unit and on the capacity of the battery. While faster charging power (at 150 kW and higher) is becoming increasingly available, the number of vehicle models suited for those speeds is still limited."

eurelectic also gives their "evidence" for their views and answers in [41], which can be read in this paper.

8.3.4.2 Summary and conclusion aggregation EV's delivery of FCR

With these input from eurelectric in mind among others, research and development of EV's with batteries and the systems already developed acc. to the two descriptions of solutions using EV delivering FCR-N ancillary service in Denmark – in no doubt there will be a future technical potential of delivering frequency reserves from aggregation of the charging/discharging of electrical vehicles.

[120] eurelectric is: The Union of the Electricity Industry
[121] https://www.eafo.eu/
[122] https://www.eurelectric.org/media/1925/20032015_paper_on_smart_charging_of_electric_vehicles_finalpsf-2015-2301-0001-01-e.pdf

8.3.5 Example 3: UPS-Systems with battery back-up

Attention has during the last couple of years been turned to flexible consumption and the topic of demand response has been addressed in scientific publications and pilot projects have been performed using UPS-systems with battery back-up participating in frequency regulation performance, delivering different types of reserves (FCR-D in this example).

The main questions to be answered are[123] [42]: Can the owners[124] (Data centres in this paper) of UPS-systems with battery systems deliver frequency response in an economically feasible way without significant risks to their primary business, and how much additional stress would be exerted on the batteries during these grid support operations?
The authors of [42] has in this paper outlined their aim to “to bridge the knowledge gap by providing a technically and economically feasible method for data centres participation in primary frequency regulation services with the batteries of UPS systems.”

The following mentioned parts of this paper’s draw some input and conclusions to be highlighted here:

- Part 2: Literature review. The results of a comprehensive literature review study are the conclusion: “There is a significant knowledge gap in the scientific literature concerning primary frequency regulation enabled by data center hardware, such as UPS systems and their batteries.”
- Part 3: Primary frequency regulation. “The currently dominant battery technology (lead-acid based batteries) in data centres is not technically capable of providing normal reserve (FCR-N) operations because of the cycle-life limitations and intolerance to operate at a partial state of charge.”
- Part 5: Different ways of using data center UPSs for primary regulation.
  - Islanding
  - Dynamic upwards regulation
  - Potential market income of different data center topologies and participation methods

Islanding: “The most straightforward way for a data center to participate in primary frequency regulation is to install a frequency-controlled breaker after the grid connection point. If the frequency goes below a set threshold, the breaker will open and the UPSs will feed energy to the critical loads until the on-site generators (genset) have had sufficient time to start.
The grid will see an upwards regulating effect, of the size of the power consumption of the critical loads, as they no longer get their power from the grid, but from on-site systems. In this case, the functionality of the power protection systems is the same as during a grid outage event. The Figure 60 illustrates the concept and the related energy flows. Doing this would allow the data center to participate in upwards regulation as a step-activated reserve.
Most, if not all, data centers currently participating in grid support activities apply this method. Some use a physical breaker in the critical power path, others take an activation signal from a frequency relay and use that information as a trigger for automation systems to perform the similar operation.”

[123] Reference [42] ELSEVIER Applied energy 229 (2018) 69-79 article: “Data centers as a source of dynamic flexibility in smart grids”.
[124] This reference [42] focus on “a data center” as the plant; but the UPS installation could be any other UPS secured plant, industrial load or consumer, which of security reasons have UPS.

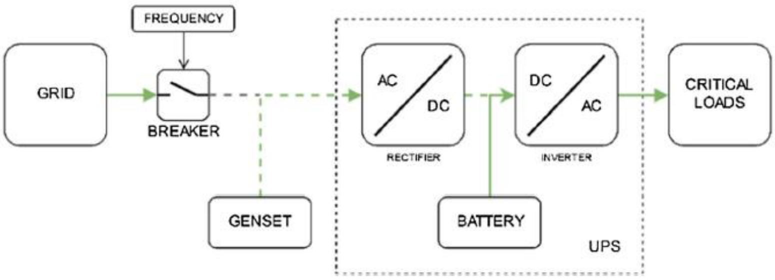


Figure 60 Off-grid or islanding demand response power system configuration and the related power flows.[125]

The dynamic upward regulation:
"In dynamic upwards regulation, the UPS system would be used to modulate the power consumption from the grid with the help of a battery system. In case of a frequency disturbance, the UPS system will discharge energy from the battery system. Depending on the current power requirement of the critical loads and the regulation need, this discharged energy will be either consumed fully by the on-site loads or, if the regulation need exceeds the power consumption of the loads, power will be fed back to the grid. The UPS system has to be compatible with the functionality; mainly the rectifier has to be able to perform two-way operations to enable feeding back power to the grid. In case of a longer disturbance, the on-site back-up generators could be used to provide additional energy if the battery state of charge level is approaching the state of charge (SoC) level allocated for ancillary services. Figure 61 illustrates the concept and the related energy flows. The main difference from data center islanding is that in this approach the regulation power is not limited to the load power, but full UPS capacity can be utilized."

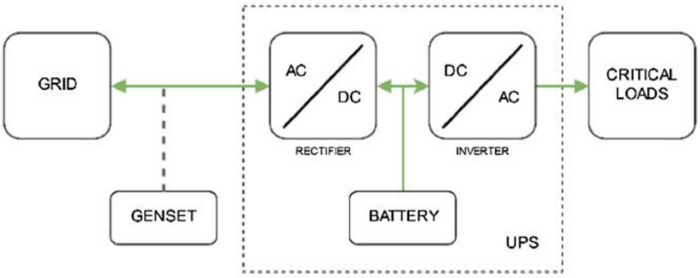


Figure 61 Dynamic upwards regulation configuration and the related power flow.[126]

Potential market income of different data centre topologies and participation methods:
"The level of revenue that primary regulation could provide for data centres and how the revenue depends on the UPS topology i.e. the level of redundancy" is also illustrated in the paper, but this report does not address this issue, refer to reference [42] page 73-74.

- Part 6: Technical feasibility and reaction speed considerations. An example is given here presenting the measurement results from FCR-D prequalification measurement performed acc. to the Nordic area specifications: "The test signal (the orange line in Figure 62) was a series of frequency steps first going down from 49.90 Hz with 0.05 Hz steps, and once the frequency reached 49.50 Hz, upwards frequency steps of 0.05 Hz were issued until 49.90 Hz was reached. The blue line in the figure shows the UPS response, which is in compliance with the FCR-D activation requirements. It should be noted that the UPS was not connected to loads during the test, and thus, all the power was fed back to the grid." More detail reaction speed test of a 200 kW 96Pm UPS by Eaton is also reported in this part of the paper [42] page 74-75, the result of the measurements

[125] Figure 60 is in the reference article [42] numbered as Fig. 2.
[126] Figure 61 is in the reference article [42] numbered as Fig. 3.

showed that “it takes two to three cycles (50 Hz) for the UPS input to fully stabilize, but the UPS is outputting energy well within one cycle from the issuance of the command.”

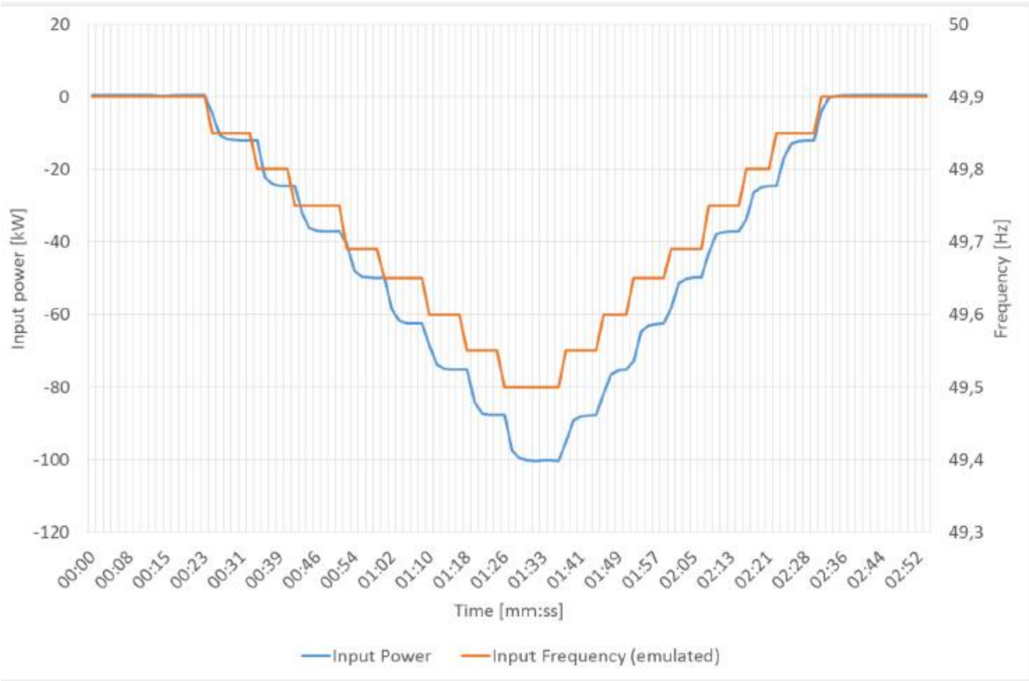


Figure 62 Results of the linearity of the reaction tests.[127]

- Part 7: Frequency analysis, simulation model and results. The simulation model used to simulate the state of charge (SoC) is shown in this report as Figure 63. The SoC behaviour information was used to study the additional stress exerted on the batteries while performing primary regulation operations. Based on a simulation with input data from year 2015 from the Nordic power system, the simulation showed that the UPS (4 x 1 MW) would have encountered roughly 200 charge/discharge events during the year. In the simulation, the depth of discharge (DoD) was limited to 42 kWh – roughly to 25 % SoC – “the number of cycles throughout the expected service life of the battery would add up to a significant figure in relation to the cyclic life expectancy: Approx. 750 cycles with DoD of 25 %. Limiting these cycles would be mandatory to ensure that demand response participation would not significantly shorten the service life of the batteries. Depending on the target market structure, the cycle count can be effectively limited with aggregating several UPS and even data centres under one bid, thus reducing the stress for a single battery system. Another way to limit the cycle count is to bid for the hourly markets and to issue a limit price for participation.”

[127]Figure 62 is in the reference article [42] numbered as Fig. 4.

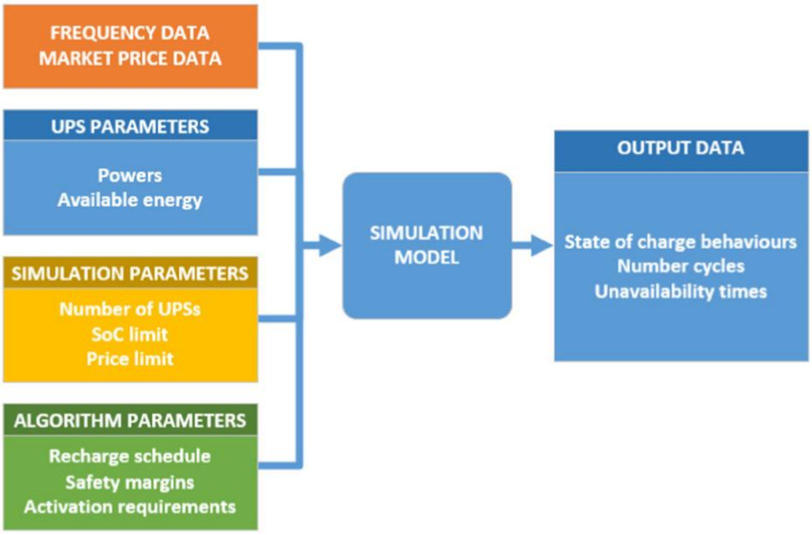


Figure 63 SoC simulation model[128]

- Part 7 continued citation: “The effects of implementing different minimum bid prices for the relative market income are also studied. Price information used in the simulation is the hourly FCR-D prices for the year 2015. The results show that implementing minimum bid price levels will have a significant effect on the number of charge/discharge cycles that the batteries are subjected to by demand response operations. Implementing these minimum price levels will also have an effect on the relative market income, but as shown below in Table 5, the decrease is moderate. Combining several UPSs into an aggregate will have a significant effect on the additional stress applied to individual battery systems. Additionally, the experienced cycle count can be significantly reduced if the market allows a selection of lower participation frequency (e.g. 49.80 Hz instead of 49.90 Hz). A typical service life expectancy for a UPS battery system (VRLA, AGM, 10-year design life) is roughly between seven and eight years. In data center usage, these batteries are expected to encounter a very limited number of charge/discharges cycles a year; a design rule of thumb is that batteries will encounter an equivalent of one to two full discharge cycles a year, and thus, the batteries could be cycled significantly more without affecting the service life. As an example, adding 45 annual cycles with a DoD of 25 % (per simulated result with 20 UPSs and a price limit of 10€/MW/h) would mean approximately 360 additional cycles during the service life of the battery system, still well within the specifications for cyclic performance, even considering the cycles the batteries will endure as a result of their primary operations.” More details regarding the data input for the calculations in Table 5 are given in the paper [42].

Price limit	Aggregate size: 4 UPSs	Aggregate size: 20 UPSs	Aggregate size: 50 UPSs	Relative income [%]
No limit	205 cycles	130 cycles	122 cycles	100
5€/MW	140 cycles	86 cycles	81 cycles	94
10€/MW	72 cycles	45 cycles	42 cycles	83
15€/MW	58 cycles	37 cycles	34 cycles	79

Table 5 Simulated number of charge/discharge cycles with different aggregate sizes, minimum bid prices and the effect of minimum bid prices on relative income[129]

[128]Figure 63 is in the reference paper [42] numbered as Fig. 4.
[129]Table 5 is in reference paper [42] numbered as Table 4.

- Part 8: Discussion. Some general citations from the paper can be highlighted: "Focusing on primary regulation enabled by the inherent redundancy and energy storages in data centres – allows data center participation to demand response without impacting the power consumption profiles or the servers. Data centres can have a lot of underused assets that could be used for primary regulation. The exact amount of excess capacity depends heavily on the applied topology and the redundancy level of the data center. The figures presented in the paper serve as an example but are highly related to real-life data center topologies and their power and back-up energy capacities. Further, in general, the more redundancy a data center has, the more excess capacity it will have to offer to the demand response markets."
  To highlight the focus of the paper [42]: "This paper focuses on data centres with existing battery systems that apply the currently dominant lead-acid battery technology. While these batteries have been identified to be feasible in the upward-regulating primary disturbance reserve (FCR-D), they are not suitable for the more common and economically more valuable bidirectional normal operations primary reserve (FCR-N). This is mostly explained by the limited cycle life and inability to operate in a partial state of charge. UPSs equipped with a different battery technology, such as lithium ion (Li-ion), could be used in the normal operations reserves to provide better market access and higher revenue. For some time now, Li-ion batteries have been suggested as a replacement for traditional lead-acid batteries, but so far, only a few data centres have implemented them. Recent developments in the prices of lithium-ion batteries alongside potential additional revenue from primary regulation could actually make a feasible business case for the data centres to change over from lead-acid batteries to lithium-ion ones."

The paper [42] contents and results given originate partly from a project performed in Sweden, where Svenska Kraftnät performed a pilot project in cooperation with Fortum and Eaton EMEA during a period of three months in 2018 – the co-author of the, Janne Paananen, is a Eaton EMEA employee and the Figure 62 originates from the test at Fortum. This projects purpose was to test flexible resources of frequency-controlled disturbance reserve, FCR-D. The status report from this pilot project [43], have gained the following conclusions:

- The prequalification test shows – refer to Figure 62 for response time – that the UPS-system is activated sufficiently fast to meet the Nordic demands for response time for FCR-D, both regarding local and remote-control monitoring of the frequency. The UPS-system also regulated linearly within the required area. The UPS-system did have difficulty logging and saving measured values locally within the 1 s resolution, this must be further investigated.
- The results from this project show that UPS-systems is a potential future resource to deliver FCR-D in the reserve markets.

The Figure 64 shows the UPS-system at Fortum answering a frequency fall the 9th of April 2018 in Sweden.

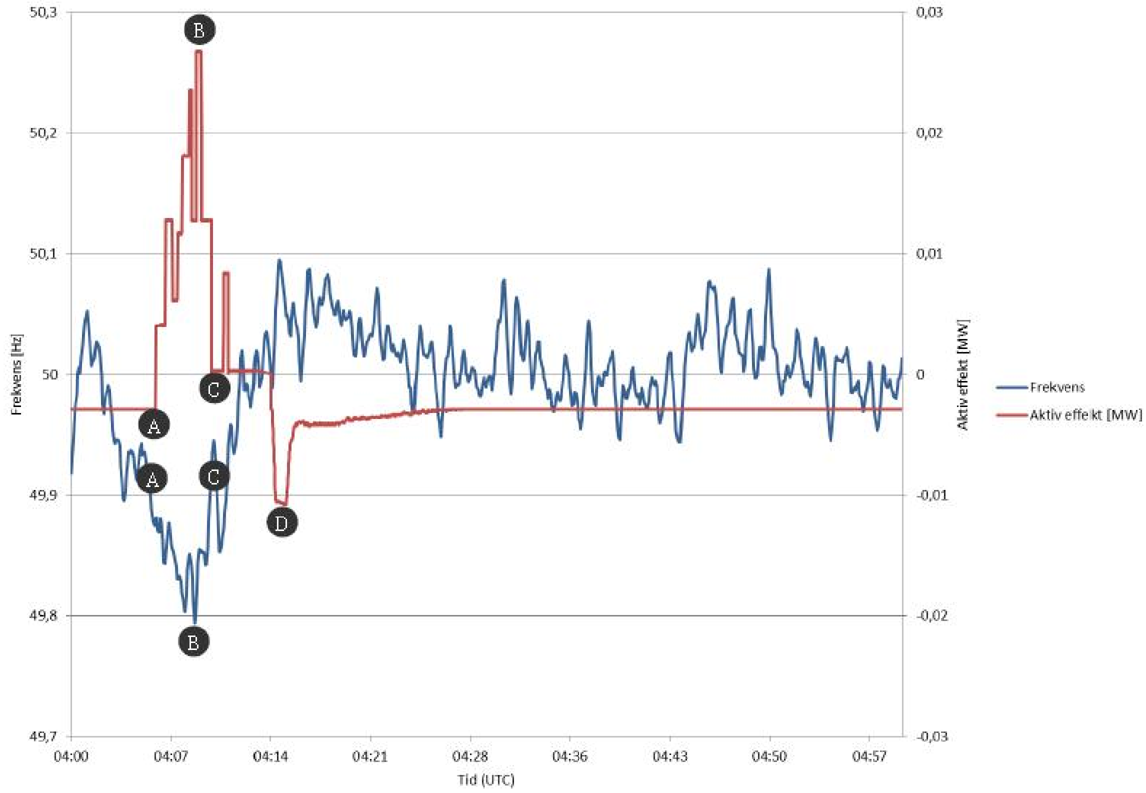


Figure 64 The activation of the UPS-system during frequency fall conditions in the Nordic area 9th April 2018.[130]

A: The frequency is below 49.9 Hz and the UPS-system starts acting.
B: The lowest frequency and the largest energy input to the grid from the UPS-system.
C: The frequency is raised again above 49.9 Hz and the UPS-system stops delivering.
D: The UPS-system start changing the batteries.

