Delivery no.: 6.3.2
Planning of installation

Photo: By & Havn / Ole Malling

DONG Energy
Daniel Sandermann Jensen

02-16-2016

Public deliverable ■
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Preface

EnergyLab Nordhavn – New Urban Energy Infrastructures is an exciting project which will continue until the year of 2019. The project will use Copenhagen's Nordhavn as a full-scale smart city energy lab, which main purpose is to do research and to develop and demonstrate future energy solutions of renewable energy.

The goal is to identify the most cost-effective smart energy system, which can contribute to the major climate challenges the world are facing.

Budget: The project has a total budget of DKK 143 m (€ 19 m), of this DKK84 m (€ 11 m) funded in two rounds by the Danish Energy Technology Development and Demonstration Programme (EUDP).

Forord

EnergyLab Nordhavn er et spændende projekt der løber til og med 2019. Projektet vil foregå i Københavns Nordhavn, og vil fungere som et fuldskala storbylaboratorium, der skal undersøge, udvikle og demonstrerer løsninger for fremtidens energisystem.

Målet er at finde fremtidens mest omkostningseffektive energisystem, der desuden kan bidrage til en løsning på de store klimaudfordringer verden står overfor nu og i fremtiden.

Budget: Projektets totale budget er DKK 143 mio. (EUR 19 mio.), hvoraf DKK 84 mio. (EUR 11 mio.) er blevet finansieret af Energiteknologisk Udviklings- og Demonstrationsprogram, EUDP.

Disclaimer

[Add standard disclaimer]

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For further information on this specific deliverable, please contact:

Daniel Sandermann
dasaj@dongenergy.dk

For other information regarding EnergyLab Nordhavn, please contact:

EnergyLab Nordhavn Secretariat
Center for Electric Power and Energy, DTU Electrical Engineering
Richard Petersens Plads
Building 325
DK-2800 Kgs. Lyngby
Denmark

E-mail eln@dtu.dk
Tlf. +45 45 25 35 54

www.energylabnordhavn.dk

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Executive Summary

As part of the Energylab Nordhavn project,[1] DONG Energy Distribution will install a battery energy storage system (BESS). The project will allow for an investigation of both the potential benefits of utilizing the battery as an integrated grid component, and further the potential impacts of a future increased implementation of 3rd party owned storage facilities in the network.

To facilitate the investigation of both utility- and commercially owned BESS in the distribution network a range of preliminary analysis and potential collaborations are currently being exploited.
This document describes the physical placement of the BESS, which will be situated within a parking garage in the Århusgade district of Nordhavn, and further describes the preliminary technological characterization, which has led to the recommendation of installing a BESS with the dimensions of 1MW/500 kWh.

[1] www.energylabnordhavn.dk

Version Control

Version	Date	Author	Description of Changes
1.0	[2016-02-16]	Daniel Sandermann	Implemented Q&A changes
Final	[2016-03-07]	Daniel Sandermann	Implemented review inputs

Quality Assurance

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Author	Reviewer	Approver
Daniel Sandermann	WP 6 participants	Ole Michael Pedersen

1. Introduction

As part of the Energylab Nordhavn project[2] DONG Energy will install a large-scale energy storage system i.e. a battery energy storage system (BESS). The project will allow for an investigation of both the potential benefits of utilizing the battery as an integrated grid component, and further the potential impacts of a future increased implementation of 3rd party owned storage facilities in the network. The primary objectives for the BESS can be subdivided in the following headlines:

- Testing of the latest BESS technology in a realistic environment
- Demonstrate the potential of utilizing energy storage for deferral of infrastructural investments
- Demonstrate control protocols and business models for a BESS for both DSO and commercial purposes
- Use test data to discuss and recommend the best possible regulatory landscape for energy storage in the distribution network

To facilitate the investigation of both utility- and commercially owned BESS in the distribution network a range of preliminary analysis is presently under development. The present document describes the physical placement of the BESS, which will be situated within a parking garage in the Århusgade district of Nordhavn, and further describes the technological dimensioning of the BESS.

2. Battery Placement

2.1 Geographical location

In the coming years the Nordhavn area will undergo a substantial transformation divided into 3 phases (see Figure 1), which entails that by 2030 the area will include 864.000 m^2 of constructions.

