Battery Energy Storage Systems as an alternative to gas turbines for the fast active disturbance reserve

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Abstract

Power systems operate at a specific frequency and constantly require a balance between production and consumption of electricity in order to maintain the frequency within a certain interval. Larger frequency deviations can cause blackouts or damage equipment connected to the grid. Balancing functions that stabilise the grid are referred to as *ancillary services*, which in Sweden include the fast active disturbance reserve (FADR) that currently consists of a fleet of gas turbines. Svenska Kraftnät Gasturbiner (SvkGT) is a subsidiary company to the Swedish Transmission System Operator (TSO), responsible for the operation of a number of these turbines devoted for FADR use. With an increasing amount of non-continuous, *intermittent energy sources* in the energy mix, the demand for ancillary services keep increasing. To achieve the Swedish national goal of zero net emissions by 2045, it is of utmost importance to evaluate potential technologies that could provide FADR services in a more environmentally sustainable way or consider using intermittent production for balancing means.

Utility scale battery energy storage systems (BESS) have lately been introduced in different parts of the world as an enabler to store intermittent energy which can be used when needed. The deployment of BESS has been drastic over the last few years, but the technology has yet to be introduced in Sweden. This report aims to evaluate BESS and the technology's potential as a complement or substitution to current gas turbines devoted for FADR use.

This report compares BESS to gas turbines through a cost-benefit analysis focused on FADR use. Initially, a requirement specification for the FADR is established based on regulations and operational data of current turbines. Three different battery technologies are evaluated through a literature study and combined with a case study of the 100 largest BESS facilities in the world. Additional interviews with a variety of battery suppliers have also been conducted.

The results indicate that the Li-ion technology currently dominates the BESS market and that the most common area of application is for primary reserves such as fast frequency regulation (FFR). FFR is considered the optimal application for batteries, mainly due to their unique ability to supply power quickly. The results also establish that all battery technologies are technically capable of meeting most of the criteria for FADR use, but practically fail to achieve the criteria of "Electricity readiness", stating that a 100-hour duration of power supply is essential for the FADR. However, the results from the operational statistics for the current FADR conclude that a battery could stay competitive to a gas turbine from a cost perspective while covering up to 97% of the FADR demand. Finally it is concluded that the Vanadium Redox Flow battery is the technology that show greatest potential for FADR use, mainly due to its low price, high robustness, low degradation rate and the fact that its poor round-trip efficiency is of smaller concern when the asset is intended for FADR operation. Additionally, projections of performance improvements for batteries, combined with a continuation of declining prices, indicate that batteries will be real game changers for ancillary services in the future.

Keywords: BESS, Energy Storage, Batteries, mFFR, Fast Active Disturbance Reserve, Gas Turbines

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Preface

> When life gives you a ton of lemons
> - Construct a Utility Scale Battery
> Energy Storage System!
>
> *Wise Fellow*

This master thesis was written during the spring of 2018 and is the final part of our Master of Science in Mechanical Engineering. The thesis was written for the Faculty of Engineering at Lund University in cooperation with Svenska Kraftnät Gasturbiner AB.

We would like to thank our supervisor at LTH, Jens Klingman, for the support throughout this project. We would also like to thank Fredrik Hermann and Peter Blomqvist at Svenska Kraftnät Gasturbiner AB for giving us the opportunity to conduct this thesis.

Lund, May 2018 Ludvig Wingren and Jonas Johnsson

Abbreviations

BESS	Battery Energy Storage System
C-rate	Power output / Capacity ([MW]/[MWh])
DOE	Department of Energy, United States Government
DSO	Distribution system operator
ESA	Energy Storage Association
EASE	European Association for Storage of Energy
EERA	European Energy Research Alliance
ENTSO-E	European Network of Transmission System Operators for Electricity
EV	Electric Vehicle
FADR	Fast Acting Disturbance Reserve
GT	Gas Turbine
HVDC	High Voltage Direct Current
Hz	Hertz
IRENA	International Renewable Energy Agency
IVA	The Royal Swedish Academy of Engineering Sciences
LCOE	Levelized cost of energy
LCOES	Levelized cost of energy storage
mFRR	manual Frequency Restoration Reserve
MW	MegaWatt (Effect)
MWh	MegaWatthours (Energy)
RES	Renewable Energy Source
SOA	Nordic System Operation Agreement
Svk	Svenska Kraftnät
SvkGT	Svenska Kraftnät Gasturbiner AB
TSO	Transmission system operator