In Demark, as another example with batteries, the EConGRID pilot project was performed during the period 2016/01 – 2017/08 based on flexible demand response from batteries on tele sites in DK1. Through this pilot project EConGRID showed that a summary supply of regulation power from many aggregated tele sites was possible. In this project[131] EConGrid worked towards defining rules for baseline calculation and online measurements of flexible energy assets, that could deliver mFRR. From this specific project EConGrid experienced, that collection of online data of the energy consumption, performing forecasts, tests and calculations as well as activations of system services from the selected sites was possible. Currently no further work is performed with this concept in Denmark; the result of several pilot projects are published in [33].

In Norway Statnett performed the pilot project: “Fast Frequency Reserves 2018 – pilot for raske frekvensreserver” [44]. The results and insights from this pilot have been used in the common framework specifying FFR in the Nordic area, refer to [14].

[130] Figure 3 from reference [43].
[131] Reference on EConGrid website: http://econgrid.com/index.php/energinet-pilot-project/?lang=en

8.4 Technology: Hybrid Power Plants

As the production of energy from renewables, wind and photovoltaic power plants, is increased – there will be times where the production will give a surplus, which besides a sector coupling to Power2X-technologies also could argue for an equalisation of the cost of energy combining wind power plants (WPP's) and/or photovoltaic power plants (PVP's) with a battery energy storage (BESS). A general trend seen are the exploitation of potentialities in the renewable produced energy amount motivates the establishment of combined offshore wind farms with BESS, PVP's with BESS and onshore wind and sun energy production plants combined with BESS.

The paper, reference [45], supports the general trend mentioned above; quoted from [45]: "Seen from the perspective of a wind power plant (WPP) developer, these hybrid solutions provide a number of benefits that could potentially reduce the LCOE and enable entrance to new markets for wind power and facilitate the transition to a more sustainable energy mix."
In reference [45] the focus is the benefits to be achieved combining:

A. Wind + solar PV
B. Wind + battery energy storage
C. Wind + solar PV + battery energy storage

As elaborated in this paper hybrid solutions provide several benefits, that could reduce the LCOE.

As this report focus on technical potential from new technologies for delivering ancillary services – the argumentation in detail regarding the findings in [45] must be read in the paper; but a few technical headlines drawn from the paper, which had a specific project in Australia, Kennedy Energy Park -Phase I (43 MW wind power, 15 MW solar PV and 2 MW/4MWh of BESS) as "experimental hybrid power park" will be highlighted here:

- ✓ Increased AEP and capacity factor combining wind and solar power.
- ✓ Reduced power fluctuations and gradients combining wind and solar power.
- ✓ Increased AEP and capacity factor combining wind, solar and BESS.
- ✓ Enhanced utilization flexibility combining wind, solar and BESS – meaning demand/load following of the plant power output can be better adjusted to the demand/load profile throughout the day.
- ✓ Reduce power forecast error combining wind, solar and BESS.
- ✓ Reduced power fluctuations and gradients combining wind, solar and BESS.

The project in Australia was performed within a co-operation project between Vestas Wind Systems, Denmark; Windlab Limited, Australia and Department of Energy Technology, Aalborg University, Denmark – and the paper was published in 2018.

Precedes this project – in 2012 the Lem Kaer demonstation project was established in order to quantify the value propositions of wind power combined with energy storage. The final report from this ForskEL project [46] gives, with reference to this report's focus the following conclusion regarding delivery of frequency reserve: "The project has serviced the TSO regarding experimental test of alternative primary regulation" – and for utilization of the project results for Vestas is stated: "The project has provided Vestas with extensive experience and in depth knowledge in relation to operation of grid connected battery systems as well as ancillary services based on provision of primary reserve from batteries in DK1."

The regulation ability for delivering ancillary services will be highlighted in the next part 8.4.1.

8.4.1 Regulation ability of hybrid plants – control strategy

In part 5.3.2 and sub-parts the regulation ability of wind turbines (Type 3 and 4), in part 5.4.1 and 5.4.2 the regulation ability of photovoltaic plants and in part 8.3.2 for battery storage systems was discussed – all three technologies are able to deliver ancillary services as stated in the respective sections. To be expected combinations of these technologies will also have the option to deliver ancillary services. Following is discussed with reference to an article in "energies 2019" [47] the response from a hybrid power plant detecting a fault and controlling the delivery of frequency regulation.

The frequency regulation issue with renewable sources is discussed, modelled as a case study of a hybrid power plant, evaluated and concluded in the article [47]; parts of the content will be presented/quoted here.

The main motivation of the authors of the article [47] is regarding the evaluation of "the Hybrid Power Plant" (HyPP) frequency regulation ability caused by their assertion "the inertia reduction suffered by worldwide power grids". The authors use the ROCOF (Rate of Change of Frequency) equation defining the simplified frequency behavior of any power system – showing how generation-demand imbalance causes a frequency variation from 50 Hz – the ROCOF equation gives that the rate of change of the frequency is inversely proportional to the inertia and the size of the system; for the purposes of their study the inertia constant has been set to 3 s; which is representative for Denmark.

In their study they are using up-to-data standards from ENTSO-E (RfG, and LFC documents as reported in Appendix 2) regarding the definitions of:

- Fast Frequency Response (FFR) – initial response
- Frequency Containment Reserve (FCR)[132] – primary response
- Frequency Restoration Reserve (FRR) – secondary response

A typical response curve caused by a disturbance in the grid is shown in Figure 65, which, moreover, is consistent with the definitions and explanations given in part 3.3.1.1 for DK1.

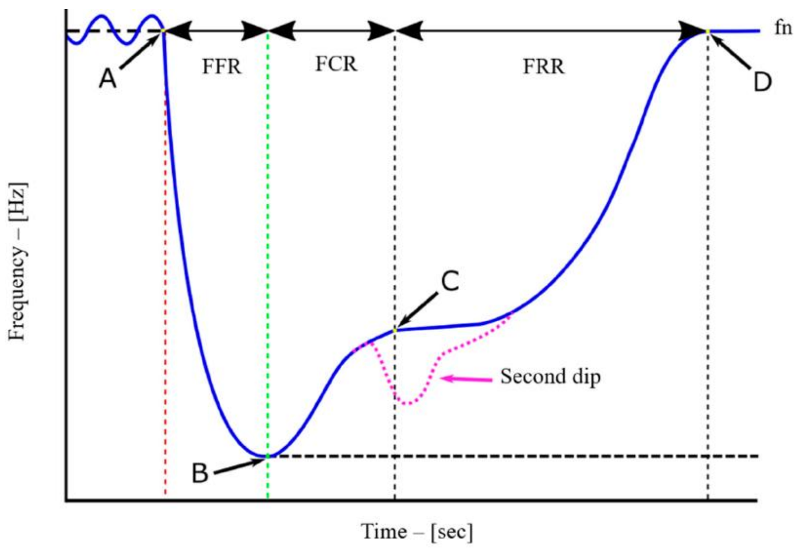


Figure 65 Typical frequency response curve caused by a disturbance.[133]

[132] The power response for FCR is allowed with and without a dead band, refer to Figure 6 and Figure 7 in part 3.3.1.1.
[133] Figure 65 is as stated "Figure 1" reproduced from [47].

Baseline is the frequency: f_n = 50 Hz± 200 mHz
A: Disturbance occur
A-B: Initial response of FFR
B-C: Containment response of FCR
C-D: Restoration response of aFRR and mFRR.

The pink part – second dip; no regulation of today is handling, if a second dip occurs; but the discussion in the article [47] will not be detailed here – do refer to part 3 in the article.

The grid model used is based on the IEEE 12-bus system and adapted for wind power integration studies. Combining an area 1 with large thermal generation and a combination of residential and industrial loads with, area 2 with rural loads also included generation with, area 3 constitutes a heavily industrial load center with reduced thermal generation and lastly area 4 with the connection of a HyPP – having WF (100 MW), PVP (31.5 MW) and BESS (28 MW); Figure 66 shows the model of the HyPP.

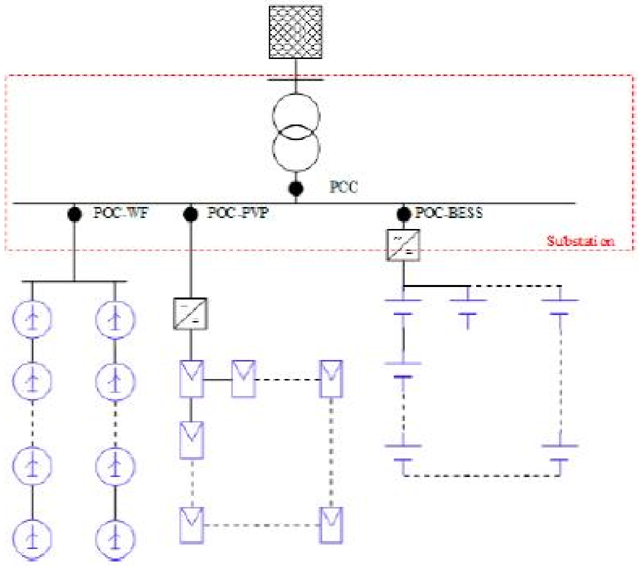


Figure 66 HyPP balance of plant.[134]

Next step is to build the control structure and design the FFR and FCR controllers – details in the paper [47] – and simulate the scenarios for the HyPP's participation in the frequency control. The considered event is a N-1 contingency, as a loss of a single generator unit (G1) or a loss of a transmission component. Without going into details here, which can be found in the paper – there are used two different fault detection methods for the frequency drop during the fault:

Difference	Scenario I	Scenario II
Event Detection	50 ± 0.2 Hz	Frequency $\notin (50 \pm 0.2$ Hz$)$ ROCOF $\notin (\pm 0.2$ Hz/s$)$
Frequency Deadband	50 ± 0.5 Hz	none
ROCOF Deadband	none	± 0.2 Hz/s

Table 6 Differences between scenarios.[135]

[134] Figure 66 is "Figure 1" reproduced from [47].
[135] Table 6 is "Table 7" reproduced from [47].

Despite not being entirely fair to the papers authors – here it will only be concluded that both types of fault detection scenarios and reactions of the HyPP result in stabilising the frequency with vary fast reactions from WF, PVP and BESS – but the detection “strategy” matters in smoothing of the curves. More discussions can be found in the paper [47] – the regulation ability is present the design of the detection methods matters and the design of the controllers as well.

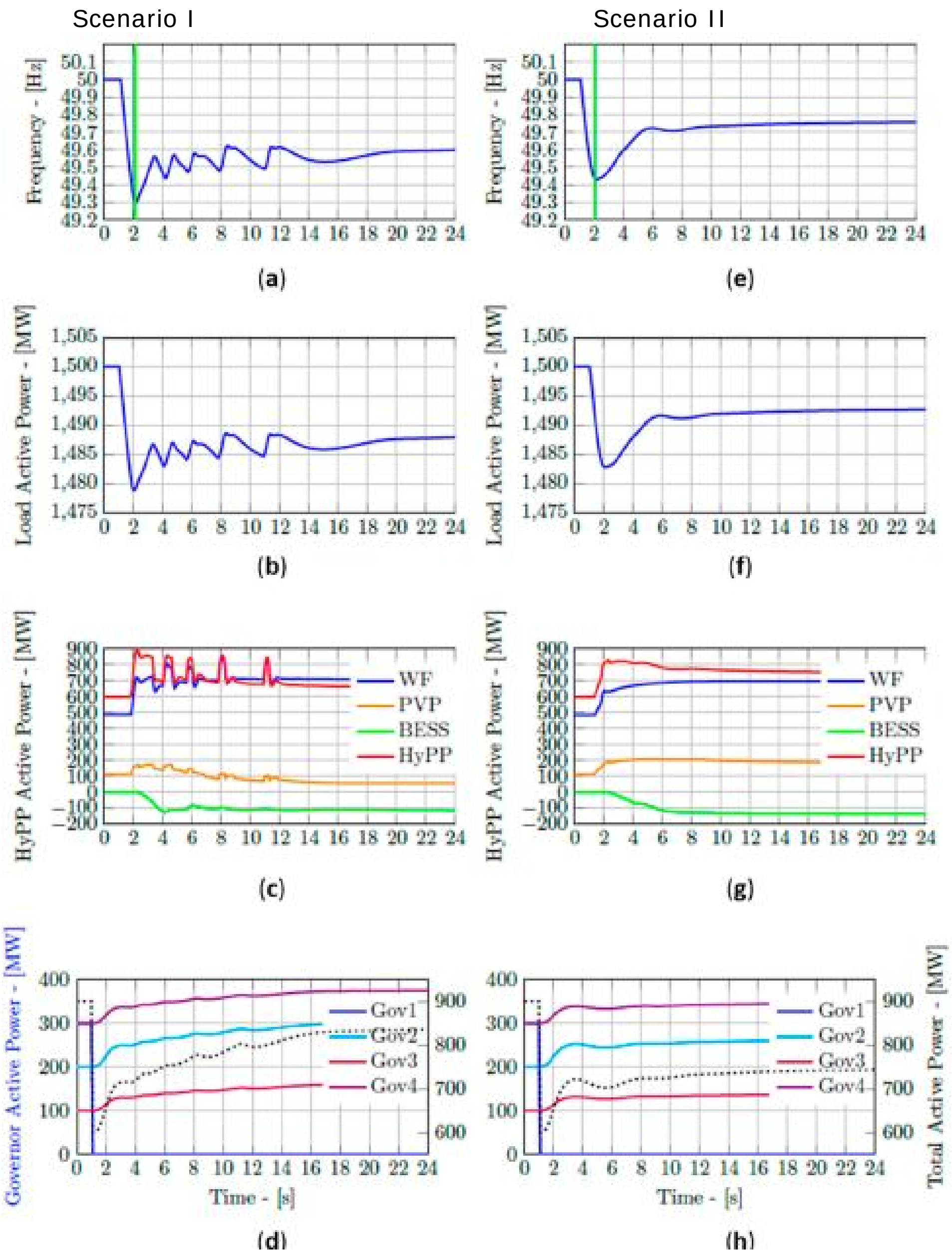


Figure 67 Test scenarios – Scenario I (a-d) and Scenario II (e – h).[136]

Explanation to Figure 67: Loss of G1 (GOV 1) results in the frequency drop (a) and (e), load active power drop (b) and (f) and HyPP reaction of WP, PVP and BESS (c) and (d) – the totally reaction of the HyPP is the red curve and lastly the thermal power generators governor’s reaction (d) and (h) on the frequency drop respectively for Scenario I and II. The authors statement of their result: “Thus, the outcome of this study is a control strategy that enables a hybrid power plant to provide frequency support in a system with reduced inertia, a large share of renewable energy, and power electronics-interfaced generation.”

[136]Figure 67 is “Figure 8” reproduced from [47].

8.4.2 Example 1: Vattenfall – Ancillary services from converter-based renewables

Vattenfall gives the following input regarding their vision of delivering ancillary services of the future:

"Vattenfall's goal is to make fossil free living possible within one generation. To make fossil free living a reality, we are transforming our own production portfolio and helping our customers to power their lives in climate smarter ways. We are phasing out fossil production, investing in renewables and innovating with new ways of energy storage. A large part of this transition includes converter-based technologies for wind, solar, and battery storage.
With the change of having most of the power producing units being rotating machines on large central power plants, towards a future where the major part of the power production units will be based on converter connected renewable energy sources, the need for an adjustment of the system operation is obvious. Today this transition is ongoing - the amount of rotating machines are decreasing and the utilisation of converter-based systems are emerging though the utilisation of the converter technology is not yet fully exhausted.
Converter operation can to a high extent be adopted to mimic the operation of rotational production units and developments within metrological models and storage technology will open the possibility of renewables as primary reserves - hence frequency related support can be expected to be fully supported by converter operated renewables in the future. The related areas being:

- Spinning reserve with backup from storage and utilisation of metrological advancements
- Frequency support schemes
- Inertia backup
- Black start capabilities

Moving toward a converter-based production setup the continued mimic of rotational machines seems though to become less and less essential for the future operation of the system.
Voltage control and reactive power can be supplied from converter operation on more than equal terms compared to the same functionality from rotating machines. Reactive power control from converters can be supplied independently from the power production even at zero power production – e.g. no/low wind and sun scenarios.

- Voltage control
- Reactive power

Voltage control and reactive power support can be fully supported by the converter based renewable technology as of today. The voltage control schemes of converter-based operation is fast and reliable.
Active harmonic filtering is another area where the converter technology can provide more performance and flexibility for future system operation than today. With a wind power plant capacity factor of 50 % and a crest factor in the range of 3 for a typical converter system - a theoretical range of short circuit current support for a wind power plant is up to 6 p.u.

- Harmonic filtering
- Short circuit contribution

These areas though calls for some design work and system considerations being new areas for further developments.
Vattenfall believe that the possibilities within converter technology for system operation & interaction are not fully exploited, and suggests that focused work, both technical, commercial, and strategic, is initiated."

9. SUMMARY AND CONCLUSIONS

9.1 Introduction

The summary and conclusions follow the parts defined in the assessment description of the delivery agreed between Energinet and Ramboll for the answering of the Danish Utility Agency's request to Energinet – refer to Chapter 1 page 5. Most of the definitions and abbreviations used in this chapter can be found in part 3.2.