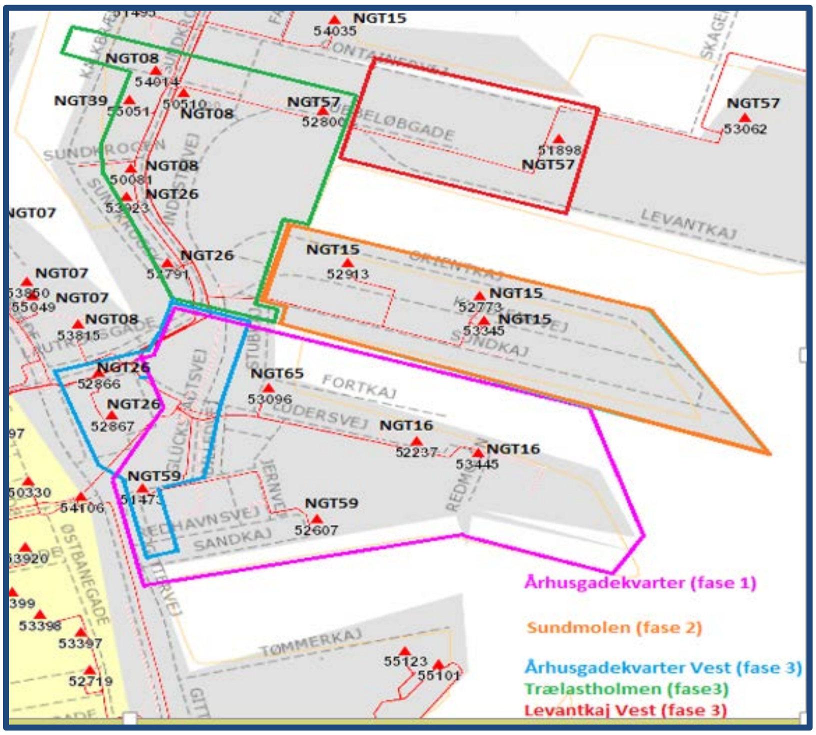

Figure 1 - Overview of phases for the construction of the Nordhavn area.

2 www.energylabnordhavn.dk

However, during the project-period (phase one - ranging from 2015-2019) the area propagation will be limited to 330.000 m^2, which is represented by the purple circumference in Figure 1.

2.2 Planning of installation

As iterated by By & Havn the overall vision for Nordhavn is that it must be the sustainable district of Copenhagen in the future, which entails that environmental responsibility, value creation and social diversity are key objectives in the planning of the area. This has set a natural restriction on the potential installation areas of the BESS as the installation of a containerized solution, which is the typical enclosure for BESS's, has been prohibited in the area.

Prior to the installation of the BESS within the Nordhavn area, DONG Energy has acquired the permission to install the BESS within a secondary transformer station, which is located within a parking garage in the Århusgade district of Nordhavn[3]. Here a transformer of a suitable size (currently estimated to 1000 kVA) will be installed for the purpose of the BESS. This entails that the physical dimensions of the BESS be limited to the dimensions shown in Figure 1 where a proposal from ABB for the placement of a 520 kW/675 kWh BESS is shown.