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1 Introduction

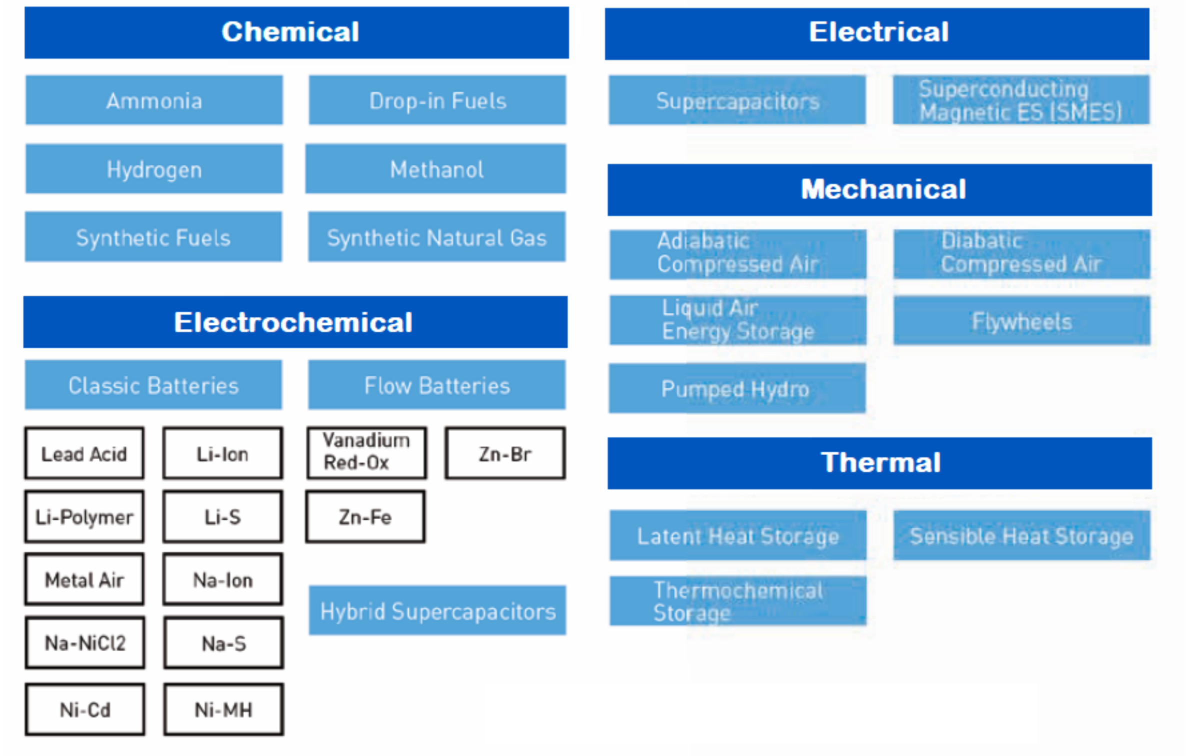
1.1 Background

In order for a power grid to function properly there is a need for balance between production and consumption of electricity. If the supply does not equal the demand, the frequency rises or falls due to the imbalance between production and consumption. Frequency varies among different power grids but in most European countries including Sweden, it is kept at 50 Hz. Larger frequency deviations can damage equipment connected to the grid and cause blackouts. Therefore it is important to maintain stability in the grid and the frequency within a certain interval. Functions in power systems that are to maintain balance in the system are referred to as ancillary services.