The first part of the assignment:

1. What are the technical requirements for ancillary services to be delivered in DK1 and DK2? Starting with Energinet's technical requirements and tender conditions for ancillary services [12] and needs for ancillary services for reserve power and energy activation in 2020 [4] – including the requirements of participating in the markets for regulation power and energy for the following frequency and non-frequency ancillary services:
    - Reserves (capacity)
        - Reserves for balancing purposes (FCR-N, aFRR and mFRR)
        - Reserves for handling of disturbances (FFR, FCR, FCR-D)
    - Reserves for activation (energy)
        - Reserves for balancing purposes (FCR-N, aFRR and mFRR)
        - Reserves for handling of disturbances (FFR, FCR, FCR-D)
        - Reserves for congestion management (mFRR capacity and special regulation)
    - Non-frequency ancillary services
        - Inertia (spinning reserve and "FFR")
        - Voltage regulation and reactive power compensation.

This first part of the assignment is performed acc. to chapter 3. "Technical requirements for ancillary services"; summary and conclusion refer to part 9.2

The second part of the assignment:

2. Select the new technologies from the Technology Data catalogues [6].

This second part of the assignment is performed acc. to chapter 4 "Ancillary services from new technologies"; summery and conclusion from chapter 4, refer to part 9.3.

The third, fourth and fifth part of the assignment:

3. Which kind of ancillary services are the selected new technologies able to deliver acc. to the technical requirements – what are their technical potentials (and not the volume) and are there technical barriers to be eliminated?
4. Give the prospect of delivering ancillary services – and the prospect of delivering more or increase the volume?
5. Which investigations, research and development potentials are being performed to have ancillary services delivered from new technologies in Denmark and in other countries/by other TSO's for the outlook with an increasing part of renewable generation and consumption integration in the grid?

The third, fourth and fifth part of the assignment are performed acc. to the contents and examples given in the respective technology chapter's 5, 6, 7 and 8, parted as follows:

- Generation Plants or Units in chapter 5.
- Demand Plants or Units in chapter 6.
- Renewable Fuels or Power2X in chapter 7.
- Energy storage in chapter 8.

The findings are highlighted from each of the technology chapters and the examples included; these will be summarised and concluded as part conclusions in part 9.4 – and presumably give rise to supporting the growth of new technologies delivering ancillary at market terms. The main conclusion refer to part 9.5.

9.2 Summary and conclusion of technical and market requirements

The first part of the assignment, as described in the introduction part 9.1, is interpreted:

- Give a descriptive overview of the main technical requirements of ancillary services to be delivered in DK1 and DK2 for balancing, handling disturbances or congestion management and system stability properties – inertia, voltage regulation and reactive power control for stabilisation of the electricity transmission grid in accordance with applicable regulations, taken as a prerequisite that the grid connection rules are fulfilled (the RfG for generation and the DCC for demand).

The first part of the assignment is reported in chapter 3:

- o Technical requirements for ancillary services

supported by:

- o Appendix 1, Danish Legislation, Rules and Regulations,
- o Appendix 2 Continental Europe synchronous area (DK1) LFC structure,
- o Appendix 3 Nordic synchronous area (DK2) LFC structure and
- o Appendix 4 Over-view of frequency ancillary services technical requirements and market rules and regulations.

On 1st of November 2019 EN published the document “Needs Assessment of Ancillary Services 2020” [4]; which gives the expectations and elaborated assessments of the needs of ancillary services – the needs are assessed from Energinet for DK1 and DK2. Table 1 in [4] will be used here to summarise the technical requirements for ancillary services to be delivered in DK1 and DK2 in an overview coupled with the markets, refer to Table 7 next page.

The technical and market requirements for the frequency reserves are due to the common framework committed in EU Regulations SOGL and EU Regulation 714/2009 as well as EBGL. For the frequency reserves for Western Denmark (DK1), reserves FCR, aFRR and mFRR, the System Operation Agreement (SOA) of Continental Europe (CE) synchronous area confirms the technical requirements of these reserves – and for Eastern Denmark (DK2), reserves FFR, FCR-N, FCR-D, (aFRR)[137] and mFRR, the System Operation Agreement (SOA) of the Nordic synchronous area confirms the technical requirements of these reserves. In Table 1 in part 3.2 the frequency quality parameters for CE area (DK1) and for the Nordic area (DK2) are informed acc. to the respective System Operation Agreements.

Changes of the technical requirements of the frequency reserves and the process implemented in the framework of the EU regulations – will require a waiver approval from the EU Regulations in question, follow-up implementing of the same changes in the Danish Energy Act and a revision of the agreement (SOA) regarding the change of characteristics’ of the reserve in question in the concerned synchronous area – which is a complicated and long lasting process; the conclusion is: The frequency reserves technical requirements and process as stated in the EU Regulations will persist many years ahead. However, ultimo 2021 the Nordic frequency reserves (FCR-N and FCR-D) will get two additional requirements to ensure both transient and small-signal stability.

Options of changing a parameter defining a specific frequency reserve could only be one or more of the following: Direction – upward and downward regulation symmetrical or asymmetrical (refer to Appendix 4 Table 1), partly availability, times defined for partly delivery (ex. 50 % within 5 s for FCR-D) of a reserve as for FCR and FCR-D (refer to Appendix 4 Table 2) - if one or more of these characteristics must change, it must be agreed in the SOA’s of CE or Nordic synchronous area.

[137] (aFRR) stated in bracket as expected implemented for DK2 in Q3/2020.

Ancillary service name:	Requirements in 2020:	Contribute to:	Commodification:
Manual Frequency Restoration Reserve Enegy (mFRR-activation) and special regulation	For balancing of production and consumption	Frequency stability	Market
Manual Frequency Restoration Reserve capacity (mFRR-capacity)	Required 684 MW in DK1 Required 623 MW in DK2	Frequency stability	Market
Automatic Frequency Restoration Reserve (aFRR-capacity)	Required 90 MW in DK1 Required 20 MW in DK2[138]	Frequency stability	Market
FCR, FCR-D og FCR-N	Required 21 MW FCR in DK1 Required + 44 MW FCR-D in DK2 Required 18 MW FCR-N in DK2	Frequency stability	Market
Fast Frequency Reserve (FFR)	Needs have not yet been clarified. It is a new reserve product, that is expected to be released in Q2/Q3 2020. The amount is being developed internationally for the Nordic synchronous area (DK2).[139]	Frequency stability	International project initiated
Voltage regulation and reactive power compensation	The need for voltage regulation in normal operation entails the preparation of a basis for providing voltage regulation and reactive power compensation with the use of a technology-neutral approach for all production connected to the transmission grid. Voltage regulation during faults is necessary for system stabilisation and voltage reconstruction. It is a mandatory requirement for all production units connected to the transmission grid and the specifications are covered by the RfG.	Voltage stability	Pilot project in a local area of DK2 (Lolland)
Congestion management	Needs for handling temporary bottlenecks in the transmission grid. Downward and upward regulation must be performed in specific locations in the transmission grid. The need for downward regulation in South Zealand is estimated at up to 85 MW in 2022.	Avoid overload in the transmission grid	Is of today managed using special regulation. Pilot project for local flexibility and for increased commodification.

Table 7 Overview of Energinet's identified needs of ancillary services for 2020 and statement of commodification [4].

[138]The amount stated will be recalculated and is likely to increase.

[139]Energinet has announced on the 13th of December 2019 the stakeholder's public consultation regarding "Methodology for technical requirements for and new procurement method of fast frequency reserve (FFR) in DK2" – consultation period from the 13th of December 2019 until the 23rd of January 2020. Refer to Energinet's website: https://energinet.dk/El/Systemydelser/Nyheder-om-systemydelser/Horing-af-FFR-metode

The test requirements for ancillary services in Denmark are as stated in [13], which currently has been updated due to insertion of the test requirements for FFR (for DK2).

For the non-frequency ancillary services, voltage regulation and reactive power compensation, a process has recently been initiated by EN for method description for voltage regulation provision requirement in the Danish transmission grid – refer to part 3.3.3.1 – this work is planned to be supported by a group of representatives from production plants owners, DSO's and other stakeholders and the result is planned to be submitted for approval at DUR in the middle of Q2/2020, refer to Figure 17, which shows the scheduled time plan. Basically, EN expects that all plants in the future, conventional as well as renewables plants, grid connected in the transmission grid acc. to the RfG must deliver voltage regulation, setting must be "voltage control mode" and EN will submit the set-point. The Mvar-compensation rules will be part of this new method description. A pilot project is currently carried out in the island of Lolland, refer to Table 7, to collect experiences. For the reactive power a ± 15 Mvar maximum limit or a ΔQ of ± 15 % of the production unit's nominal power is expected to be implemented. Stakeholders are invited by EN to take part in a meeting on 21st of January 2020[140] discussing the task of voltage regulation and reactive compensation. Interested readers are in reference [4] "Tabel 24" given the over-view of how this matter are treated in other countries.

The market requirements regarding settlement and technical requirement for metering, IT communication etc. are described in short in part 3.5; the DSO's in Denmark are the responsible parties for metering acc. to the Danish Energy Act. Implementation of the measurement set-up to measure the energy supplied, if delivering any kind of ancillary services to the TSO (EN), must be part of the plan for delivering ancillary services and the expenses for the measurement requirements, signals implementation and the IT communication must be included in the developer's business case.

The requirements of the applicable Danish market rules are described in document "Ancillary services to be delivered in Denmark tender conditions" [12]. To provide an over-view of the market requirements and obligations of the players (definition refer to part 3.2), these rules are implemented in Appendix 4 in the following tables:

- Appendix 4 Table 4 Market requirements procurement, deadlines and communication for ancillary services used in Denmark.
- Appendix 4 Table 5 Market requirements regarding bids and volumes for ancillary services used in Denmark.
- Appendix 4 Table 6 Market requirements regarding bids and prices for ancillary services used in Denmark.
- Appendix 4 Table 7 Market requirements regarding acceptance of bids for ancillary services used in Denmark.
- Appendix 4 Table 8 Market rules for payment, closing and activation for the ancillary services used in Denmark.
- Appendix 4 Table 9 Market rules regarding obligations of the players for ancillary services used in Denmark.
- Appendix 4 Table 10 Market rules – player's planning for delivery of ancillary services in Denmark.

These rules will, supposedly, remain to apply until the new market platforms NBM, PICASSO and MARI are established with implementation of the different sorts of capacity and energy markets, refer to part 3.1. In the current existing markets locally in Denmark and at Nord Pool, EN

[140] Energinet's website: https://energinet.dk/Om-os/Arrangementer/Workshop-2-om-kontinuert-spaendingsregulering-210120

purchases today reserve capacity and reserve energy to balance and handle disturbances. The ancillary markets are characterised by having a merit order list (MOL).

The tender condition for delivering FFR in DK2 will be included in an update of [12] after the DUR approval of the "Methodology for technical requirements for and new procurement method of fast frequency reserve (FFR) in DK2", which EN published for stakeholders' public consultation the 13th of December 2019.

9.3 Summary and conclusion of the selection of the new technologies

In managing the second part of the assignment from Energinet, Ramboll followed a process as described below – including contact to several developers, producers, BRP's and contact persons of universities during research in this area.

The process tasks implemented by Ramboll:

- Screening of new technologies described in the Technology Data catalogues, which can be evaluated having a technical potential of delivering ancillary services.
- Screening of new technology trends of unit or plant projects implemented during the last few years as pilot projects at markets conditions or with minor exceptions with dispensation given from Energinet and the Danish Energy Agency regarding the measures taken of delivering ancillary services.
- Selecting and describing the new technologies regarding their technical potential to deliver different types of reserves and services.
- Evaluate the technical potential of "the new technology" highlighting the advantages, disadvantages; technical as well as markets barriers to enter into the reserve capacity and energy activation markets.
- Participation in the player's forum meeting on 23rd October 2019 with a presentation[141] of the Ramboll assignment to be performed for Energinet for the stakeholders at the meeting – with the request of having their input regarding the current and future trends of new technologies participating in the reserve capacity and energy markets.
- State and describe "the good examples" of national, international or other TSO's trials within the pilot projects delivering the different sorts of ancillary services from "new technology sources" – and highlight the lessons learned.
- Participation in the Energinet Workshop on "Continuous voltage regulation and reactive power compensation" the 15th November 2019 having discussions with more stakeholders for input to this report – as "good examples" delivering ancillary services including voltage regulation and reactive power compensation.
- Summarise and draw conclusions of the potential of "new technologies" delivering ancillary services in the future and their integration in the present existing markets with focus on technical as well as markets barriers for their integration.

In chapter 4.3 the criteria for the selection of "a new technology" is described. Technologies will be investigated for the technical potential of delivering ancillary services, if a production, demand, renewable fuels or storage energy technology having already to a small extent shown potential or if the technology is foreseen to show potential of delivering ancillary services in the near future with a time perspective of 2-5 years from now.

[141] The collected PowerPoint Presentation from 23rd of October can be downloaded in Energinet's website: https://energinet.dk/El/Elmarkedet/Samarbejde-paa-elmarkedet/Aktoerarbejdsgruppen

The evaluation process resulted in the selection of the technologies and examples listed next page (as shown in part 4.3); the examples given are primarily a result of Ramboll's requests among developers, companies or BRP's, who already are delivering ancillary services or have taken part in pilot projects in cooperation with EN in the past.

The "New Technology" category – the chosen technology – and the examples, which are described in the chapters 5, 6, 7 and 8, because they were identified as a new technology, which can provide frequency ancillary services/system stability properties, but today only do so to a minor extent or not at all contributes.

- New Technology – Generation Plants or Units:
  - Part 5.3 Technology: Wind Turbines and Wind Power Plant.
    - ✓ Example 1: Trial at Burbo Bank Wind Farm (UK).
    - ✓ Example 2: Australian wind farm tests with frequency control.
    - ✓ Example 3: Energinet's pilot project - Voltage regulation.
    - ✓ Example 4: New Energinet's pilot project – Reserves from RE.
    - ✓ Example 5: New Energinet pilot project – Congestion management.
- New Technology – Generation Plants or Units:
  - Technology: Photovoltaic plants and household/industrial units.
    - ✓ Example 1: Mind4Energy MINT® PV data Acquisition and Control.
- New Technology – Demand Plants or Units:
  - Technology: Household, industrial or heating sector equipment.
    - ✓ Example 1: FlexHeat Heat Pump – EnergyLab Nordhavn.
    - ✓ Example 2: Flexibility from household/industry heat pumps.
    - ✓ Example 3: Flexible demand industrial consumers – Energi Danmark.
    - ✓ Example 4: COOP Danmark A/S – FCR Data analysis DK1.
- New Technology – Renewable Fuels or Power2X Technology:
  - Technology: Biogas Plants.
    - ✓ Example 1: Nature Energy statement regarding ancillary services.
  - Technology: Solid Oxide Electrolyser Cell.
  - Technology: Methanol from Power.
    - ✓ Example 1: Electrolysers in the electricity markets in Denmark.
    - ✓ Example 2: Haldor Topsoe – Electrical driven hydrogen and synthesis gas generation.
- New Technology – Energy Storage:
  - Technology: Battery Energy Storage Systems (BESS).
    - ✓ Example 1: BESS installed as part of the EnergyLab Nordhavn.
    - ✓ Example 2: Automotive Battery Systems – Electrical Vehicles (EV).
    - ✓ Example 3: UPS-Systems with battery back-up.
  - Technology: Hybrid Power Plants.
    - ✓ Regulation ability of hybrid plants – control strategy
    - ✓ Example 1: Vattenfall – Ancillary services from converter-based renewables.

Table 8 List of New Technology categories, specific technology and the examples given in chapter 5, 6, 7 and 8.

The definition of a "new technology" is linked to a former work performed in a cooperation between DEA and EN publishing in five Technology Data catalogues [6]. In part 4.1 the background of these Technology Data catalogues is discussed; and the disclosed differences in the data specification of the property "regulation ability" are highlighted. The regulation ability evaluation of the specific technology is important assessing the technology's suitability of delivering ancillary services.

In the Technology Data catalogue of "Generation of Electricity and District heating"[142] [6] the parameters of regulation ability are the following:

- Primary regulation (% per 30 s)
- Secondary regulation (% per 1 min)
- Minimum load (% of full load)
- Warm start-up time (hours)
- Cold start-up time (hours)

These parameters are perfect for evaluation and selection of the obvious candidates for further evaluation regarding the technical potential for delivery of ancillary services; as this catalogue most of all describes generation units, it shows most of all, that the traditional thinking is: "The ancillary services will be delivered by generation units" – which do not need to be the case in the future:

"Generally, upward regulation with a reserve can be provided either by increasing electricity production or by reducing electricity consumption. Conversely, downward regulation with a reserve can generally be delivered either by reducing electricity generation or by increasing electricity consumption."

The regulation ability data given for the following three catalogues:

- Technology Data for Heating installations
- Technology Data for Renewable Fuel
- Technology Data for Energy Storage

are different (refer to part 4.1 for details); Ramboll's suggestion is, that in an update of these catalogues further considerations are performed regarding, whether the technology could be capable of delivering ancillary services – and which type of reserve or property?

Virtually all technologies can deliver aFRR, mFRR and special regulation – generation or demand unit – by specific planning of the delivery; as one single unit or as several aggregated units.

[142] Part of reference [6], DEA website specific link: https://ens.dk/en/our-services/projections-and-models/technology-data/technology-data-generation-electricity-and

9.4 Summary and conclusion "Technical potential of new technologies"

This part will be subdivided in four parts; one for each technical chapter 5, 6, 7 and 8.

For chapter 5 – New Technology – Generation Plants or Units two technologies, wind turbines/wind power plants and photovoltaic units/plants; refer to part 9.4.1 for summary and conclusion.

In chapter 6 – New Technology – Demand Plants or Units, reporting from three different examples: Flexheat Heat Pump (large heat pump), from aggregation of small heat pumps and from the pilot project performed by Energi Danmark based on flexible demand from industrial consumers, refer to part 9.4.2 for summery and conclusion.

In chapter 7 – New Technology – Renewable fuels and Power2X technology; reporting from Nature Energy's statement and two different examples: "Example 1: Electrolysers in the electricity markets in Denmark" from Centrica Energy Trading and "Example 2: Haldor Topsoe – Electrical driven hydrogen and synthesis gas generation"; refer to part 9.4.3 for summary andconclusion.