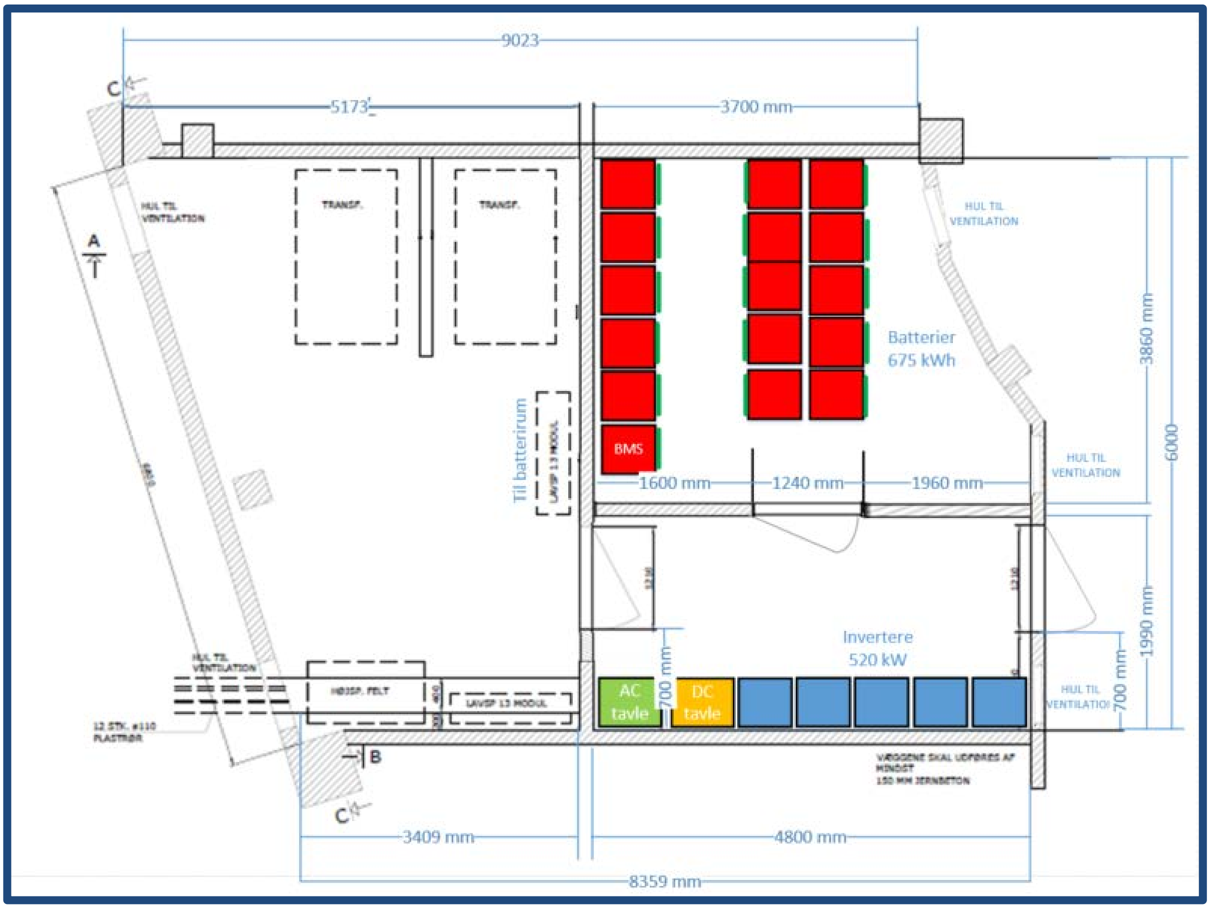

Figure 2 - Schematic overview of transformer + BESS room located in the parking garage in Nordhavn.

3 www.byoghavn.dk

In addition to the considerations regarding the spatial restrictions w.r.t. the footprint of the storage, another key consideration prior to the installation of the BESS is safety. To this end, DONG Energy Distribution Grid Strategy has been in contact with the internal Quality, Health, Safety and Environment (QHSE), and further potential BESS providers to ensure that the BESS installation lives up to the high safety standards of DONG Energy. It has been found that the guidelines iterated in the technical guidelines regarding transformer stations within rooms made available for DONG Energy, fulfills the required safety requirements, and as such the BESS room has been designed in accordance with these guidelines.

3. Battery Dimensioning

3.1 BESS applications

When identifying the required technological characteristics of any energy storage system the first natural step is to identify the applications that the energy storage system needs to perform. The potential applications provided by energy storage technologies can be categorized in a number of different applications under five umbrella groups as illustrated in Figure 3.