There are several different types of ancillary services provided to maintain a constant voltage and a stable frequency. Historically power grids have been stabilised using production facilities, meaning production has been adjusted to match consumer demand. The Swedish power grid is built on this principle and over the years, large investments have been made in production reserves to cover consumption peaks. With the aim of moving towards a sustainable energy supply, more non-continuous, or so called intermittent energy sources such as wind and solar power is introduced to the market. This changes the traditional relationship between production and consumption. Factors such as economies of scale, technological improvements, greater competition in supply chains combined with the right policy conditions are driving up the performance and down the cost of renewable energy production, enhancing its competitiveness with traditional techniques. According to the International Renewable Energy Agency (IRENA), more than 80% of the world's electricity supply could derive from renewable energy sources by 2050. Solar and wind power could at that point represent 52% of the entire electricity generation (IRENA 2015).

The introduction of non-dispatchable energy production changes the dynamics of the power supply. Historically the consumption side has been the volatile part of the equation but with increasing amounts of intermittent energy sources, variations in the production are increasing rapidly. Fluctuations on the production side enhance the challenge of covering peaks of high consumption during periods of low production. There are however different ways of using intermittent energy production for ancillary services. In Denmark for example, frequency stability enhancement is achieved using synthetic inertia from wind turbines (Nguyen et al. 2017). Another option is to store power from intermittent energy sources using different types of energy storage techniques. In Table 1, the five main types of energy storage are demonstrated and further subcategorised into different technologies (Bortolotti 2017).

Table 1: Energy storage families



Pumped hydro storage is the clear dominating type of energy storage today. However, electrochemical storage, also known as batteries is the fastest growing storage technique today and has undergone vast development lately with falling costs and improving performance. By 2030, the cost of storage to support ancillary services could fall by 50-66%. Large scale battery energy storage systems, often referred to as BESS are built and frequently announced in different parts of the world and the storage capacity of BESS in stationary applications is estimated to increase vastly in both short and long term (IRENA 2017).

1.2 Problematization

In the Swedish power system today, there are a number of market solutions, reserves and system securities to ensure balance and reliability in the grid. Ancillary services in Sweden is handled through a cooperation between the Nordic countries where Sweden has a specific responsibility for the region. Swedish ancillary services are divided into three main categories; *primary*, *secondary* and *tertiary reserves*. The main difference between the categories is the activation time. Primary reserves are activated close to immediately in case of imbalance in the grid, secondary reserves are activated in the case of larger imbalances and tertiary reserves are activated when disturbances reach such levels that the first two reserves are unable to manage them. This section mainly covers parts of the tertiary reserve while all reserves are further explained in the theoretical part of the report (Svk 2017).

The tertiary reserve consists of three primary functions; the Nordic Regulatory Power Market, the power reserve and the fast active disturbance reserve. This section focuses on the fast active disturbance reserve while all functions are further explained later in the report. The fast active disturbance reserve is frequently discussed throughout the report and is further on referred to as the FADR. FADR mainly consists of a number of gas turbines that are available for activation in the case of larger deficiencies in electricity production to ensure restoration of balance and reliability in the grid. The FADR is to fulfil a number of specific goals according to the Nordic System Operation Agreement(SOA). One of the main goals is the so called N-1 criteria stating that the power system must withstand the loss of a single main component(production unit, wire, transformer etc.) which today equals one of the nuclear reactors at Oskarshamnsverket with a power output of 1450 MW.

Svenska Kraftnät Gastubiner AB is a wholly owned subsidiary company of Svenska Kraftnät and is responsible for part of the FADR, meaning the company owns and operates a number of gas turbines at the command of Svenska Kraftnät. Most of these turbines were commissioned in the 1970s and all have a limited lifespan. The internal report *Störningsreservens långsiktiga hantering* (2014) is a review of today's fast active disturbance reserve where needs, requirements and opportunities for future design of the FADR are identified and discussed. The report concludes that today's solution of gas turbines, in the long run, could be complemented or replaced by other technologies that could provide similar functions. Reinvestment in new gas turbines is extensively evaluated while other technologies such as part-regulation of wind power, energy storage and consumption reduction are discussed more briefly. The report estimates that the existing gas turbines have a lifespan that extends to approximately 2030 and it is therefore of great importance to further investigate and evaluate the alternative solutions to be able to decide on a future strategy for the fast active disturbance reserve (Moberg 2012).