In chapter 8 – New technology – Energy Storage; reporting from three different technology examples: "Example 1: BESS installed as part of the EnergyLab Nordhavn", Example 2: Automotive Battery Systems – Electrical Vehicles (EV)" and "Example 3: UPS-Systems with battery back-up". For Technology: Hybrid Power Plants a scientific articles is discussed regarding development of a control strategy controlling a plant consisting of wind turbines, photovoltaic plant and BESS and this chapter is closed with a statement from Vattenfall sharing their thoughts or vision for delivering ancillary services in the future from new technologies; refer to part 9.4.4 for summary and part conclusions.

9.4.1 Generation: Wind turbines and photovoltaic plants

9.4.1.1 Wind turbines and wind power plants

Initially, in chapter 5.1, is accounted for the short and longer planning of wind power expansion in Denmark – offshore wind power plants in the transmission grid and minor onshore parks and stand-alone wind turbines in the distribution grid – which demands for continuing development of the interfaces between the TSO, the DSO's and plant operators, as the larger amount of power production is feed into the distribution grid. This might cause local bottlenecks and result in need of balancing power estimation and control with shorter time span closer to the moment of production. Controlling the balance between production and demand needs features and estimation tools, which gives reliable data for tendering and provision of the reserves needed.

Regarding the state and lookout, the power production of these renewable units are feeding into the grid supplied through frequency converters; in the future setup of balancing production and consumption, their deliveries of power in-feed into the grid must also include delivery of ancillary services as supplement to or even substituting reserves today delivered by conventional power plants.

Today EN's tender conditions: "Ancillary services to be delivered in Denmark tender conditions" [12] – demands: "Furthermore, a group of wind turbines cannot submit bids on their own in the different ancillary services markets. Wind turbines may be included along with other production to guarantee supply in the event that the wind turbines are unable to deliver the required performance due to failing wind."

This is a technical barrier for wind turbines and wind power plants as stand-alone utilities submitting bids for the ancillary service power and energy markets. As wind turbines/wind power plants can, if the wind turbine are of Type 3 or Type 4 (definition refer to part 5.3.2) deliver:

- Frequency support
- Inertia support (FFR)
- Voltage regulation and reactive power support

which is the short conclusion of part 5.3.2 based on reference [22].

Example 1: Trial at Burbo Bank Wind Farm (UK) shows test of the frequency control and FFR reaction with Siemens Gamesa 3.6 MW wind turbines.

Example 2: Australian wind farm tests with frequency control – gives similar result as Example 1.

Example 3: Energinet's pilot project - Voltage regulation; one of the challenges with voltage control is that the voltage must be controlled locally – the voltage is not a feature, which can be transported through the system, as the voltage is a condition in any point of the electrical system. Voltage regulation equipment must be available, where the need for voltage stabilisation arises. The results from the pilot project has not beeb reported so far – the wind farm, Rødsand 2, will deliver the voltage regulation and reactive power control, so, hopefully this pilot project will result in some experiences.

Two more pilot projects by EN are announced early in December 2019 – refer to part 5.3.6 and 5.3.7:
Example 4: New Energinet's pilot project – Reserves from RE
Example 5: New Energinet pilot project – Congestion management
Performing these kinds of pilot project with wind turbines (or photovoltaic plants) will supposedly give valuable experiences for future use of wind turbines delivering ancillary services.

The financial support scheme in Denmark; providing subsidies for renewable energy production, as for the energy delivered, has been the motivation for the establishment of wind power plants. Delivering ancillary services will acquire reduction of production in all circumstances – for downward regulation it is obvious; but also, being ready for upward regulation there must be some reduction in production in advance as preparation for upward regulation of the active power production, loss of hours with full production time is the consequence.

Some of the remarks received from Oersted confirms above assumption:

- "The barriers delivering ancillary services from wind power are markets requirements. (The wind power producer will lose production, which gives energy payment acc. to the subsidy scheme).
- The energy payment is relatively too high– compared with the payment for ancillary services.
- There is an "unknown penalty" for non-delivery of the reserve.
- The technical implementation of the facilities delivering ancillary services is relatively complex and having a high CAPEX; thus, a long payback time (frequency control functions, measurements, SCADA & IT-communication – including prioritising of resources as an example the IT staff)."

These remarks must be considered by EN for further evaluation.

Conclusion:
Wind turbines/wind power plants have the technical potential and a large volume (proportional factor of the installed power).

9.4.1.2 Photovoltaic plants and household/industrial units
Exactly same conclusion as above for wind turbines/wind power plants can be drawn for photovoltaic plants; without proving it with practically completed project examples.

The planned installations of new photovoltaic power plants in the next couple of years are stated in part 5.1 (262 MW) – but the further outlook, refer to Figure 32, GW's of photovoltaic plants are expected to be installed in Denmark.

In Germany, Belgium and Northern Ireland photovoltaic plants project have been established using the Mind4Enwergy MINT® PV data Acquisition and control system, refer to part 5.4.2, Example 1: Mind4Energy MINT® PV data Acquisition and Control:
This system's available features are quoted from data sheet:

- "Real-time monitoring and real-time control of your PV plant.
- Control of the PV plant based on dynamic signals like real-time or forecasted energy prices.
- Control of active and reactive power with or without ramp rate.
- Frequency support (via active power).
- Voltage support (via reactive power).
- Cos φ-control (even at night, with specific inverters).
- Export limitation.
- Battery management.
- Soft start and soft stop of the facility.
- Compliance with DNO (=DSO)/TSO communication requirements.
- Flexible interfaces and secure connections with third parties."

Unfortunately, Ramboll did not succeed with getting in touch with any of the Danish developers of photovoltaic power plants; so, it cannot be stated how they assess the near future delivering ancillary services – the support scheme for photovoltaic power plants is nearly the same as for wind turbines/wind power plants, which gives also the same disadvantage of the reduction in production with reservation of production for "spinning reserve"/upward regulation.

In part 5.4.1 results from the RePlan-project [25] are reported; the results from this project confirms, that aggregation of smaller PV units can deliver FRR.

Conclusion:
Photovoltaic plants have the technical potential and a large volume (proportional factor of the installed power).

9.4.2 Demand: Large, small heat pumps and industrial consumers

Today, only a very small parts of reserves has been delivered by consumers. The deliveries originate from pilot projects or research demonstration projects.

In part 6.3.1, the Example 1: FlexHeat Heat Pump – EnergyLab Nordhavn is reported; from this project Ramboll has received a memo giving a comprehensive reporting of HOFOR's experiences. Summarised here, as follows, the statements given:

“Regarding bid limits after test with Heat Pump:

- FCR-D: minimum bid 0.3 MW lowered to 0.1 MW
- FCR-N: minimum bid 0.3 MW lowered to 0.1 MW
- aFRR: minimum bid 1 MW lowered to 0.5 MW
- mFRR: minimum bid 5 MW lowered to 1 MW

<u>For delivering FCR-D:</u>
Present situation: The heat pump can shut down momentarily and thus provide a service within approx. 30 s. However, the requirements cannot be maintained by 50 % within the first 5 s and then the remaining within 25 s - but the total amount of reserve can be delivered within 30 s. In addition, the challenge is that the heat pump is stationary for approx. 20 min, and it takes another 6 min to start the system - therefore it cannot be restored within the 15 min demand.

<u>Suggestions for restructuring of FCR-D reserve requirements:</u> Based on the testing experience, 100 % capacity is required within 30 s, and recovery can take place after 30-45 min, depending on the size of the heat pump. Then heat pumps could play a role.

<u>For delivering FCR-N:</u>
Present situation: The heat pump can deliver partial load regulation within 3-5 min in most cases without being optimised for it. The preliminary results regarding intelligent control, where the system is preheated to be able to deliver faster regulation, tell that the system will be able to deliver this within 1.5 min. Future heat pumps could be designed more appropriately in relation to providing this service based on the same principles.

<u>Suggestions for reconstruction of the FCR-N reserve requirements:</u> With the new measures, it is expected that the heat pump will be able to deliver part of the capacity within 2.5 min (≤ 150 s) as specified for the FCR-N service. A possibility of securing heat pumps as a player in this market could be increasing the time to 3-3.5 min, in order to deliver a higher capacity. For this purpose, heat pumps are preferred to provide an up-regulation service, and therefore it would be less advantageous to retain capacity to deliver FCR-N symmetrically. Asymmetric services would therefore make it more attractive to deliver into this market.

<u>For delivery of aFRR and mFRR:</u>
Present situation: The heat pump can deliver this to a large extent due to demand of delivery within 5 min, even without the intelligent conversion. Here, a significantly higher capacity in part load regulation can be delivered from larger heat pumps than it appears regarding delivery of FCR-N.

<u>Suggestions for restructuring of the FRR reserve requirements:</u> The heat pump could provide significant capacity in this market. Requirements for the 15 min’s recovery time can prevent full shutdown and startup operations, but since this is hardly appropriate anyway, it is only a minor obstacle.”

Based on HOFOR’s experiences with the testing of a heat pump delivering reserves, the above proposals have been stated providing better opportunities for heat pumps to participate in the ancillary service markets in the future.

HOFOR has also reported for electrical boilers, which is out of this reports scope, caused by electrical boiler plants already deliver ancillary services; refer to part 6.3.1.

In the pilot project, reported in part 6.3.2: Example 2: Flexibility from household/industry heat pumps – where it succeeded to aggregate a pool of 315 kW heat pumps in a collaboration between Insero Energy and Neogrid Technologies; their point of view after closing of the pilot project is as follows: “There are no significant technical barriers to participation in the markets - the barriers are all due to the market’s nature – the economical achievement delivering ancillary services by aggregating multiple plants does not meet the cost of establishing the technical solutions.”

The third project, reported in part 6.3.3, where consumers load has been used delivering capacity to the regulation power market with very few activations during the pilot project – their experience was that the integration of the needed control in existing system is expensive and time-consuming.

The following input are summarised in general regarding barriers from the technical and market requirement of EN’s rules and respectively summarised some barriers from the stakeholders/flexible consumers primarily from Energi Danmark, refer to part 6.3.3:

“Barriers from the rules and regulations/Energinet:

- The rule from [12] regarding “back-up capacity from other production units is a demand if production from renewables (wind) are submitted as bids to the capacity reserve market”.
- The demand of full activation time periods of demand products of ancillary services – for FCR 4 hours’ time blocks and for mFRR 1 hour of activation.
- Minimum bids of 0.3 MW of FCR-N to be lowered to 0.1 MW – most important for demand bids – (Svenska Kraftnät allows this).
- Minimum bid of 5 MW of mFRR - most important regarding demand bids – lowering to 1 MW will presumable result in faster introduction of demand bids.
- Also, to allow asymmetrical bids of FCR-N, FCR-D and aFRR in DK1(and in DK2 expected Q3/2020).
- Time settlement of auctions the-day-before-operation is a challenge for demand units and their planning of operation.
- Uncertainties regarding future more restrictive requirements of on-line measurements and control, IT-security and more signal exchange with EN.
- The pool of production and demand is not allowed – more demand units, besides electrical boiler plants, can participate if they become allowed pooled with production units.
- Costs and demands of grid connection and energy measurement requirements (measurement responsibility is now located at the DSO’s).
- Static price tariffs of electricity, which follow a daily profile and not the market prices. The tariffs of electricity must support consumers to act flexible.”

“Barriers seen from the owners of the demand units:

- A widespread understanding of showing flexibility but the operation of the company’s business always comes first in line.
- Implementing the technically features in the demand units’ given the control- and activation potential delivering ancillary services shows long pay-back times. Long pay-back times cause projects implementation to die…
- The flexible consumers are not familiar submitting planning schedules of their operation possibilities to give the baseline of capacity bidding.
- Fear of being unable to deliver in the operation hour and thus receiving financial punishment of no delivery (the risk must stay at the company not at the BRP).”

And for the last subject: “What is it that drive the stakeholders to go for the ancillary market:

- The stakeholders want to make a difference, be climate friendly, optimise their processes and plan for saving energy costs etc.
- The revenue from the sales of ancillary services is secondary – but it matters anyway.”

The last project, reported in part 6.3.4, Example 4: COOP Danmark A/S – FCR Data analysis DK1 – Ramboll was allowed to inform the technical findings, that it actually matters what accuracy the instrument performing the frequency measurement has on the numbers of deactivation of load delivering FCR – if the accuracy is very good (1 mHz) – more deactivations/activations will be the result, which results in more wear of the equipment

<u>Conclusion:</u>
Without doubt heat pumps stand-alone units or combined with electrical boiler plants, which already deliver a larger part of ancillary services today, can in the long term deliver part of ancillary services (FCR, aFRR and mFRR); some of the rules regarding minimum size of bids, part availability, time of regulation, minimum volume of bid, bids hour-by-hour as block bids and the rules, which says, that consumption and production bids must not be aggregated, must be considered changed for these units to participate at market conditions. The willingness to participate delivering ancillary services is great in the district heating community – and in all probability a not utilized technical potential in the cooling industry.

9.4.3 Renewable fuels and Power2X technology

The renewable fuels or Power2X technology sector is an upcoming pioneer sector; which uses electricity converting for fuels or other gasses to be used for industrial purposes as biogas, hydrogen, methanol, ammonia etc.

Ramboll has asked Nature Energy, how they the future delivering ancillary services as a consumer. The answer are in short; the business is primary to focus on process optimisation and product outcome both as biogas and output raw material as liquid manure back to the farmers.

As the production of biogas is rising and the infrastructure is established for the transportation in an expanded gas grid; the biogas is today nearly half/half used for production of heat and electricity in gas power plants – refer to Figure 49. The gas power plants already contribute delivering ancillary services; which can continue in the future with “green gas”.

Two electrolysis projects, refer to part 7.4.1, which gives the Example 1: Electrolysers in the electricity markets in Denmark; here Centrica Energy Trading is balance responsible party for HyBalance (FCR) in Hobro and BioCat Avedøre (mFRR); both these plant can participate in the regulation markets. There remains no doubt these electrolysis utilities can deliver ancillary services – and the volume can be a proportion of the plants size in MW.

Haldor Topsoe has for more than a decade worked with electrolysis, upgrading biogas, generating ammonia synthesis gas, refer to part 7.4.2 with the Example 2: Haldor Topsoe – Electrical driven hydrogen and synthesis gas generation. The project “El upgraded biogas” has demonstrated that the technology can deliver ancillary services – 2-4 % of the design load is the lower operation load for upward regulation; the plant regulates very fast in seconds up- or downward.

<u>Conclusion:</u>

The upcoming and fast expanding sector has undoubtedly both the technical potential and a large potential volume for delivering ancillary services in the future.

The biogas plants are relatively “smaller industrial consumers”; so, as a consumer it will not make sense to deliver ancillary services, but the conversion of the biogas to electricity via a gas turbine/generator, which can deliver ancillary services will be exploitable making more sense as these plants already exist.

9.4.4 Energy storage – electrical systems

Today there are approximately 1.5 MW of stand-alone batteries and 0.5 Mw of electrical vehicles providing ancillary services to Energinet. The development in this scientific area has increased in the last couple of years – new technics of storage systems have been developed – in the coming years funding from the Danish state will give developers of new energy storage technologies the change to develop and demonstrate on a larger scale. In this report only electrical storage systems are considered.

In part 8.3.2 of this report is accounted for the battery energy store systems (BESS's) excellent regulation abilities – BESS can deliver all types of reserves (FFR, FCR, FCR-N, FCR-D, aFRR and mFRR), the only reservation is that a limited storage capacity is available due to the sizing of the battery, which gives also a limited energy transfer in time – hence it can be seen that the BESS are best suited to operate in the FCR and future expected FFR markets, where their speed of operation is an advantage.

The strong fluctuation of the frequency in the Nordic synchronous area, which results in a high number of activations of FCR-N as well as provision of response energy, will cause the BESS to be exposed by many cycles and rapid changes in SoC, these operation conditions could potentially result in severe battery degradation [38]. The high demand of response energy could also deplete the battery, which could cause the battery to be unavailable several days a year. FCR-D shows the lowest response energy turnover in the Nordic synchronous system, which means the battery here will only complete few full-cycles per year. Regarding delivery of FFR the conclusion is that the envelope and power tolerance experienced for delivery of EFR (Enhanced Frequency Response) and FFR in UK (in UK "FFR" means Firm Frequency Reserve) are found to provide the greatest flexibility of the dynamically utilized degree of freedom to support SoC maintenance – hence, similar approaches could be beneficial for BESS providing FFR in other countries.

Battery energy storage systems are also capable to operate in voltage regulation mode in the transmission grid and can control the voltage at the point of connection in the grid, the BESS voltage control mode is a droop control mode. In reactive power mode the BESS can be fixed at an agreed reactive power output but will not respond to voltage variations; this is feasible in the distribution grid. In power factor mode the BESS will operate with a fixed value at an agreed power factor value but will not respond to voltage variations.

Besides all the valuable technical potentials from BESS regarding fast response to frequency change, excellent voltage regulation and reactive power support, there are a few technical challenges regarding BESS integration in the grid, these are listed in part 8.3.2.3.

Starting with the example described in part 8.3.3, the Example 1: BESS installed as part of the EnergyLab Nordhavn; the highlights of the findings in this project are:

- A BESS could be a cost-effective solution/alternative for upgrading in the distribution grid postponing investments in new feeders if peak savings could be provided from the BESS; developers must be able to see this as a good investment/business case – as the DSO's are not allowed to own/install battery systems acc. to the Danish Energy Act [1].
- In the business case, as mentioned above, the income from the BESS delivering ancillary services would have to be feasible for having a business case at all.
- The sizing/dimensioning of the BESS is vital depending of which type of frequency reserve to deliver.
- The BESS installed at Nordhavn managed the test requirements [12] for delivering FCR-D.
- The battery management system and communication system operate satisfyingly after adjustments performed by the system supplier ABB.

More details are available in the source [40] giving the final status report of the EnergyLab Nordhavn installed BESS.

<u>Part conclusion BESS:</u>
Battery energy storage systems have excellent properties for delivering ancillary services; only limited by the capacity of the battery and can be controlled in voltage, reactive or power factor mode.

The two next cases regarding batteries, as described in part 8.3.4 is Example 2: Automotive Battery Systems – Electrical Vehicles (EV), respective Example 2A: True Energy ApS – Aggregation of EV batteries and Example 2B: Nuuve Corporation – Aggregation of EV batteries – gives the following inputs for the summary:

- True Energy and Nuvve Corporation are both managing to deliver FCR-N in DK2 from aggregation of charging/discharging of electrical vehicles.