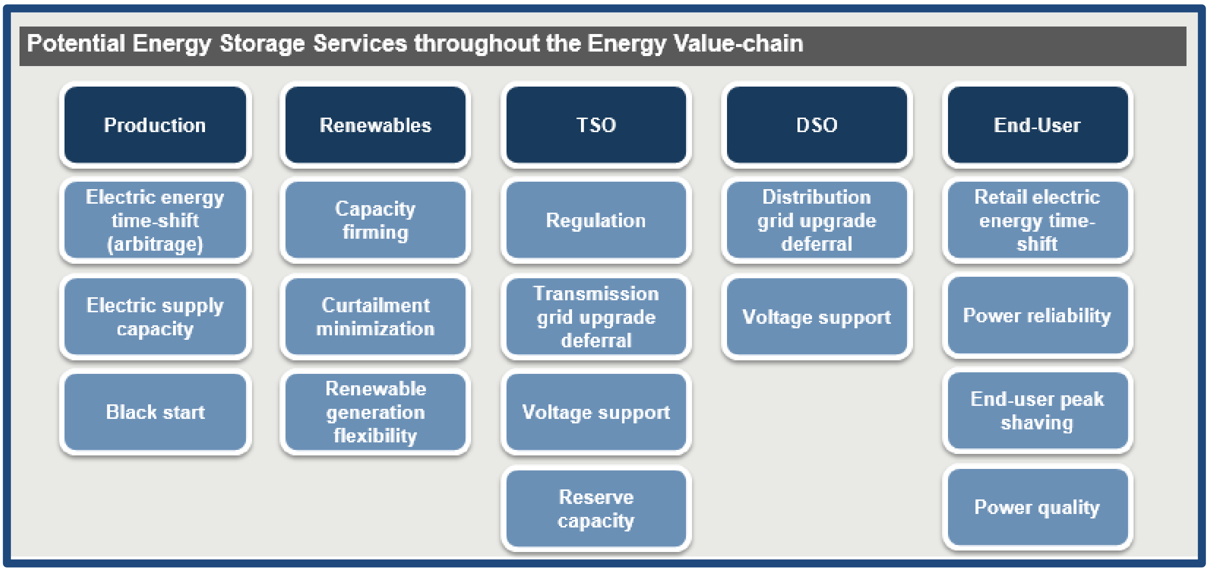

Figure 3 - Potential energy storage services throughout the energy value-chain. Based on the work in [1].

The potential energy storage applications represents the entire energy value chain with applications relating to the production side of the value chain, renewable energy services, both TSO and DSO services and lastly end-user applications, which may become an increasingly popular service given the relatively recent deployment of for example the Tesla Powerwall and other domestic storage solutions.

As a DSO the most obvious applications of interest for DONG Energy Distribution are the internal DSO applications which includes distribution grid upgrade deferral and voltage support, both of which will briefly be discussed in the following sections.

3.1.1 Distribution grid upgrade deferral

Utilizing energy storage technologies for distribution upgrade deferral refers to the application of postponement or total avoidance of distribution upgrades that would otherwise be necessary to maintain adequate distribution capacity to serve all load requirements. Here the avoided investment could be potential replacements of e.g. an aging or over-stressed existing distribution transformer at a substation or replacement/enforcement of cables.

The attractiveness of utilizing energy storage for distribution grid upgrade deferral lies especially in the potential of the application to avoid the general both long term and short term underutilization associated with conventional distribution network upgrades. As an example, when a transformer is replaced, it is typically dimensioned to accommodate the future anticipated development in the maximum peak loading in the specific area, and as such a large fraction of the investment is underutilized in the majority of its useful lifecycle. Furthermore, for the vast majority of nodes within the distribution infrastructure, the maximum loading of the assets occur on relatively few days per anno, and for only a few hours within these days. Thus, the future investments necessary in the future distribution grid (characterized by a higher volatility) can largely be considered as an atrocious investment unless new (disruptive) technologies and strategies e.g. energy storage technologies are implemented.

The process of utilizing BESS for distribution upgrade deferral involves discharging the storage during the hours of peak consumption, and thus limiting the required load provided from the distribution assets. An important implication of utilizing storage for this application is that it can contribute significant benefits with limited discharges, as illustrated in Figure 4.