Large scale battery storage systems is a fast growing technology. Facilities are frequently built or announced in different parts of the world but the technology is yet to be introduced in Sweden. These facilities are meant to recharge during periods of low consumption and discharge during periods of higher demand, thereby reducing the dependence of gas-fired power plants like the ones owned by SvkGT today. SvkGT has limited knowledge of battery storage technologies that could possibly complement or partially replace their current fleet of gas turbines. Therefore it is of great importance to analyse and evaluate alternative options, especially considering the limited lifespan of current turbines.

1.3 Purpose

The purpose of this report is to examine and to gain an understanding for Battery Energy Storage Systems (BESS) and the technology's potential for fast active disturbance reserve use. The thesis focuses on evaluating BESS against current gas turbines owned by Svenska Kraftnät Gasturbiner AB and their function today by comparing key figure information for current gas turbine technology with BESS. Further will aspects regarding environmental implications be examined to a limited extent. The purpose is limited to answering the following questions:

- What functions are existing or announced BESS facilities intended to handle?
- Can BESS fill the fast active disturbance reserves future needs for grid disturbance, balancing, voltage support, black start and island mode operation?
- How does BESS compare to gas turbines economically in terms of investment/MW, investment/MWh, operational and maintenance costs as well as the Levelized cost of energy?

1.4 Goals

The goal of this project is for the authors to be able to provide knowledge and understanding for BESS as well as ancillary services and the possible functions BESS could have regarding balancing of power grids in Sweden. Specifically the report aims to evaluate BESS against current gas turbine technology on an investment basis by comparing specific key figures for the different technologies. The report also aims at providing the sponsor, Svenska Kraftnät Gasturbiner AB with necessary material for further evaluations regarding the future of the fast active disturbance reserve. The goals are summarised in the following main areas:

- Map out different battery technologies suitable for grid application.
- Understand different application areas for BESS facilities.
- Understand key drivers for today's BESS market.
- Compare BESS technology with the current gas turbine technology used for tertiary balancing services in Sweden.

1.5 Delimitations

This thesis is the first step of an initiative to investigate BESS technology for the Swedish power system and particularly for FADR use. The report is conducted on behalf of Svenska Kraftnät Gasturbiner AB. The company today has great insight into gas turbine technology and operation which is why detailed focus is paid to battery storage facilities rather than on gas turbines. The main purpose of this prestudy is to get a first understanding of a new technology. Therefore aspects such as the market structure is only vaguely considered and discussed but not taken into consideration when evaluating one technology against the other. The limitations of the thesis are summarised in the following areas:

- The case study of BESS facilities around the world is conducted in a limited amount of time and therefore likely to miss out on some suitable facilities for evaluation.
- The Swedish energy market structure is described briefly but not taken into consideration when evaluating different technologies, meaning technologies are mainly

evaluated from a cost perspective and possible revenue streams are not considered in great detail.

- Due to confidentiality reasons some information regarding pricing is not included in the report.
- The report covers a limited number of battery technologies.

2 Method

This part of the report aims to describe how the research, gathering of information and analysis are conducted throughout the project and more specifically why. The process of choosing topic and sequential approach for the thesis is presented shortly after which the main part of different applicable methodologies are explained and specific choice of methods is motivated. At the end of the chapter the credibility of different material is discussed briefly.

2.1 Choosing of Topic

The main task assigned from SvkGT is to investigate if battery storage could replace the gas turbines in the fast active disturbance reserve. The task is well suited within the *M. Sc programme in Mechanical Engineering at The Faculty Of Engineering - Lund University* where the thesis is conducted and the subject is highly relevant, well discussed at the moment and by many considered as a possible game changer for power supply and power markets.

2.2 Approach

Through this report the technical and economic potential of introducing large scale battery energy storage systems (BESS) to the Swedish market is compared to the alternative of replacing or renovating the current fleet of gas turbines to maintain desirable functions in the fast active disturbance reserve. The approach to the project is roughly carried out in four main steps stated below and represented in Figure 1.