True Energy has given the following statement regarding the challenges of delivering FCR-N in DK2:
"On the technical side True Energy's challenges included:

- Getting responses from the EV's and servers, that were fast enough to provide frequency regulation within the time limits of the specific services True Energy delivers (FCR and FCR-N)
- The development of algorithms, that included the users' needs and behaviours, the demands from the TSO and the varieties of the EV's – and still produce a solid output (= frequency regulation) every time."

"On the market side True Energy's challenges included:

- Having enough EV's under management in order to be able to bid the minimum capacity."

True Energy's suggestions – "What would make it even better than today:

- Asymmetric regulation is much better for True Energy hence our services would benefit from new services being traded for DK2 (like asymmetric FCR).
- In DK2 we are paid as bid. Getting paid the maximum bid, as in DK1, would make it easier for us to bid in DK2 – so if Energinet wants to support the development of (new) services instead of trading skills, then more services should be paid as in DK1."

From Nuuve Corporation the following statement regarding the challenges of delivering FCR-N in DK2:

- "The EV as an asset opens a number of opportunities for the grid companies (DSO's) and the TSO to gain flexibility and significant savings
- However, there are some challenges to get there:
    - Tariffs are paid twice, when the EV is performing services for the grid. This problem has to be eliminated and that can be done implementing a <u>tariff-neutral re-export</u> of power to the grid (a rather simple exercise on the technical side).
    - Since the V2G chargers has not yet reached mainstream and mass production they are expensive. To expand the infrastructure of V2G chargers an amount must be dedicated for V2G chargers and support for V2G ready vehicles for fleet owners across the country. We are happy to assist in calculating the needed amount.
    - Information of V2G technology is needed. Support to raise the awareness level is needed in terms of campaigns and education for the main markets."

In part 8.3.4.1 Ramboll refers to a prospect [41] published by the Union of the Electricity Industry – eurelectic – and together with the input from True Energy and Nuuve Corporation the following part conclusion regarding reserves provided by EV's can be stated.

<u>Part conclusion batteries from EV's:</u>
As the research and development of EV's with batteries and the systems already developed delivering FCR-N in DK 2 of True Energy and Nuuve Corporation, who also are represented in more countries in Europe, shows, there is no doubt, that there is a future growing technical potential of delivering frequency reserves from aggregation of the charging/discharging of electrical vehicles.

In part 8.3.5 the Example 3: UPS-Systems with battery back-up are presented delivering primary frequency regulation; reference [42]and [43] are reported – the summary from this part are:

- Batteries of UPS-systems can deliver FCR-N (Svenska Kraftnät and Eaton EMEA cooperation); but due to many frequency activations in the Nordic synchronous area, it will cause wear of the battery, which must be considered in the business case.
- The topology of the UPS-system must be considered very carefully (refer to [42]),
- Method to be used for delivering ancillary services – islanding or the dynamic regulation.
- In the project in Sweden the prequalification test for delivering FCR-D was successfully completed; besides the logging and saving measured values locally within the 1 s resolution requirement.
- The result from this project show that UPS-systems is a potential future resource to deliver FCR-D in the reserve market.

<u>Part conclusion batteries from UPS-systems:</u>
The main conclusion from Svenska Kraftnät and Eaton EMEA cooperation project are that UPS-systems with battery back-up have a technical potential delivering FCR-D in the future.

Battery energy storage systems can be installed in combination with wind power plants or photovoltaic power plants or all three technologies combined in a Hybrid Power Plant (HyPP) – this is considered in part 8.4. Describing the Technology: Hybrid Power Plants – combining all three technologies is performed in reference [47] seeking for an control strategy of controlling a HyPP for delivery of FFR, FCR and FRR – and it succeeded– as their main conclusion states:

- "Thus, the outcome of this study is a control strategy that enables a hybrid power plant to provide frequency support in a system with reduced inertia, a large share of renewable energy, and power electronics-interfaced generation."

<u>Part conclusion combining BESS with other renewable production sources:</u>
Ramboll has not been able to provide documentation reports or system tests of combined plants – as a HyPP – the general assumption from reviewing [47] is:

- It is to be expected, that combinations of these technologies will also have the option to deliver ancillary services with research and development of control strategy and controllers for each technology working together.

As the production of energy from renewables, wind and photovoltaic power plants, is increasing – there will be times where the production will give a surplus, which besides a sector coupling to Power2X-technologies also could argue for an equalisation of the cost of energy combining wind power plants (WPP's) and/or photovoltaic power plants (PVP's) with a battery energy storage (BESS). A general trend seen is the exploitation of potentialities in the renewable produced energy amount motivates the establishment of combined offshore wind farms with BESS, PVP's with BESS and onshore wind and sun energy production plants combined with BESS.

9.5 Conclusion

Ramboll delivers a report acc. to the agreement with Energinet, which can be used answering the initiating assignment by the Danish Utility Regulator:

- *“The Danish Utility Regulator requests that Energinet continue supporting the growth of new technologies in the development of market design and provide a better overview of the potential of these new technologies. In this context, the Danish Utility Regulator recommends that Energinet identifies and works to remove unnecessary entry barriers and challenges to make use of new technologies in the reserve capacity and energy activation markets. The Danish Utility Regulator recommends that Energinet, with the involvement of market players and international experience, prepares and publishes a report of the potentials of new technologies based on the Technology Data catalogue before the end of 2019."*

Part conclusions are worked out and stated in part 9.2, 9.3 and 9.4:

Summary and conclusion of technical and market requirements:

The frequency reserves technical requirements and process as stated in the EU Regulations will be lasting many years ahead.

Options of changing a parameter defining a specific frequency reserve could only be one or more of the following: Direction – upward and downward regulation symmetrical or asymmetrical (refer to Appendix 4 Table 1), partly availability, times defined for partly delivery (ex. 50 % within 5 s for FCR-D) of a reserve as for FCR and FCR-D (refer to Appendix 4 Table 2) - if one or more of these characteristics must change, it must be agreed in the SOA’s of CE or Nordic synchronous area.

More changes has been suggested by consumers and BRP’s – especially concerning integration of more ancillary services delivered from consumers, listed in this summary:

- FCR-D: minimum bid 0.3 MW lowered to 0.1 MW
- FCR-N: minimum bid 0.3 MW lowered to 0.1 MW
- aFRR: minimum bid 1 MW lowered to 0.5 MW
- mFRR: minimum bid 5 MW lowered to 1 MW
- Minimum bid of 5 MW of mFRR - most important regarding demand bids – lowering to 1 MW will presumable result in faster introduction of demand bids.
- The demand of full activation time periods for demand products of ancillary services e.g. with FCR in 4 hours’ time blocks and mFRR in1 hour of activation should be adjusted to shorter time periods.
- Allowing asymmetrical bids of FCR-N in DK2 and aFRR in DK1 (and later in DK2 as expected Q3/2020).
- Time settlement of auctions the-day-before-operation is a challenge for demand units and their plan of operation.
- Uncertainties regarding future more restrictive requirements of on-line measurements and control, IT-security and more signal exchange with EN.
- The pool of production and demand is not allowed – more demand units, besides electrical boiler plants, can participate if they become allowed pooled with production units.
- Demands for grid connection and energy measurement requirements (measurement responsibility is now located at the DSO’s) are costly for the consumers.
- Static price tariffs of electricity, which follow a daily profile and not the market prices. The tariffs of electricity must support consumers to act flexible.

Barriers seen from the owners of the demand units:

- A widespread understanding of showing flexibility but the operation of the company's business always comes first in line.
- Implementing the technical features in the demand units' given the control- and activation potential delivering ancillary services shows long pay-back times. Long pay-back times cause projects implementation to die out.
- The flexible consumers are not familiar submitting planning schedules of their operation possibilities to give the baseline of capacity bidding.
- Fear of being unable to deliver in the operation hour and thus receiving financial punishment of no delivery (the risk must stay at the consumer company not by the BRP).

And for the last subject: What is it that drive the stakeholders to go for the ancillary market:

- The stakeholders want to make a difference, be climate friendly, optimise their processes and plan for saving energy costs etc.
- The revenue from the sales of ancillary services is secondary – but it matters anyway.

The above listed input must be considered by EN to especially give more demand units and plants to deliver ancillary services.

The current market rules will supposedly continue to apply until the new market platforms NBM, PICASSO and MARI are established with implementation of the different sorts of capacity and energy markets, refer to part 3.1. In the current existing markets locally in Denmark and at Nord Pool, EN purchases today reserve capacity and reserve energy to balance and handle disturbances. The ancillary markets are characterised by having a merit order list (MOL).

The tender condition for delivering FFR in DK2 will be included in an update of [12] after the DUR approval of the "Methodology for technical requirements for and new procurement method of fast frequency reserve (FFR) in DK2", which EN published for stakeholders public consultation the 13th of December 2019.

Suggestions for adjustment of the market rules:
Today EN's rules in the tender conditions of ancillary services [12] delivered by wind turbines are as follows (page 4/44 in [12]): "Furthermore, a group of wind turbines cannot submit bids on their own in the different ancillary services markets. Wind turbines may be included along with other production to guarantee supply in the event that the wind turbines are unable to deliver the required performance due to failing wind."

Above rule is, of cause, justified because the balancing process must be performed securely, reliable, efficiently and with enough quantity and quality; but the rule provides challenges - as more and more developers/producers of power do not have a mix of power plants in their portfolio, then the mixing of reserves of security reasons must be performed elsewhere in the organisation of the market – this question has to be solved in the auspices of new market solution and rules combined with risk assessment. "The rules in the tender conditions [12] quoted above must be changed considering this issue."

Summary and conclusion of the selection of the new technologies:
The "New Technology" category – the chosen technology – and the examples, which are described in the chapters 5, 6, 7 and 8, because they were identified as a new technology, which can provide frequency ancillary services/system stability properties, but today only do so to a minor extent or not at all contributes.

Ramboll's suggestion is, that in an update of the Technology Data catalogues:

- Technology Data for Heating installations
- Technology Data for Renewable Fuel
- Technology Data for Energy Storage

further considerations are performed regarding, whether the technology could be capable of delivering ancillary services – and which type of reserve or property?

Summary and conclusion "Technical potential of new technologies":
Four main categories of new technology have been surveyed from the Technology Data catalogues for potential to deliver ancillary services:

- Generation Plants or Units
  - Wind turbines/wind power plants have the technical potential and a large volume (proportionally factor of the installed power).
  - Photovoltaic plants have the technical potential and a large volume (proportionally factor of the installed power).
- Demand Plants or Units
  - Heat Pumps: Without no doubt heat pumps stand-alone units or combined with electrical boiler plants and gas fueled CHP (today based on fossil gas, but in longer term based on "green gas"), which already deliver a larger part of ancillary services today, can in the long term deliver part of ancillary services (FCR, aFRR and mFRR); some of the rules regarding minimum size of bids, part availability, time of regulation, minimum volume of bid, bids hour-by-hour as block bids and the rules, which says, that consumption and production bids must not be aggregated must be considered changed for these units to participate on market conditions.
  - The electric boilers are e.g. excellent for delivering services directly in the grid without any conversion as for batteries. The willingness to participate delivering ancillary services is great in the district heating community, and in case of cost-effective incentives, which reflect the advantage of this regulation will boost the development.
  - Cooling: In all probability a not utilized technical potential is present in the cooling industry, as district cooling based on large heat pumps for combined heating and cooling in combination with chilled water storage tanks and even ground source cooling is a new system approach which can offer almost the same services as the district heating.
- Renewable Fuels or Power2X
  - The upcoming and fast expanding sector has in no doubt both the technical potential and a large volume for delivering ancillary services in the future.
  - The biogas plants are relatively "smaller industrial consumers"; so, as a consumer it will not make sense to deliver ancillary services, but the conversion of the biogas to electricity via a gas turbine/generator, which can deliver ancillary services will be exploitable making more sense as these plants already exist.
- Energy Storage
  - Battery energy storage systems have excellent properties for delivering ancillary services; only limited by the capacity of the battery and can be controlled in voltage, reactive or power factor mode.
  - As the research and development of EV's with batteries and the systems already developed delivering FCR-N in DK 2 of True Energy and Nuuve Corporation, who also are represented in more countries in Europe, shows, there is no doubt about, that there are future growing technical potential of delivering frequency reserves from aggregation of the charging/discharging of electrical vehicles.

- o The main conclusion from Svenska Kraftnät and Eaton EMEA cooperation project are that UPS-systems with battery back-up have a technical potential delivering FCR-D in the future.
- o Ramboll has not been able to provide documentation reports of system tests of combined plants – as a HyPP – the general assumption from reviewing [47] is: It is to be expected, that combinations of these technologies will also have the option to deliver ancillary services with research and development of control strategy and controllers for each technology working together.
- o As the production of energy from renewables, wind and photovoltaic power plants, is increasing – there will be times where the production will give a surplus, which besides a sector coupling to Power2X-technologies also could argue for an equalisation of the cost of energy combining wind power plants (WPP's) and/or photovoltaic power plants (PVP's) with a battery energy storage (BESS). A general trend seen are the exploitation of potentialities in the renewable produced energy amount motivates the establishment of combined offshore wind farms with BESS, PVP's with BESS and onshore wind and sun energy production plants combined with BESS.

Ramboll has found that there is without a doubt technical potential for delivery of ancillary services from new types of converter-based generation units with source from wind and sun, wind turbines and photovoltaic plants, refer to part 8.4.2. Demand plants and units, such as large heat pumps or aggregated cooling equipment, which are also increasingly being supplied via converters, can already supply ancillary services or are being prepared for delivering ancillary services, when accounts are taken of dimensioning the associated thermal and/or mechanical systems accordingly. Supplementary deliveries of ancillary services from Power2X technologies are possible today, as shown in 7.4.1 and 7.4.2, the technical potential is available, and the amount of plants will supposedly expand in the coming years. Battery energy storages can be highlighted as having excellent technical potential in terms of delivering ancillary services within the limits of the installed capacity.

10. REFERENCES

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[30] RePlan D2 deliverable: Voltage control support and coordination between ReGen plants in distribution systems. The report can be downloaded from RePlan-project website: http://www.replanproject.dk/publications/deliverable-reports

[31] RePlan D3 deliverable: Frequency stability control support from Regen plants, 2017. The report can be downloaded from RePlan-project website: http://www.replanproject.dk/publications/deliverable-reports

[32] Mind4Enery MINT Flyer-MINT_v1.0.pdf, which can be downloaded: https://www.mind4energy.com/downloads/

[33] Energinet report "Rapport Evaluering – Pilotprojekter, Nye teknologier i markedet for systemydelser"; published the 28th of May 2018 to be downloaded in Energinet's website (only in Danish): https://energinet.dk/El/Systemydelser/Nyheder-om-systemydelser/Nye-teknologier-i-markedet-for-systemydelser

[34] Energinet report: "PTX in Denmark before 2030, Short term potential of PtX in Denmark from a system perspective"; published April 2019, the report can be downloaded in both an English and a Danish version (below in the right corner of): https://energinet.dk/Analyse-og-Forskning/Analyser/RS-Analyse-April-2019-PtX-i-Danmark-foer-2030

[35] Presentation: "Solid Oxide Cell Enabled Ammonia based Power production", John Boegild Hansen, Haldor Topsoe A/S; the presentation can be downloaded at: https://nh3fuelassociation.org/wp-content/uploads/2017/11/NH3-Energy-2017-John-Hansen.pdf

[36] Sandia National Laboratories: "Electricity Storage Handbook in Collaboration with NRECA", download website: https://prod-ng.sandia.gov/techlib-noauth/access-control.cgi/2015/151002.pdf

[37] Energinet: Technical regulation 3.3.1 (is currently in revision phase); download in Energinet's website: https://en.energinet.dk/Electricity/Rules-and-Regulations/Regulations-for-grid-connection

[38] Fast Frequency Response with BESS: A Comparative Analysis of Germany, Great Britain and Sweden. Raphael Hollinger, Agustin Motte Cortes and Thomas Erge. Intersectoral Energy Systems and Grid Integration, Fraunhofer Institute for Solar Energy Systems ISE Freiburg, Germany. ©2018.