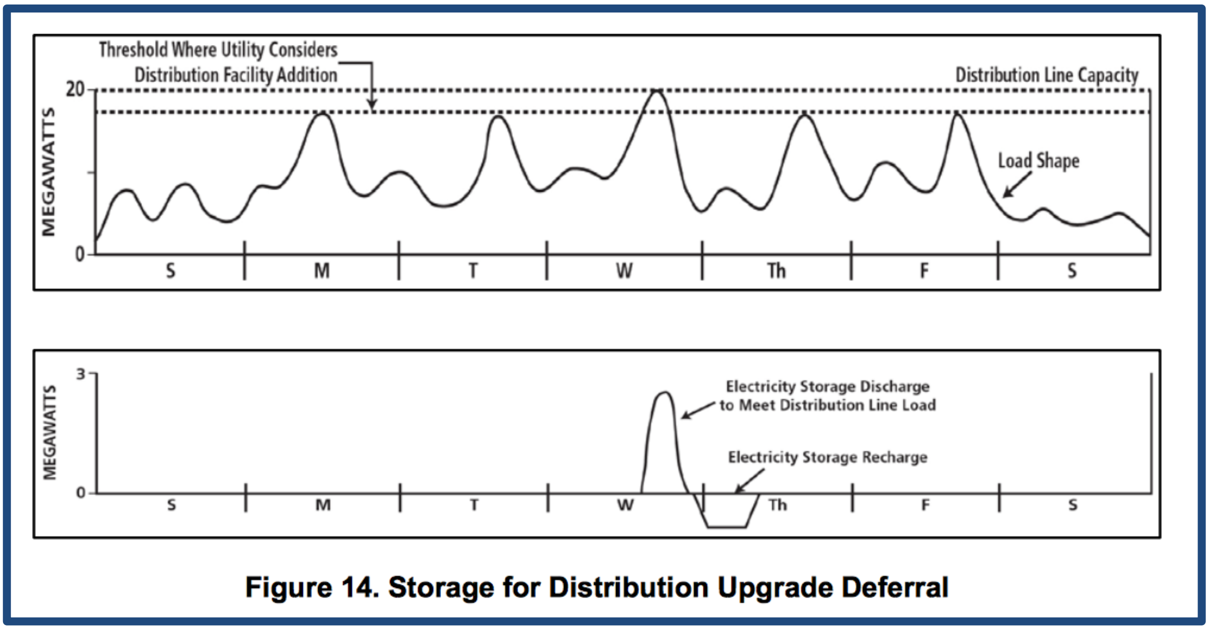

Figure 4 - Utilization of energy storage for distribution grid upgrade deferral [1].

As seen in lower subplot the energy storage is discharged on Wednesday (W) afternoon to compensate for the high loading of the area shown in the upper subplot. Following the event of maximum loading of the area, the energy storage is subsequently recharged during late night i.e. off-peak hours.

3.1.2 Voltage support

In addition to providing distribution grid upgrade deferral, energy storage technologies could potentially provide voltage support in the distribution network, which is a central DSO business area. In this application the aim is to maintain the voltage of a specified network segment within a predefined voltage range i.e. ± 10 %. The ability of energy storage technologies to provide voltage support can in general be specified in terms of the physical nature of the power delivered to provide the service i.e. active or reactive power.

When utilizing energy storage for active power voltage control the energy storage charges in events of over-voltages and conversely discharges the storage when voltage levels are becoming too low in the network segment. In reactive power voltage control applications the energy storage relies on the ability of the associated power electronics (converter) to inject or absorb reactive power in events of inadequate and excessive voltage levels respectively. In the future power system with an increasing penetration of especially photovoltaics in the low voltage grid that introduce a substantial degree of volatility in the distribution grid implies that voltage stability will become an increasing problem. Thus, the reactive power compensation capabilities of energy storage systems may become a valuable mechanism in the future transition of the distribution network, and is gradually gaining increased attention as a research area [1].

3.1.3 Synergetic applications

As mentioned in the above, the potential applications relating directly to the internal DSO business area includes applications that are both economic in nature, namely Distribution grid upgrade deferral, and the more technical application voltage control.

While these applications are naturally situated in the DSO framework, one of the key potentials of energy storage is to pursue synergies between applications, where some of the potential applications to couple with the internal DSO services could be:

- **Market related synergies**
- **Renewable enabling synergies**

Here potential market-related synergies could be coupling internal DSO applications with either the provision of energy-time-shift or ancillary services, and further from a more energy system perspective there is a large potential for coupling the DSO applications with renewable energy facilitating applications, such as renewable generation flexibility.

For the ELN (EnergyLab Nordhavn) BESS project, it has been decided that the BESS will be operated with the key objective of investigating the potential of utilizing storage technologies as integrated components within the distribution grid asset portfolio, where the BESS will be utilized for distribution grid upgrade deferral. However, as the typical utilization degree of BESS for this application is typically relatively low < 30 days per annum, synergies with other applications will also be exploited. To facilitate the integration of energy storage technologies within the distribution grid asset portfolio, the key parameter will be the economic competiveness of the storage technology relative to other assets available for the same application. Here market related synergies could increase the economic attractiveness, and to investigate this it has been decided that the BESS initially will be operated for both distribution grid upgrade deferral and the provision of ancillary services.

In addition to the investigation of the potential of utilizing the BESS for market related synergies, renewable enabling synergies e.g. coupling the BESS with a PV plant to allow for an increased penetration of renewable energy in the area, and further utilizing the BESS for turbo-charging EVs and E-Busses, could be investigated. However, seeing as both the PV- and EV and E-Bus penetration within the Nordhavn area is still under debate, these applications are considered as potential additions to the project in the longer term.

3.2 Technological requirements

Following the determination of the BESS applications in the above, a technological characterization of the required battery specifications in terms of energy capacity and power rating was performed. As illustrated by the above treatment of the potential applications provided by BESS, the potential applications encompass the whole energy value chain.

This implies that both the spatial, temporal and technical requirements for the capability of providing the BESS applications may substantially differ. This consideration is especially relevant when considering the potential of investigating the two applications: Distribution grid upgrade deferral and ancillary services.