- Subject Orientation Phase
- Mapping of gas turbines devoted for mFRR (FADR)
- Mapping of BESS
- GTs vs. BESS

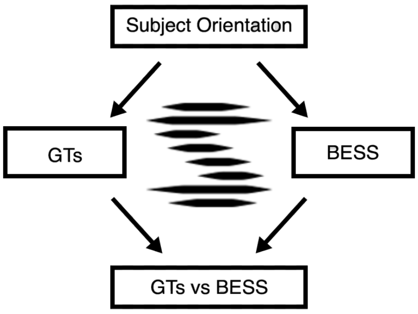


Figure 1: Approach

2.2.1 Subject Orientation Phase

The authors as well as the sponsor SvkGT are well acquainted with gas turbine technology and have a fundamental understanding of power systems and markets. However, the level of detail in which ancillary services as well as battery technology is to be examined is unfamiliar territory. Therefore the initiation phase of the thesis is conducted through a literature study focusing on ancillary services and BESS technology but with a wide perspective. The idea of this study is to encounter as many areas as possible on a basic level through the chain of information which leads to new information. This method is referred to as snowballing (Olhager, 2018) and can be a time-consuming concept due to its unstructured character, but at the same time an effective way to encounter a vast variety of information easing the process of determining the scope and focus of the study.

2.2.2 Mapping of FADR

Understanding ancillary services and the fast active disturbance reserve (FADR) is essential for achieving the goal of this project. This part of the work is among the most straightforward ones. The collaboration with SvkGT through the project allows for easy access to all necessary information regarding the fast active disturbance reserve. Mapping of the reserve is mainly conducted through internal information gathering from within SvkGT and Svk along with a series of interviews with representatives from the two companies. The primary purpose of evaluating the FADR is to conduct a requirement specification for the reserve. This specification is mainly based on the two reports *Störningsreservens långsiktiga hantering* and *Svenska Kraftnät - System development plan 2018-2027* along with operational data on assets devoted for the FADR and interviews with people responsible for the operation of the FADR.

2.2.3 Mapping of BESS

The primary focus of the project is to understand and explain BESS. Initially a literature study focusing on what existing research there is regarding BESS for grid application is performed. As mentioned earlier though, there is limited information on the subject due to the recent introduction of the technology. SvkGT is also greatly interested in facilities constructed recently and therefore, a case study of different facilities around the world is conducted throughout the project.

2.2.4 GTs vs. BESS

Finally BESS technology is evaluated against gas turbine technology on a functional and economical basis. The two technologies are compared to one another through a cost-benefit analysis and roughly follows a framework from *Cost-Benefit Analysis: Concepts and Practice* that mainly divides the analysis into the following eight steps (Boardman et al. 2014)

- Specify the set of alternatives

- Decide what benefits are to be evaluated
- Identify the impact areas
- Predict the impact over the life of the project
- Discount benefits to obtain present values
- Compute the net present value of each alternative
- Perform sensitivity analysis
- Make recommendation

A difficult part of this process is to determine corresponding functional and economic factors of the two different technologies. Batteries and gas turbines are like apples and oranges in some aspects. Therefore, the two technologies are compared to one another to a limited extent and non-common functions are discussed for each technology separately.

2.3 Research methodology

This section aims at discussing the considered methodological approaches to the study. There are many methods and strategies to choose from and this study uses a combination of several methods. The main purpose of deciding on a suitable combination of methods for the problem is to conduct the research efficiently, always working goal oriented towards the aim of the project. Choosing of method is thus about using time and other resources in an efficient manner in order to create as much value, knowledge and experience as possible throughout the study (Björklund and Paulsson 2014).

2.3.1 Explorative, descriptive, explanatory and normative studies

An important aspect to consider when choosing in what manner a study is carried out is the current existing amount of information there is within the field of the study. According to *Academic papers and theses*(2014) by Björklund and Paulsson, scientific approaches can be divided into four categories. *Explorative*, or so called investigatory studies that are usually carried out when there is little information within the area of the study and the authors are trying to attain and deliver a fundamental understanding of the subject. *Descriptive* studies are commonly used when there is a fundamental understanding of the subject and the aim is to describe but not explain the phenomenon. *Explanatory* studies are used when searching for more profound knowledge in a field with the ambition to both describe and explain. Ultimately, *normative* studies are used when there already is existing knowledge and understanding of the area of research and the authors ambition is to provide guidance and suggest measures for the phenomenon (Björklund and Paulsson, p.64).