[39] Master Thesis: Camilla Lund, "Techno-economic analysis of operational strategies for a battery energy storage system installed in Nordhavn", June 2017. Download website: http://www.energylabnordhavn.com/phd-and-master-theses.html

[40] Delivery no.: D6.3.4 + D6.3.7 "Results on Radius Elnet usage of Battery", Authors: Niels Chr. Nordentoft, Ole Michael Pedersen, Mads Paabøl Jensen and Davide Innocenti. Dated 2019-10-23/WPL. Download on website: http://www.energylabnordhavn.com/uploads/3/9/5/5/39555879/d6.3.4_and_d.6.3.7_results_on_radius_elnet_usage_of_battery.pdf

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[42] "Data centers as a source of dynamic flexibility in smart girds", Ilari Alaperä, Samuli Honkapuro, Janne Paananen ELSEVIER Applied Energy 229 (2018) 69-79, Download on website: https://www.sciencedirect.com/science/article/abs/pii/S0306261918310845?via%3Dihub

[43] Svenska Kraftnät: "Slutrapport pilotprojekt inom förbrukningsflexibilitet och energilager", Ärendenr: SVk 2017/3551, dated 2018-06-29, download on website: https://www.svk.se/siteassets/om-oss/rapporter/2018/slutrapport-pilotprojekt-inom-forbrukningsflexibilitet-och-energilager.pdf

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[45] Paper from Proceedings of the 3rd International Hybrid Power Systems Workshop: "Vestas Power Plants Solutions Integrating Wind, Solar PV and Energy Storage", authors: Lennart Petersen, Bo Hesselbæk, Antonio Martinez, Roberto M. Borsotti-Andruszkiewicz, Claudio German, Nathan Steggel and Dave Osmond; the paper can be downloaded here: https://vbn.aau.dk/ws/files/275293644/TENE18_78.pdf

[46] Final report ForskEL project no. 10739: "BESS project, Smart grid ready, Battery Energy Storage System for future grid", Danish Technological Institute, Energi Danmark and Vestas. Submitted 13th of January 2017. Report can be downloaded on energiforskning.dk: https://energiforskning.dk/sites/energiteknologi.dk/files/slutrapporter/bess_final_report_forskel_10731.pdf

[47] Article in Energies 2019, 12, 919; doi:10.3390/ en12050919: "A Novel Control Architecture for Hybrid Power Plants to Provde Coordinated Frequency reserves"; Daniel Vázques Pombo, Florin Iov and Daniel-Ioan Stroe; published 9th of March 2019: https://www.mdpi.com/1996-1073/12/5/919

[48] Document: "All CE TSO's agreement on the load-frequency-control structure in accordance with article 139 of the commission regulation (EU) 2017/1485 of 2 august 2017 (SOGL) establishing a guideline on electricity transmission system operation." Download ENTSO-E website: https://docstore.entsoe.eu/Documents/nc-tasks/SOGL/SOGL_A118.1_180808_CE%20SAOA%20part%20A_final_180914.pdf

[49] Nordic TSO's agreement: bilag-21-main-document-lfc-block-proposal-nordic-synchronous-area-_final-clean.pdf & bilag-22-explanatory-document-lfc-block-proposal-final-clean.pdf; the documents can be downloaded on the Danish Utility Regulator website in Danish: https://forsyningstilsynet.dk/el/afgoerelser/godkendelse-af-forslag-til-fastlaeggelse-af-lfc-kontrolblokke-i-norden

APPENDIX 1
DANISH LEGISLATION, RULES AND REGULATIONS

1. The Danish Electricity Supply Act (Elforsyningsloven)

The Danish Electricity Supply Act (in Danish “Elforsyningsloven”), latest version 15th of August 2019 as LBK nr. 840, which can be downloaded on “Retsinformation’s homepage in Danish language https://www.retsinformation.dk/Forms/R0710.aspx?id=209985
The purpose of the law is to ensure that the Denmark’s electricity supply is organized and implemented in accordance with the regards to security of electricity supply, social economy, environment and consumer protection. The law must within for this objective secure the consumers access to cheap electricity and continue to give the consumers influence on the management of the values of the electricity sector.
The Danish Electricity Supply Act must comply with above provisions, promoting a sustainable energy use, including energy savings and the use of cogeneration of heat and power, renewable and environmentally friendly energy sources, as well as ensuring efficient economically use of resources and creating competition on markets for electricity production and trade.
The law applies to the production, transport, trade and supply of electricity.

The Danish Electricity Supply Act is subject to several ministerial orders published (in Danish “Bekendtgørelser”) to be mentioned here are the following:

a. Revenue framework of Distribution System Operators (“Bekendtgørelse om indtægtsrammer for netvirksomheder netvirksomheder”), https://www.retsinformation.dk/pdfPrint.aspx?id=202321 https://www.retsinformation.dk/Forms/R0710.aspx?id=205135

2. Act on Energinet (Lov om Energinet)

The Act on Energinet (in Danish “Bekendtgørelse af lov om Energinet”), latest version 27th of June 2018 as LBK no. 997, which can be downloaded on “Retsinformation’s homepage in Danish language: https://www.retsinformation.dk/pdfPrint.aspx?id=202154
The purpose of Energinet is to ensure the efficient operation and development of the overall infrastructure on electricity and gas infrastructure and to ensure open and equal access for all network users.

3. Act on Promotion of Renewable Energy (VE-loven)

The Act on promotion of Renewable Energy (in Danish “Bekendtgørelse af lov om fremme af vedvarende energi”), latest version 4th of April 2019 as LBK no. 356, which can be downloaded on “Retsinformation’s homepage in Danish language:
https://www.retsinformation.dk/pdfPrint.aspx?id=208204
The purpose of the act is to promote the production of energy by using renewable energy sources accordingly with a view of reducing climate, environmental and socio-economic considering the dependence of fossil fuels, ensuring the security of supply and reduce emissions of CO_2 and other greenhouse gases. The act shall contribute to ensuring the fulfilment of national and international objectives to increase the proportion of energy produced using renewable energy sources.

4. Act on EUDP-program (Lov om EUDP)

The Act on EUDP-program (in Danish: "Bekendtgørelse af lov om et Energiteknologisk Udviklings- og Demonstrationsprogram og om Green Labs DK-programmet") latest version 28th of August 2019 as LBK no. 895, which can be downloaded on "Retsinformation's homepage in Danish language: https://www.retsinformation.dk/pdfPrint.aspx?id=210053

The purpose of this act is to support the energy policy objectives regarding security of supply, Danish independence of fossil fuels, consideration of the global climate and a cleaner environment, as well as cost efficiency in development projects. The law must at the same time promote the exploitation and development of business potential in the field for the benefit of growth and employment.

5. Danish rules and regulations for grid connection of production units

The Danish rules for grid connection of production units on the transmission grid acc. to the implementation of the RfG's rules in Denmark in force from 27th of April 2019 is available on Energinet's website available links:
https://energinet.dk/El/Nettilslutning-og-drift/Regler-for-nye-anlaeg
https://energinet.dk/El/Nettilslutning-og-drift/Nettilslutning-og-teknik

The Danish rules for grid connection of production units on the distribution and low voltage grid acc. to the implementation of the RfG's rules in Denmark in force from April 2019 is available on Dansk Energi's website (in Danish):
https://www.danskenergi.dk/vejledning/nettilslutning/tekniske-regler-produktion

Old versions of the grid connection rules of production units connected before 27th of April 2019 can be found on Energinet's website available links:
https://en.energinet.dk/Electricity/Rules-and-Regulations/Regulations-for-grid-connection
https://energinet.dk/El/Nettilslutning-og-drift/Regler-for-eksisterende-anlaeg

6. Danish rules and regulations for grid connection of demand units

The Danish rules for grid connection of demand units on the transmission grid acc. to the implementation of the DCC's rules in Denmark in force from 18th of August 2019 is available on Energinet's website available links:
https://energinet.dk/El/Nettilslutning-og-drift/Regler-for-nye-anlaeg
https://energinet.dk/El/Nettilslutning-og-drift/Nettilslutning-og-teknik
https://energinet.dk/El/Nettilslutning-og-drift/Regler-for-eksisterende-anlaeg#AnlaegTilOgMed11kW

The Danish rules for grid connection of demand units on the distribution and low voltage grid acc. to the implementation of the DCC's rules in Denmark in force from April 2019 is available on Dansk Energi's website (in Danish):
https://www.danskenergi.dk/vejledning/nettilslutning/tekniske-regler-forbrug

Old versions of the grid connection rules for demand units connected before 27th of April 2019 can be found on Energinet's website available links:

https://energinet.dk/El/Nettilslutning-og-drift/Regler-for-eksisterende-anlaeg#Forbrugsanlaeg

7. Danish rules and regulations for electricity market

The directive (EU) 2019/944L of 5 June 2019 “on common rules for the internal market for electricity and amending Directive 2012/27/EU” can be downloaded from EUR-Lex: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32019L0944

The Danish rules and regulations for electricity markets participants:
The rights and obligations of grid companies and commercial players in the Danish electricity market are regulated by the market regulations and rules. The market regulations are guidelines that are necessary in order to ensure that the electricity market functions properly and that settlement is performed correctly. The market regulations deal with issues such as terms and conditions for change of supplier, daily handling of notifications, balance settlement and standards governing the transfer of data between players.
The market regulations are primarily aimed at balance responsible parties, electricity suppliers and grid companies.
The market regulations can be found on Energinet’s website in English:
https://en.energinet.dk/Electricity/Rules-and-Regulations/Market-Regulations
The market rules and regulation (in English):
Regulation A: Principles for the electricity market
Regulation B: Terms of electricity market access
Regulation C1: Terms of balance responsibility
Regulation C2: Balancing market
Regulation C3: Handling of notifications and schedules
Regulation D1: Settlement metering
Regulation D2: Technical requirements for electricity metering
Regulation E: Settlement of environmentally friendly electricity generation
Regulation F: EDI Communication
Regulation F1: EDI communication with the DataHub in the electricity market
Regulation G: Discretionary policy and data protection procedures
Regulation I: Master data.

The market regulations can be found on Energinet’s website in Danish:
https://en.energinet.dk/Electricity/Rules-and-Regulations
The market rules and regulations (in Danish):
Forskrift A: Principper for elmarkedet
Forskrift B: Vilkår for adgang til elmarkedet
Forskrift C1: Vilkår for balanceansvar
Forskrift C2: Balancemarkedet og balanceafregning
Forskrift C3: Planhåndtering - daglige procedure
Forskrift D1: Afregningsmåling og afregningsgrundlag
Forskrift D2: Tekniske krav til elmåling
Forskrift E: Miljøvenlig elproduktion og anden udligning
Forskrift F: EDI-kommunikation
Forskrift F1: EDI-kommunikation med DataHub i elmarkedet
Forskrift G: Diskretionspolitik og procedurer vedr. datasikkerhed
Forskrift I: Stamdata.

All the stated documents listed as “Forskrift X” can be downloaded in Energinet’s website, refer to: https://energinet.dk/El/Elmarkedet/Regler-for-elmarkedet/Markedsforskrifter

8. The Heating Supply Act ("Varmeforsyningsloven")

The Heating Supply Act (in Danish "Varmeforsyningsloven"), latest version 21st of January 2019 as LBK nr. 840, which can be downloaded on "Retsinformation's homepage in Danish language: https://www.retsinformation.dk/Forms/R0710.aspx?id=206417

The purpose of the law is to promote the most socio-economic, including environmentally friendly, use of energy for building heating, supply of hot water and within this framework to reduce energy supply dependence on fossil fuels.

APPENDIX 2
CONTINENTAL EUROPE SYNCHRONOUS AREA (DK1) LFC STRUCTURE

REFERENCE for Appendix 2

In this appendix the load-frequency-control (LFC) structure is described using extract from the CE TSO's agreement approved by the regulators, the agreement reference: "All CE TSO's agreement on the load-frequency-control structure in accordance with article 139 of the commission regulation (EU) 2017/1485 of 2 august 2017 (SOGL) establishing a guideline on electricity transmission system operation"[143][48].

Excerpt quoted from the document for the approved LFC structure in DK1:

"LFC Block Determination

"The operation of Load-Frequency Control processes is based on operational areas, where every area has their own responsibilities in the LFC structure. The overall body is the Synchronous Area in which frequency and phase are the same for the whole area. The Synchronous Area CE consists of several LFC Blocks, each LFC Block consists of one or more LFC Areas. An LFC Area itself consists of one or more Monitoring Areas, which also consist of one or more Scheduling Areas.

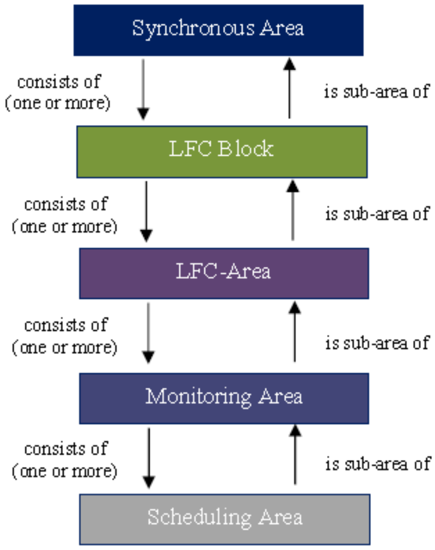

Figure 1: Hierarchy of operational areas

The above described hierarchy is illustrated in Figure 1: Hierarchy of operational areas. Each of these operational areas have their own obligations. A Scheduling Area is responsible for the scheduling process in that area. A Monitoring Area has in addition to the scheduling the obligation to calculate and measure the active power interchange in real-time in that area. An LFC Area has the additional obligation to fulfil the Frequency Restoration Control Error Target Parameters by using the Frequency Restoration Process.

A LFC Block is additionally responsible for the dimensioning of FRR and RR. The Synchronous Area has the obligation to fulfil the Frequency Restoration Control Error Target Parameters by using the Frequency Containment Process."

Resumé from the text quoted above:

TSO EN for Western Denmark (DK1) is a "Scheduling Area" and a "Monitoring Area", an "LFC-Area" together with TTG (TenneT TSO GmbH Germany), and forming a LFC block together with TNG (TransnetBW GmbH Germany), TTG (TenneT TSO GmbH Germany), AMP (Amprion

[143]Document can be downloaded here: https://docstore.entsoe.eu/Documents/nc-tasks/SOGL/SOGL_A118.1_180808_CE%20SAOA%20part%20B_final_180914.pdf

Germany), 50HZT (50Hertz Transmission GmbH Germany) and CREOS (Creos Luxembourg) in the CE "Synchronous Area" with reference to Figure 1.

Continuation of excerpt quoted from document reference [48]:
"Demarcation of Scheduling Areas, Monitoring Areas, LFC Areas and LFC Blocks
Each TSO operating a Monitoring Area, an LFC Area or a LFC Block shall cooperate with TSOs of neighbouring Monitoring Areas, LFC Areas and LFC Blocks

- to demarcate its areas by the position of physical points of measurement of the interchanged power over Tie-Lines and Virtual Tie-Lines;
- the TSOs operating a Tie-Line shall agree on one physical measurement point which serves as the common point of control for both TSOs;
- the TSOs operating a Tie-Line shall agree on a fall-back physical measurement point;
- to declare the list of Tie-Lines and Virtual Tie-Lines of each Monitoring Area, LFC Area and LFC Block in operation (including transmission lines and transformers of the different voltage levels between the areas) to the SG CSO and
- to maintain and update the list of Tie-Lines and Virtual Tie-Lines.

Connection of Power Generating Modules and Demand Facilities via Virtual Tie-Lines
Two or more TSOs of more than one LFC Areas shall have the right to agree on cross-border operation of Power Generating Modules or Demand Facilities through Virtual Tie-Lines. In this case, a share of the respective Active Power output is transferred via the Virtual Tie-Line.

Process Activation Structure
The Process Activation Structure of the synchronous area CE according to Article 140 of the SOGL includes mandatory processes:

- the Frequency Containment Process (FCP);
- the Frequency Restoration Process (FRP) and
- the Time Control Process.

Furthermore, there are optional processes:

- the Reserve Replacement Process (RRP);
- the Imbalance Netting Process;
- the Cross-Border FRR Activation Processes and
- the Cross-Border RR Activation Process.

In case of cross-border process, the FRCE might be recalculated in a coordinated manner in order to correspond to the remaining imbalance the LFC area is responsible for. The recalculation of FRCE is using optionally as inputs: The Virtual Tie-Line(s) involved in the cross-border process, the set-points of FRR activation and the effective FRR activation.

In any case, the calculation of FRCE is mandatory for an LFC Area. When there is no coordinated calculation of FRCE, the ACE for an LFC Area is directly determined as equal to the opposite of the LFC input according to Figure 2.

The Process Activation Structure of the synchronous area CE is implemented in each LFC Area according to the control process in

- The control error, i.e. input, of the FCP is the frequency deviation;
- The control error, i.e. input, of aFRP is the LFC input of an LFC Area;
- The mFRP and RRP are manually triggered by the TSO in order to release or to supplement aFRP based on observed or expected imbalances;

- Optionally, optimization of local aFRP may be introduced leading to additional aFRR activation (e.g. predictive aFRR activation)."

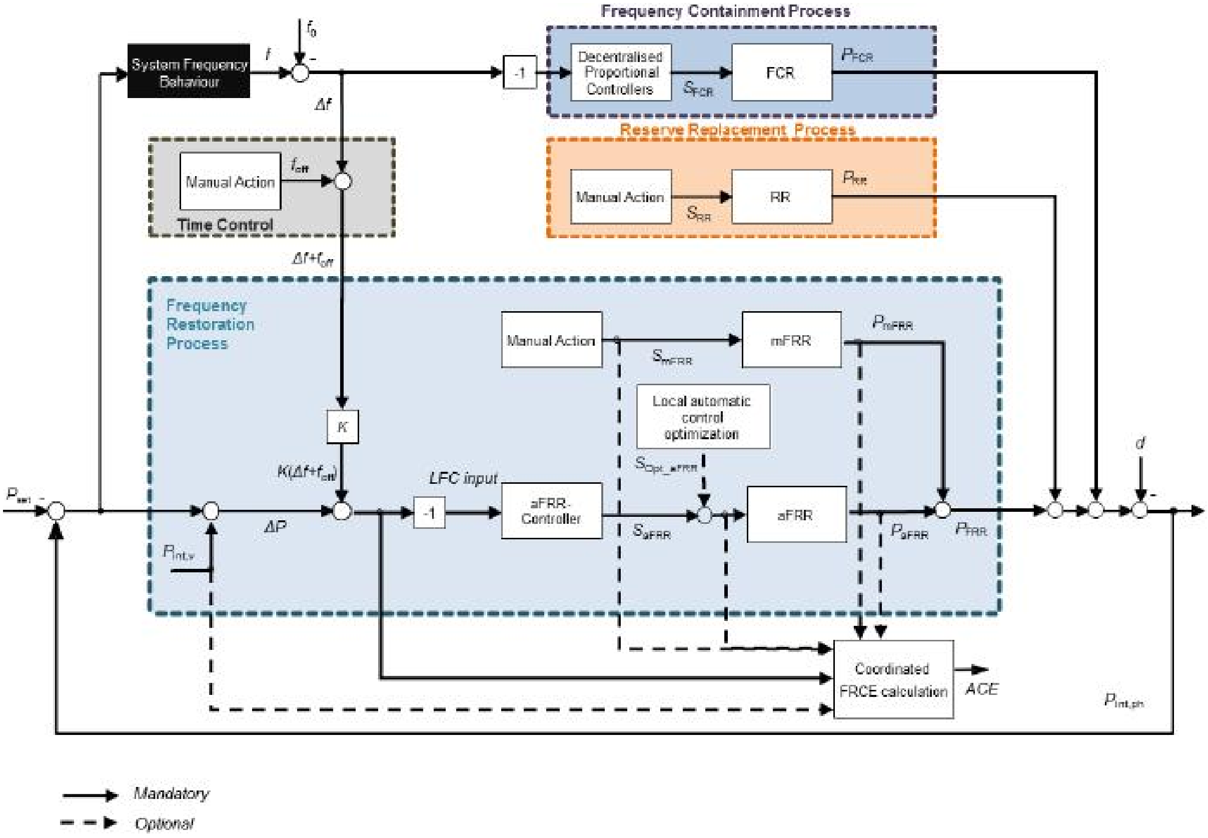

Figure 2: Control Process[1]

"1 The mandatory ACE arrow leading to the box of this coordinated calculation is only mandatory when there is no coordinated FRCE calculation."