The dimensioning of a BESS for distribution grid upgrade deferral is naturally required to provide a sufficient load for the necessary time to ensure that the loading of the infrastructural assets are below the specified limit, as was shown in Figure 4. In most cases, this entails that the BESS is required to maintain the discharge power for a duration between 1-4 hours. For frequency regulation applications on the other hand, the BESS is typically at the very maximum required to maintain a discharge duration for about 15min. However, as already mentioned the key criteria of the BESS project is to investigate the potential of utilizing the BESS for distribution grid upgrade deferral, and as such the initial analysis investigates the required specifications to provide this application.

3.3 Technological requirements - distribution grid upgrade deferral

In Figure 5 the 24 hour consumption profiles for seven select days are illustrated, where the top 3 curves represents the most heavily loaded days in 2015.

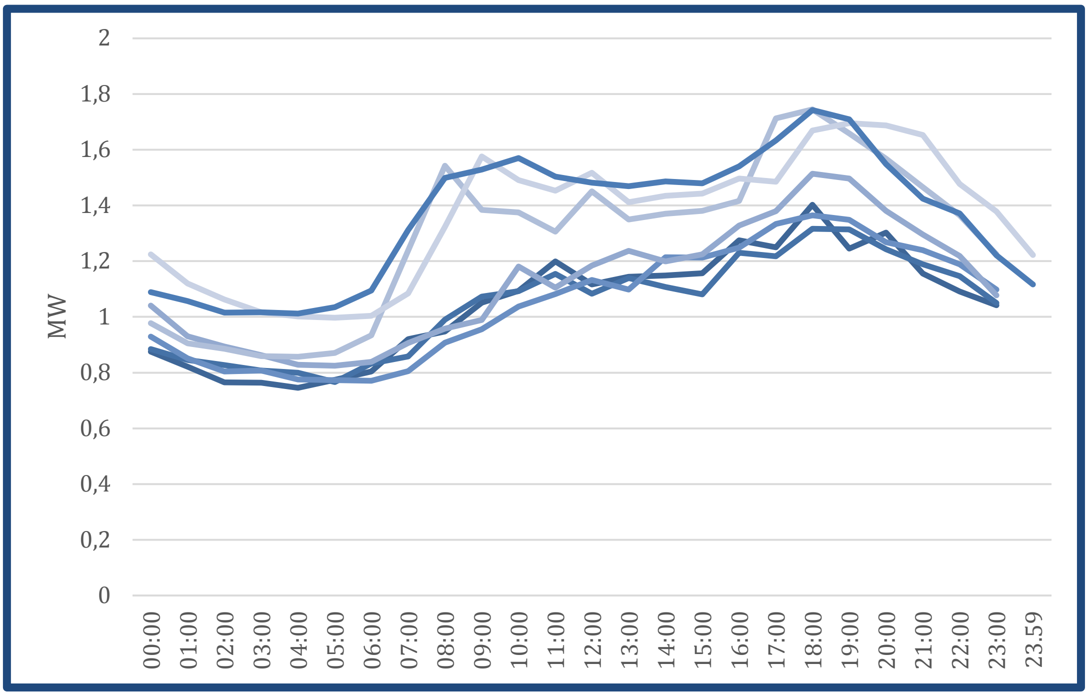

Figure 5 - 24 hour load profiles for the Århusgade area.

Utilizing these consumption profiles, an investigation of the optimum shaved peak was investigated based on the assumption of both a fixed linear incremental cost of the energy storage capacity in the BESS ($/kWh) and a linear incremental saving for providing the distribution grid upgrade deferral application ($/MW). The results from the analysis is shown in Figure 6.

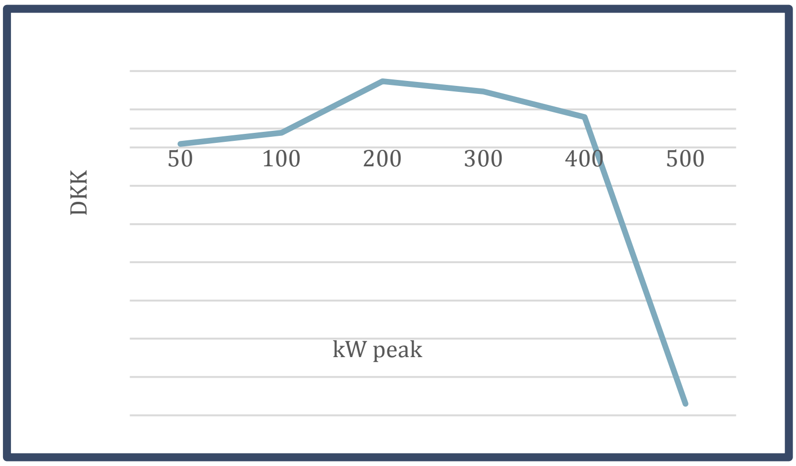

Figure 6 - optimum peak shaving in the Arhusgade area.