Resumé from the text quoted above:
"Table 1: Short Descriptions and Sign Conventions" for the variables of the regulation process shown in "Figure 2" can be found in the original document, refer to reference [47], whereas the abbreviations used in "Figure 2" are defined in part 3.2. The purpose to reproduce this part of the agreements content and "Figure 2" here in appendix is to explain the implementation of the processes in the control & regulating circuit, as outlined in the figure, of the "Frequency Containment Process" and the "Frequency Restoration Process". Figure 4 in part 3.3.1.1 is identical with "Figure 2" except for the "Reserve Replacement Process" shown in the orange box in "Figure 2", as this process isn't used in the LFC Block of DE-LU-DK. The processes in the LFC Block of DE-LU-DK must be supported by the delivery of frequency reserves: FCR, aFRR and mFRR acc. to the requirements of each TSO and among them EN for the CE synchronous area and LFC Block DE-LU-DK, as described in part 3.3.1.1.

Continuation of excerpt quoted from the document reference [48]:

"*Frequency Containment Process (FCP)*
Implementation of the Control Function
Each TSO of each LFC Area shall implement the Frequency Containment Process and organise the availability of the corresponding reserves, according to Article 142 of the SOGL.

Dimensioning rules for FCR for the TSO's of CE the synchronous area are:
"The FCR dimensioning for the synchronous area CE in positive and negative direction is equal to the reference incident of 3000 MW, according to SOGL article 153(2b.i).

The shares of the reserve capacity on FCR required for each TSO P_i as initial FCR obligation for a considered calendar year t shall be based on the following expression, according to Article 153(2d) for all TSOs in SA CE:

$$P_{i,t} = FCR_{dimensioning} \cdot \left(\frac{G_{i,t-2} + L_{i,t-2}}{G_{u,t-2} + L_{u,t-2}} \right)$$

With:

- $P_{i,t}$ being the inital FCR obligation for TSO i for the calendar year t;
- $FCR_{dimensioning}$ being the FCR dimensioning value calculated for synchronous area CE;
- $G_{i,t-2}$ being the electricity generated in the control area i (including the electricity production for exchange of reserves and scheduled electricity production from jointly operated units or groups) during the second last calendar year with respect to the considered year t;
- $L_{i,t-2}$ being the electricity consumption in the control area i during the second last calendar year with respect to the considered year t;
- $G_{u,t-2}$ being the total (sum of) electricity production in all control areas of the synchronous area CE during the second last calendar year with respect to the considered year t;
- $L_{u,t-2}$ being the total consumption in all control areas of the synchronous area CE during the second last calendar year with respect to the considered year t.

Every year but not later than March 31th, each TSO of the synchronous area CE shall provide to each other the data regarding the generation and consumption in its control area in the previous calendar year."

Continuation of excerpt quoted from the document reference [48]:

Implementation of the Frequency Restoration Process (FRP)
Implementation of the Control Function
Each TSO of each LFC Area shall implement the Frequency Restoration Process (FRP) with a respective Frequency Restoration Controller and organise the availability of the respective reserves. The FRR shall be used for the Frequency Restoration Process, according to Article 143 of SOGL, in order to regulate the ACE to zero, other purposes, for example, the minimisation of unintentional energy exchange, are not allowed."

Comment:
The details describing the frequency restoration controller operation modes isn't reproduced here, refer to the original document with reference to note 143.

The last part of the document of reference [48] is reproduced here:

"aFRR minimum amount recommendation:
The amount of aFRR is the range of adjustment within which the Frequency Restoration Controller can operate automatically, in both directions (positive and negative) at the time concerned, from the working point of the Frequency Restoration Reserves.
The amount of the aFRR that is needed typically depends on the size of load variations, schedule changes and generating units. In this respect, the recommended minimum amount of aFRR has to ensure

- that the positive aFRR is larger than the 1st percentile of the difference[2] of the 1-minute average ACEol[3] and the 15 minutes average ACEol of the LFC Block of the corresponding quarter of hour[4], and
- that the negative aFRR is larger than the 99th percentile of the difference of the 1-minute average ACEol and the 15 minutes average ACEol of the LFC Block of the corresponding quarter of hour.

This recommended statistical approach is based on historical data.

[2] Difference to be calculated on 1-minute resolution
[3] **ACEol** means remaining ACE open loop without contribution of mFRR and RR activations.
[4] To be calculated between minutes 0:00-14:59, 15:00-29:59, 30:00-44:59, 45:00-59:59 of each hour of the day.

An alternative approach based on empiric noise management (recommended in the former UCTE) may also be taken into account leading to recommended minimum amount of aFRR given in the following Figure 3:

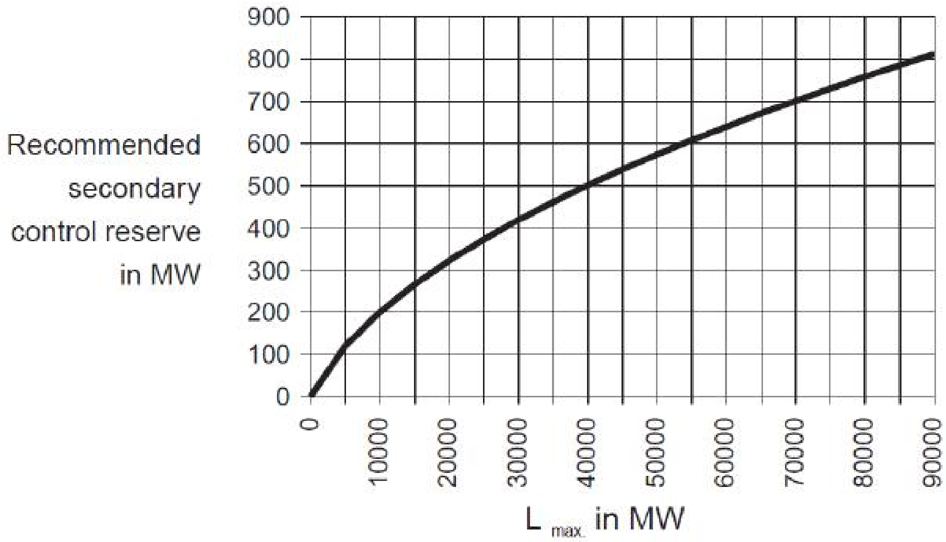

Figure 3: Recommended minimum aFRR reserve in the former UCTE.

With L_{max} being the maximum anticipated consumer load for an LFC Area over the period considered. A comparison between the new and the legacy recommendation for data between 2010 and 2014 resulted in comparable amounts per LFC Block; however, the new recommendation is considered more future-proof as it implicitly considers not only peak load, but all imbalances. Both approaches may also be combined."

Resumé and conclusions of the rules agreed:

TSO EN requirements of aFRR has continued to be determined after Synchronous Area Operational Agreement, Annex 1, Policy on Load-frequency Control and Reserves[144]: The amount of aFRR for TSO EN is fixed to +/- 90 MW. The value isn't expected to change significant during the next years, refer to part 3.3.1.1. The following text are part of the agreement for the LFC block of DE-LU-DK : The aFRR capacity dimensioned for the DK1 area shall at least cover the stochastic imbalances remaining after activation of mFRR. The aFRR capacity shall be at least 90 MW. The mFRR capacity is equal to the difference between the dimensioning incident and the aFRR capacity.

[144] ENTSO-E website: https://consultations.entsoe.eu/system-operations/synchronous-area-operational-agreement-policy-1-lo/

APPENDIX 3
NORDIC SYNCHRONOUS AREA (DK2) LFC STRUCTURE

REFERENCE for Appendix 3

In this appendix the load-frequency-control (LFC) structure is described using extract from the Nordic TSO's agreement [49] the documents referred to from the agreement can be downloaded on the Danish Utility Regulator website in Danish:
https://forsyningstilsynet.dk/el/afgoerelser/godkendelse-af-forslag-til-fastlaeggelse-af-lfc-kontrolblokke-i-norden

In document[145] is discussed the approach and best practice to fulfil Article 139 (LOAD-FREQUENCY CONTROL STRUCTURE - Basic structure), Article 140 (Process activation structure) and Article 141 (Process responsibility structure) for the Nordic synchronous area. The results are concluded in in document[146]:

- The Nordic synchronous area corresponds to an LFC block and a bidding zone corresponds to an LFC area and a monitoring area. Eastern Denmark, DK2, is as so an LFC area and monitoring area. Figure 68 shows an illustration of the LFC block Nordic and Figure 69 shows the map of the current bidding zones of the Nordic synchronous area.
- A network element belongs to the LFC block, LFC area or monitoring area, where the geographic point for measurements of that network element has been agreed between the relevant TSO's to be located.

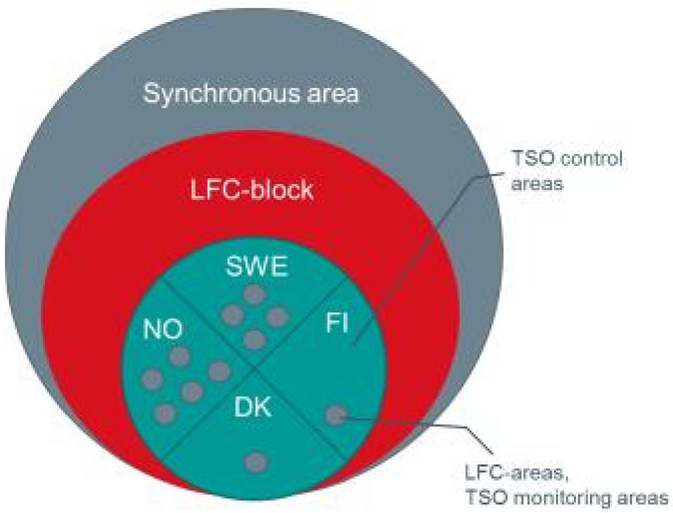

Figure 68 LFC structure in Nordic synchronous area[147]

[145]Reference: bilag-22-explanatory-document-lfc-block-proposal-final-clean.pdf
[146]Reference: bilag-21-main-document-lfc-block-proposal-nordic-synchronous-area-_final-clean.pdf
[147]Figure 4 of bilag-22-explanatory-document-lfc-block-proposal-final-clean.pdf

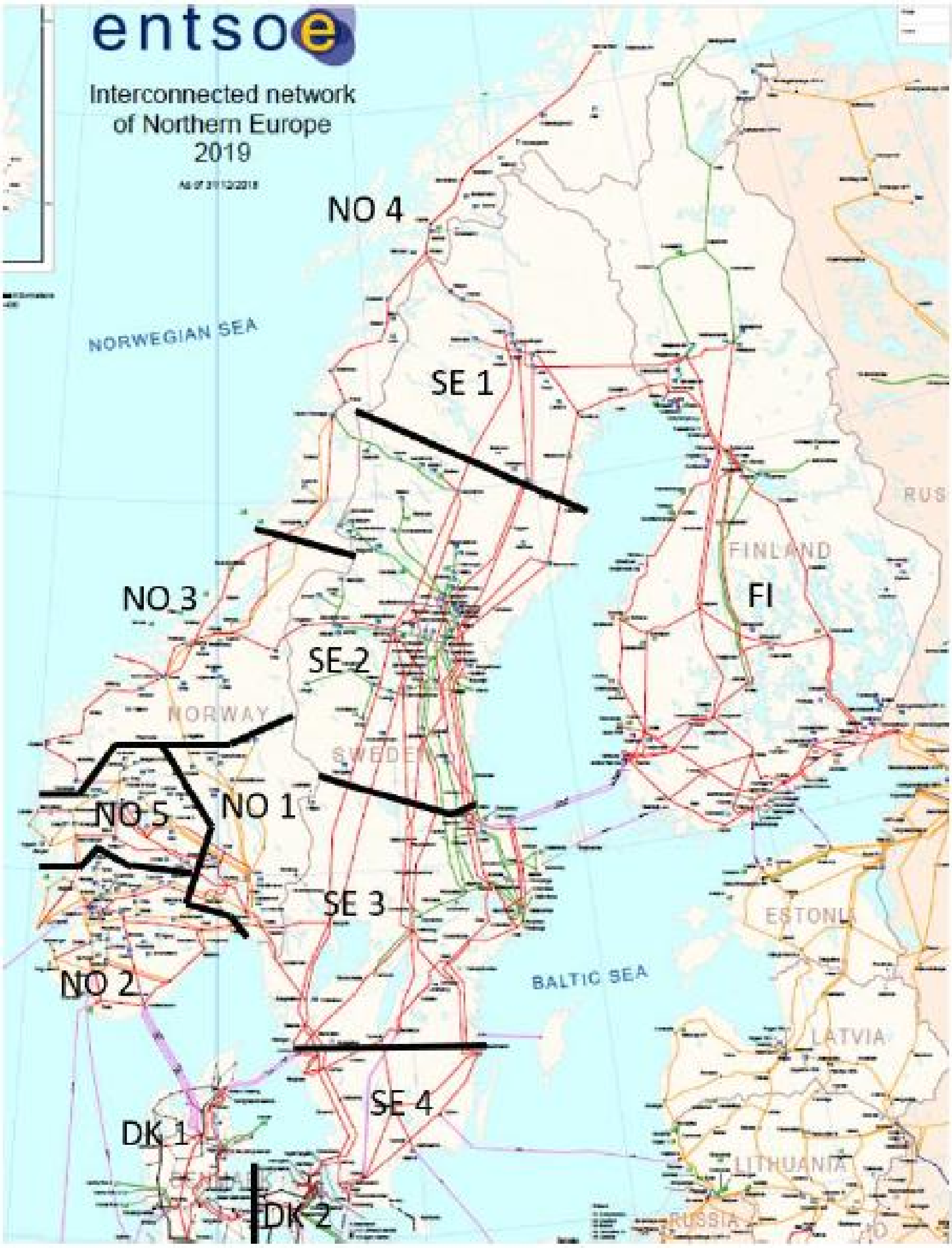

Figure 69 Map of the current bidding zones within the Nordic synchronous area[148]

The Nordic TSO's are highlighting the following capabilities and benefits of the LFC structure, quotation from [49]:

- "A common dimensioning methodology for frequency restoration reserves (FRR). One LFC block facilities exchange and sharing of reserves to a higher degree than with multiple LFC blocks. This is regulated in the LFC Block agreement between the TSO's.
- In the proposed LFC block determination, where all the balancing actions are coordinated throughout synchronous area, TSO's are able to minimize the amount of counter

[148] Reference document: nordic-bzrr-alternative-configuration.-bidding-zone-1.pdf

activation of frequency restoration reserves (FRR) and aim to activate the most efficient reserve resources to balance the system.

- A common balancing market ensures transparency among all the balance service providers (BSP's) in a synchronous area and ensures market-based mechanisms in the widest possible extent.
- Each TSO in the Nordic synchronous area has responsibility to monitor and managing its operational security on its own control area."

APPENDIX 4
OVER-VIEW OF FREQUENCY ANCILLARY SERVICES TECHNICAL REQUIREMENTS AND MARKET RULES AND REGULATIONS

Appendix 4

This appendix will consist of a series of summary tables for the frequency ancillary services acc. to Energinet's tender conditions [12], the data given in document "Needs Assessment of Ancillary Services 2020" (Behovsvurdering for systemydelser 2020) acc. to reference [4] will be used and more market regulations as listed below:

The market rules and regulation (in English):
Regulation A: Principles for the electricity market
Regulation B: Terms of electricity market access
Regulation C1: Terms of balance responsibility
Regulation C2: Balancing market
Regulation C3: Handling of notifications and schedules
Regulation D1: Settlement metering
Regulation D2: Technical requirements for electricity metering
Regulation E: Settlement of environmentally friendly electricity generation
Regulation F: EDI Communication
Regulation F1: EDI communication with the DataHub in the electricity market
Regulation G: Discretionary policy and data protection procedures
Regulation I: Master data.

The market rules and regulations (in Danish):
Forskrift A: Principper for elmarkedet
Forskrift B: Vilkår for adgang til elmarkedet
Forskrift C1: Vilkår for balanceansvar
Forskrift C2: Balancemarkedet og balanceafregning
Forskrift C3: Planhåndtering - daglige procedure
Forskrift D1: Afregningsmåling og afregningsgrundlag
Forskrift D2: Tekniske krav til elmåling
Forskrift E: Miljøvenlig elproduktion og anden udligning
Forskrift F: EDI-kommunikation
Forskrift F1: EDI-kommunikation med DataHub i elmarkedet
Forskrift G: Diskretionspolitik og procedurer vedr. datasikkerhed
Forskrift I: Stamdata.

All the stated documents can be downloaded in Energinet's website, refer to:
https://en.energinet.dk/Electricity/Rules-and-Regulations/Market-Regulations
https://energinet.dk/El/Elmarkedet/Regler-for-elmarkedet/Markedsforskrifter

Abbreviations used in the tables:
EN: Energinet
NA: Not Applicable (or relevant)
TBD: To Be Determined

The tables will be divided into categories, which will appear as the line in the top of the table and the Appendix 4 Table "X" text stated.

The technical requirements of the ancillary services to be delivered in Denmark are parted in the three following tables to give an over-view regarding the specifications acc. to [4] and [12].

<table>
<tr><th></th><th>ENTSO-E</th><th colspan="2">Area designation</th><th colspan="6">Technical requirements of volume and frequency range</th></tr>
<tr><th></th><th></th><th>DK1</th><th>DK2</th><th>Regulation</th><th>Direction</th><th>Total volume requirement</th><th>Frequency range</th><th>Full response range</th><th>Maximum insensitivity</th></tr>
<tr><td rowspan="3">Primary frequency control reserves</td><td rowspan="3">Frequency Containment Reserves</td><td>FCR</td><td>NA</td><td rowspan="3">Automatic</td><td>Up / Down Asymmetric</td><td>± 21 MW</td><td>49.8 Hz < f < 50.2 Hz</td><td>± 200 mHz</td><td>± 20 mHz</td></tr>
<tr><td rowspan="2">NA</td><td>FCR-N</td><td>Up / Down Symmetric</td><td>± 18 MW</td><td>49.9 Hz < f < 50.1 Hz</td><td>± 100 mHz</td><td rowspan="2">No dead band</td></tr>
<tr><td>FCR-D</td><td>Upward regulation only</td><td>+ 44 MW</td><td>49.5 Hz < f < 49.9 Hz</td><td>- 100 mHz
to
- 500 mHz</td></tr>
<tr><td rowspan="2">Secondary frequency control reserves</td><td rowspan="2">Frequency Restoration Reserves</td><td>aFRR</td><td>NA</td><td rowspan="2">Automatic</td><td rowspan="2">Up & Down Symmetrical</td><td>In DK1:
± 90 MW</td><td rowspan="4">Frequency restoration range is not used in CE/Nordic areas</td><td rowspan="4">NA</td><td rowspan="4">No dead band</td></tr>
<tr><td>NA</td><td>aFRR Expected Q3 2020</td><td>In DK2 expected:
± 12 MW -
± 30 MW</td></tr>
<tr><td rowspan="2">Tertiary frequency control reserves</td><td rowspan="2">Frequency Restoration Reserves</td><td>mFRR</td><td>NA</td><td rowspan="2">Manual</td><td>Upward regulation only</td><td>In DK1: 684 MW (Share with DK2 300 MW) Purchase: 284 MW</td></tr>
<tr><td>NA</td><td>mFRR</td><td>Upward regulation only</td><td>In DK2: 623 MW (Share with DK1 300 MW) Purchase: 623 - 638 MW</td></tr>
</table>

Appendix 4 Table 1 Technical requirements volume and frequency range of ancillary services used in Denmark.

The requirements of the regulation start, ramping time etc. are shown in this table:

<table>
<tr><th></th><th>ENTSO-E</th><th colspan="2">Area designation</th><th colspan="5">Technical requirements of regulation</th></tr>
<tr><th></th><th></th><th>DK1</th><th>DK2</th><th>Start</th><th>Part availability</th><th>Full availability (Ramping time)</th><th>End</th><th>Re-establishment of the reserve</th></tr>
<tr><td rowspan="3">Primary frequency control reserves</td><td rowspan="3">Frequency Containment Reserves</td><td>FCR</td><td>NA</td><td rowspan="3">Immediately</td><td>50 % within 15 s</td><td>≤ 30 s</td><td>≥ 15 min</td><td>15 min after the completion of regulation</td></tr>
<tr><td rowspan="2">NA</td><td>FCR-N</td><td>Linearly supply</td><td>≤ 150 s</td><td>Maintain continuously</td><td>NA</td></tr>
<tr><td>FCR-D</td><td>50 % within 5 s</td><td>≤ 30 s</td><td>≥ 15 min</td><td>15 min after the completion of regulation</td></tr>
<tr><td rowspan="2">Secondary frequency control reserves</td><td rowspan="2">Frequency Restoration Reserves</td><td>aFRR</td><td>NA</td><td rowspan="2">Immediately</td><td rowspan="4">Linearly supply</td><td>≤ 15 min</td><td rowspan="4">Maintain continuously</td><td rowspan="4">NA</td></tr>
<tr><td>NA</td><td>aFRR Expected Q3 2020</td><td>≤ 5 min</td></tr>
<tr><td rowspan="2">Tertiary frequency control reserves</td><td rowspan="2">Frequency Restoration Reserves</td><td>mFRR</td><td>NA</td><td rowspan="2">Manually ordering from Energinet</td><td rowspan="2">≤ 15 min</td></tr>
<tr><td>NA</td><td>mFRR</td></tr>
</table>

Appendix 4 Table 2 Technical requirements of the regulation for ancillary services used in Denmark.

Measurement requirements are stated in the next table; besides these measurements the delivered energy must be measured acc. to the requirements stated in D1 and D2 rules (only in Danish language):
Forskrift D1: Afregningsmåling og afregningsgrundlag
Forskrift D2: Tekniske krav til elmåling

	ENTSO-E	Area designation		Measurements accuracy and signals			
		DK1	DK2	Accuracy of frequency measurement	Sensitivity of frequency measurement	Resolution of player's SCADA system	Response signal
Primary frequency control reserves	Frequency Containment Reserves	FCR	NA	10 mHz	± 10 mHz	≤ 1 s	Signal for response must be given and stored for at least one week in player's system.
		NA	FCR-N				
			FCR-D				
Secondary frequency control reserves	Frequency Restoration Reserves	aFRR	NA	NA (Following a setpoint signal)	NA	NA	Signal for response must be given and stored for at least one week in player's system. More signals must be available for the Energinet Control Centre.
		NA	aFRR Expected Q3 2020	NA	NA	NA	TBD
Tertiary frequency control reserves	Frequency Restoration Reserves	mFRR	NA	NA	NA	NA	Information/data are exchanged acc. to agreement between the player and Energinet via information technology.
		NA	mFRR				

Appendix 4 Table 3 Measurements accuracy and signals requirements for ancillary services used in Denmark.

The market rules are plot into the following tables trying to give an over-view. This over-view is a snapshot of the current picture of the rules and regulations in Denmark acc. to [4], [12] and more, with the prospects of establishment of new markets in the next few years (NBM, PICASSO, MARI). As the first coulombs of the tables must show up each time in a table, the market requirements and rules gives several tables, refer to Appendix 4 Table 4 up to and including Appendix 4 Table 10.

	ENTSO-E	Area designation		Markets requirements procurement, deadlines and communication			
		DK1	DK2	Procurement	Deadline submitting bids	Deadline changing bids	Communication for bids
Primary frequency control reserves	Frequency Containment Reserves	FCR	NA	Daily capacity auctions one day ahead of operation	Latest at 15:00 on the day before the day of operation	Latest at 15:00 for previously submitted bids	Ediel or Self-service portal
		NA	FCR-N	Daily capacity auctions one part D-2 and one part D-1 ahead of operation	1) Latest at 15:00 two day before the day of operation for D-2 bids. 2) Latest at 18:00 on the day before the day of operation for D-1 bids.	1) Latest at 15:00 for previously D-2 submitted bids 2) Latest at 18:00 for previously D-1 submitted bids	
			FCR-D				
Secondary frequency control reserves	Frequency Restoration Reserves	aFRR	NA	(Daily auctions in 2019) Monthly tender/auctions in 2020	Bids for the monthly auction can be submitted as capability bid (month/year)	NA	By e-mail to kontrolcenterel@ energinet.dk
		NA	aFRR Expected Q3 2020	Procurement expected Q3 2020	TBD	TBD	TBD
Tertiary frequency control reserves	Frequency Restoration Reserves	mFRR	NA	Daily capacity auctions one day ahead of operation	Bids connected with daily capacity auctions must reach Energinet not later than 9.30 on the day before operation.	Bids connected with daily capacity auctions must reach Energinet not later than 9.30 on the day before operation.	Ediel or Self-service portal
		NA	mFRR	Tender/contract for 2016-2020			

Appendix 4 Table 4 Market requirements procurement, deadlines and communication for ancillary services used in Denmark.

More market requirements:

	ENTSO-E	Area designation		Market requirements regarding bids and volumes				
		DK1	DK2	Bids	Detail of bids regarding volume	Minimum volume of bid	Maximum volume of bid	Detail of MW volume
Primary frequency control reserves	Frequency Containment Reserves	FCR	NA	Volume and price statement hour-by-hour as block bids: Block 1: 00.00-04.00; Block 2: 04.00-08.00 Block 3: 08.00-12.00; Block 4: 12.00-16.00 Block 5: 16.00-20.00; Block 6: 20.00-24.00	Volume in MW must be the same hour-by-hour in each block	0.3 MW	NA	In MW with one decimal
		NA	FCR-N	Volume and price statement hour-by-hour	(If the player uses block bids, volume must be the same in each block)			
			FCR-D	Volume and price statement hour-by-hour	(If the player uses block bids, volume must be the same in each block)			
Secondary frequency control reserves	Frequency Restoration Reserves	aFRR	NA	± Volume and price statement throughout the prescribed period to which the need refers.	± Volume in MW must be the same throughout the prescribed period to which the need refers.	1 MW	50 MW	In MW with one decimal
		NA	aFRR Expected Q3 2020	TBD	TBD	TBD	TBD	TBD
Tertiary frequency control reserves	Frequency Restoration Reserves	mFRR	NA	± Volume hour-by-hour and price statement throughout the prescribed period to which the need refers.	NA	5 MW	50 MW	In MW with one decimal
		NA	mFRR					

Appendix 4 Table 5 Market requirements regarding bids and volumes for ancillary services used in Denmark.

More market requirements:

<table>
<tr><td></td><td>ENTSO-E</td><td colspan="2">Area designation</td><td colspan="3">Market requirements regarding bids and prices</td></tr>
<tr><td></td><td></td><td>DK1</td><td>DK2</td><td>Details of bids regarding price</td><td>Detail of price</td><td>Product codes</td></tr>
<tr><td rowspan="3">Primary frequency control reserves</td><td rowspan="3">Frequency Containment Reserves</td><td>FCR</td><td>NA</td><td>Price statement must be per MW per hour and the same for each block</td><td rowspan="3">In DKK/MW/h or EUR/MW/h with two decimals.</td><td>Product code used for:
Up-ward regulation
Down-ward regulation
Symmetrical regulation.</td></tr>
<tr><td rowspan="2">NA</td><td>FCR-N</td><td>(If the players uses block bids, the price must be the same for the entire block)</td><td rowspan="2">NA</td></tr>
<tr><td>FCR-D</td><td>(If the players uses block bids, the price must be the same for the entire block)</td></tr>
<tr><td rowspan="2">Secondary frequency control reserves</td><td rowspan="2">Frequency Restoration Reserves</td><td>aFRR</td><td>NA</td><td>NA</td><td>In DKK/MW and refer to the specified offer of volume throughout the prescribed period to which the need refers.</td><td>NA</td></tr>
<tr><td>NA</td><td>aFRR Expected Q3 2020</td><td>TBD</td><td>TBD</td><td>TBD</td></tr>
<tr><td rowspan="2">Tertiary frequency control reserves</td><td rowspan="2">Frequency Restoration Reserves</td><td>mFRR</td><td>NA</td><td rowspan="2">NA</td><td rowspan="2">In DKK/MW or EUR/MW/h with two decimals.</td><td rowspan="2">Product code used for:
Up-ward regulation
Down-ward regulation
Symmetrical regulation.</td></tr>
<tr><td>NA</td><td>mFRR</td></tr>
</table>

Appendix 4 Table 6 Market requirements regarding bids and prices for ancillary services used in Denmark.

More market requirements:

	ENTSO-E	Area designation		Market requirements regarding acceptance of bids		
		DK1	DK2	EN's acceptance of bids	Detail of EN's acceptance of bids	Detail regarding volume of bids
Primary frequency control reserves	Frequency Containment Reserves	FCR	NA	Selecting bids in order of increasing price starting with lowest	Bids are always accepted in their entirety or not at all	Bids of more than 5 MW can be disregarded if next in line and it cause excess of the fulfilment of EN's requirement
		NA	FCR-N			If not enough bids are received to cover EN's and Svenska Kraftnät's requirements, EN will send an e-mail to all player's asking them to submit more bids.
			FCR-D			
Secondary frequency control reserves	Frequency Restoration Reserves	aFRR	NA	EN selects the bids such that the total need is met at the lowest possible cost.	Bids are always accepted in their entirety or not at all. If the number of bids received is insufficient to cover EN's requirements, EN will send an e-mail to all player's asking them to submit more bids.	If the number of bids received is insufficient to cover EN's requirements, EN will send an e-mail to all player's asking them to submit more bids.
		NA	aFRR Expected Q3 2020	TBD	TBD	TBD
Tertiary frequency control reserves	Frequency Restoration Reserves	mFRR	NA	Selecting bids in order of increasing price starting with lowest	Bids are always accepted in their entirety or not at all. If bids more than 25 MW will lead to excess fulfilment as next bid, Energinet may disregard such bids. If the number of bids received is insufficient to cover EN's requirements, EN will send an e-mail to all player's asking them to submit more bids.	Combined delivery from suppliers from several production units or consumption units within the required response time is accepted; but a delivery cannot be made of a mix of consumption and production units , refer to Market regulation C1.
		NA	mFRR			

Appendix 4 Table 7 Market requirements regarding acceptance of bids for ancillary services used in Denmark.

More market rules:

	ENTSO-E	Area designation		Market rules for payment, closing and activation		
		DK1	DK2	Payment	Closing & feedback to player's	Activation of reserves
Primary frequency control reserves	Frequency Containment Reserves	FCR	NA	All bids for regulation accepted will be paid the marginal price (price of highest bid)	At 15:30 EN informs the player's having the bids accepted together with payment allocated	Automatically activation based on the suppliers own frequency measurement
		NA	FCR-N	All accepted bids for FCR-N receive an availability payment corresponding to player's bidding price (pay-as bid) upward respective downward regulation	1) At 16:00 two days before the day of operation EN informs the player's having the D-2 bids accepted together with availability payment allocated. 2) At 20:00 one day before the day of operation EN informs the player's having the D-1 bids accepted together with availability payment allocated	
			FCR-D	All accepted bids for upward regulation FCR-D receive an availability payment corresponding to the player's bidding price (pay-as-bid)		
Secondary frequency control reserves	Frequency Restoration Reserves	aFRR	NA	All accepted bids will receive payment corresponding to the price requested by the supplier (pay-as-bid).	The outcome of the auction will be available and notified to the participating player's three hours after the expiry of the bidding deadline. Following the evaluation of the bids, a contract will be drawn up with the bidder(s) chosen in the form of a purchase order.	Automatically based on the suppliers own frequency measurement
		NA	aFRR Expected Q3 2020	TBD	TBD	TBD
Tertiary frequency control reserves	Frequency Restoration Reserves	mFRR	NA	The calculation of the energy volumes supplied (regulation power) from mFRR and the settlement of regulation power are based on Market regulation C2.	Feedback to player's at 10.00 with the outcome of the accepted bids by Energinet and statement of the availability payment allocated on an hour-by-hour basis.	Manually activation by Energinet to the players with the accepted bids.
		NA	mFRR			

Appendix 4 Table 8 Market rules for payment, closing and activation for the ancillary services used in Denmark.

More market rules:

<table>
<tr><th></th><th>ENTSO-E</th><th colspan="2">Area designation</th><th>Market rules regarding obligations of the players</th></tr>
<tr><td></td><td></td><td>DK1</td><td>DK2</td><td>Obligations of the players</td></tr>
<tr><td rowspan="3">Primary frequency control reserves</td><td rowspan="3">Frequency Containment Reserves</td><td>FCR</td><td>NA</td><td>If it turns out that the capacity of a bid is not available by occurrence of an incident the availability payment is cancelled. Same incident rules as for aFRR is valid (see below line).</td></tr>
<tr><td rowspan="2">NA</td><td>FCR-N</td><td rowspan="2">If it turns out that the capacity of a bid is not available by occurrence of an incident the availability payment is cancelled. Same incident rules as for aFRR is valid (see below line).</td></tr>
<tr><td>FCR-D</td></tr>
<tr><td rowspan="2">Secondary frequency control reserves</td><td rowspan="2">Frequency Restoration Reserves</td><td>aFRR</td><td>NA</td><td>For the availability payment to be effected, the capacity must in fact be available. This means that the availability payment is cancelled if it subsequently turns out that the capacity is not available. In case of incidents resulting in a plant being unable to supply the aFRR, FCR-N or FCR-D the reserve must be re-established at one or more plants, which can supply the reserve as soon as possible and within 30 minutes after the incident at the latest. If the supplier is unable to re-establish the reserve, EN must be contacted within 15 minutes and informed where and when the reserve can be re-established.</td></tr>
<tr><td>NA</td><td>aFRR Expected Q3 2020</td><td>TBD</td></tr>
<tr><td rowspan="2">Tertiary frequency control reserves</td><td rowspan="2">Frequency Restoration Reserves</td><td>mFRR</td><td>NA</td><td rowspan="2">For the availability payment to be effected:
1) The player must subsequently submit a bid for activating all the capacity for which an availability payment is obtained
2) The capacity must in fact be available.
The obligation under 2) means that the availability payment is cancelled if it subsequently turns out that the capacity is not available. In case of incidents resulting in a plant being unable to supply the mFRR the reserve must be re-established at one or more plants, which can supply the reserve as soon as possible and within 30 minutes after the incident at the latest. If the supplier is unable to re-establish the reserve, EN must be contacted within 15 minutes and informed where and when the reserve can be re-established.</td></tr>
<tr><td>NA</td><td>mFRR</td></tr>
</table>

Appendix 4 Table 9 Market rules regarding obligations of the players for ancillary services used in Denmark.

The last table of the market requirements and rules:

<table>
<tr><th></th><th>ENTSO-E</th><th colspan="2">Area designation</th><th>Market rules - player's planning</th></tr>
<tr><td></td><td></td><td>DK1</td><td>DK2</td><td>Planning by the player</td></tr>
<tr><td rowspan="3">Primary frequency control reserves</td><td rowspan="3">Frequency Containment Reserves</td><td>FCR</td><td>NA</td><td>Acc. to Market regulation C3: Handling of notifications and schedules the volume of FCR reserved must be stated prior to and during the day of operation</td></tr>
<tr><td rowspan="2">NA</td><td>FCR-N</td><td>Acc. to Market regulation C3: Handling of notifications and schedules the volume of FCR-N reserved must be stated prior to and during the day of operation</td></tr>
<tr><td>FCR-D</td><td>Acc. to Market regulation C3: Handling of notifications and schedules the volume of FCR-D reserved must be stated prior to and during the day of operation</td></tr>
<tr><td rowspan="2">Secondary frequency control reserves</td><td rowspan="2">Frequency Restoration Reserves</td><td>aFRR</td><td>NA</td><td>The player's operational schedules prior to and during the day of operation must state the volumes of secondary upward regulation power and secondary downward regulation power which have been re-served on an hour-by-hour basis, see Market regulation C3: Handling of notifications and schedules.</td></tr>
<tr><td>NA</td><td>aFRR Expected Q3 2020</td><td>TBD</td></tr>
<tr><td rowspan="2">Tertiary frequency control reserves</td><td rowspan="2">Frequency Restoration Reserves</td><td>mFRR</td><td>NA</td><td rowspan="2">Regulation power orders must be included in the player's operational schedules prior to and during the day of operation acc. to Market regulation C3.</td></tr>
<tr><td>NA</td><td>mFRR</td></tr>
</table>

Appendix 4 Table 10 Market rules – player's planning for delivery of ancillary services in Denmark.