As shown by the results an optimum peak can be observed at 200 kW, which based on the loadprofiles shown in Figure 5, have been found to correspond to a required energy capacity of the BESS of approximately 500 kWh. This entails that the BESS in terms of adequacy of providing distribution grid upgrade deferral should be dimensioned with a power rating of 200 kW an energy capacity of 500 kWh.

In addition to the required energy capacity of the battery, the theoretical utilization degree of the BESS throughout a year was also investigated. From historical data it was found that the BESS would only be required to provide the peak shaving for approximately 20 days throughout a year, which points towards the previously mentioned low economic attractiveness of utilizing a BESS for the sole application of distribution grid upgrade deferral.

3.4 Technological requirements – ancillary services

The ancillary market within eastern Denmark primarily relies on 3 different services, namely the frequency-controlled normal operation reserve (FNR), the frequency-controlled disturbance reserve (FDR) and the manual reserves as shown in Figure 7. For the present analysis, the potential of the BESS to provide FNR and FDR has been investigated since it is assumed that the potential revenues from these two services represents the most economic attractive solutions.

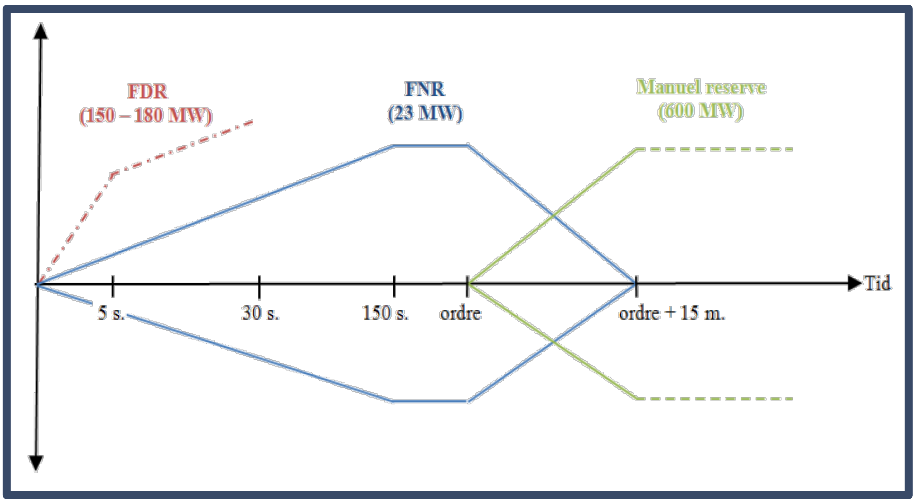

Figure 7 - Ancillary services within Easten Denmark. Reprinted from [2]

3.4.1 Frequency-controlled normal operation reserve (FNR)

The requirements within the normal frequency reserve market includes:

- The service must be provided within frequency deviations between + - 100 mHz
- The deliveraries must be made without a deadband
- The provision must be supplied with a linear response

Based on these requirements and utilizing historical 1 second resolution frequency data for the first week of 2016, the state-of-charge of a BESS participation within the FNR for 1 week was simulated.

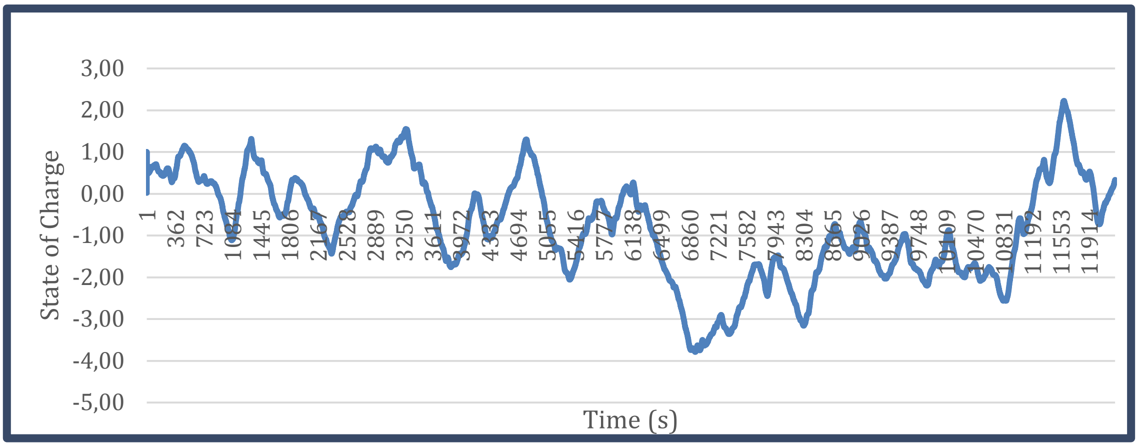

Figure 8 state of charge simulation of 1 MW/1MWh BESS participating in FNR.

Based on the results shown in Figure 8, the required BESS power to energy ratio to participate within the FNR market under the current requirements was quantified to a power to energy ratio of approximately 1 to 6. However, given the spatial restrictions described in section 2.1-2, and further due to economic restrictions this is not a viable option within the ELN project.

3.4.2 Frequency-controlled disturbance reserve (FDR)

The requirements within the normal frequency reserve market includes:

- Power is supplied inverse linear at frequency deviations between 49.9 and 49,5 Hz
- And the response time has to be 50 % within 5 seconds, and the remaining 50% after 25 seconds
- The economic compensation for providing this service is an availability payment, which is payed no matter how often u are actually scheduled

In correspondence with the above, based on the requirements and utilizing historical 1 second resolution frequency data, the state-of-charge of a BESS participation within the FDR was simulated, the results are shown in Figure 9.

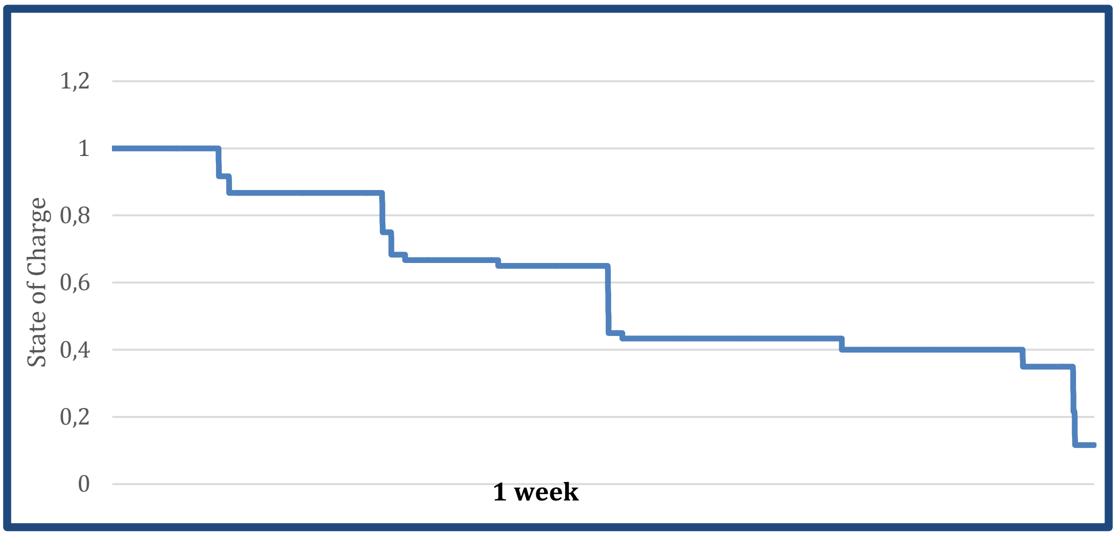

Figure 9 - state of charge simulation of 1 MW/1MWh BESS participating in FDR.

From inspection of the result in Figure 9, evidently the state of charge of the battery is maintained above 10% at the end of a full week of participation within the FDR market even with the exclusion of charging throughout the week. These results implies that the FDR service would be a technological feasible market for the BESS, which has led to the decision that the market related synergies exploited with the BESS will primarily include the combination of the applications distribution grid upgrade deferral and participation within the FDR market. Furthermore, as the availability payment for FDR participation is linear proportional to the power rating of the BESS, it has been decided that the potential of acquiring a power rating of up to at least 1 MW will be investigated. Further, the FDR is by nature (by rule) asymmetric, which may potentially be an advantage in multiple objective BESS operation.

4. Conclusion

Based on an investigation of both the spatial and technological requirements for the BESS project, it is recommended that a BESS with a 1MW/500kWh capacity be utilized for the synergetic application of distribution grid upgrade deferral and frequency disturbance response (FDR), with the potential longer-term implementation of renewable generation flexibility.

5. References

[1] Department of Energy (US). Electricity storage handbook in collaboration with nreca. Technical report, 2015.
[2] Energitilsynet. Analyse af markedet for frekvensstyrede reserver i Danmark. 2013