This project is a first initiative to investigate BESS suitability for FADR use. Battery technology is an old science and there are lots of studies of different kinds of battery technologies. However, using batteries for grid application and ancillary services is quite a new area and yet to be introduced to many power systems including the Swedish one. Different types of facilities have been implemented lately but the documentation of both application areas and economic aspects is limited. This project aims to examine batteries suitability for grid application and more particularly tertiary ancillary services in Sweden. In order to investigate this, a fundamental understanding of different types of battery technologies is necessary. Therefore battery technologies are examined through a descriptive study in order to give the authors and readers a fundamental understanding of the technology providing the ancillary services in focus for this project. Application areas are more thoroughly investigated through an explanatory study mainly based on a case study of a variety of facilities around the world due to the partial lack of existing documentation. The last goal, comparing BESS to current gas turbine technology is carried out through a normative study with the aim to provide SvkGT with guidance and measures to go forth with their strategy regarding the FADR.

2.3.2 Qualitative and Quantitative analysis

The primary aim of this thesis is to examine and compare functional and economic aspects of BESS technology as well as gas turbine technology. Economic aspects are in general well suited for quantitative analysis and in this particular case, most functional aspects are as well thus they can be described numerically (Björklund and Paulsson, 2014 p.69). Economic aspects are therefore evaluated, and most functional aspects are quantified to an extent as great as possible.

2.3.3 Data collection

Data collection for this study is conducted through a combination of primary and secondary data divided into four categories but mainly focusing on the first three stated below (Björklund and Paulsson 2014).

- Literature studies
- Interviews
- Observations
- Presentations at lectures, conferences etc.

Literature studies lay the foundation for the frame of reference for the thesis. The empirical part of the study is mainly based on interviews and internal data from within Svk. A great deal of information regarding operation of the FADR is attained through internal data provided by Svk and SvkGT, considered as primary data from observations. Part of the thesis also includes the author's participation and attendance at a variety of conferences focusing on energy storage. The main aim of attending the conferences is to conduct interviews and take advantage of the gathering of knowledgeable people at the same place.

Litterature studies

As stated earlier the initial part of the literature study is basically conducted without any limitations according to a method previously referred to as snowballing. After achieving a fundamental understanding of the problem it was discovered that a great part of the acquired information was highly irrelevant due to many different reasons, the major one being the publication time of the data. As aforementioned, BESS-technology has gone through vast changes lately resulting in outdating of older findings and documentation. Therefore strict requirements for data collection were set, especially in regards to timeliness. All information regarding BESS was set to be published no earlier than 2015 initially. This is further discussed and motivated later in the report. Being a rather new subject always comes with lots of publicity of greatly varying reliability. Therefore the literature study mainly focuses on publications from larger, more recognised and trusted organisations. When only considering literature studies findings in this thesis is mainly based on three reports; *Störningsreservens långsiktiga hantering*, *Svenska Kraftnät - System Development report* both of which are published by Svk and finally *Electricity Storage and Renewables: Costs and Markets to 2030* published by The International Renewable Energy Agency(IRENA). Limiting the number of information sources also increases consistency of the results of the study.

Interviews

The series of interviews conducted with associates at Svk can be considered as unstructured interviews as many of them are conducted with the purpose to get acquainted with the subject where the structure of the interview was better controlled by the more experienced and knowledgeable interviewee. However, most interviews conducted later in the project with BESS-suppliers, people responsible for the FADR etc. can be considered as structured interviews where the agenda was set to attain quite specific information as well as attain similar information on different BESS facilities (Björklund and Paulsson 2014).

Observations

There are some regulations as to what capabilities the FADR should provide, but the information is limited. A great part of this thesis therefore includes analysing of the current operation pattern of the FADR which is intended as an indicator of what characteristics the FADR should have. Data from 2010 and fourth for all assets devoted for FADR use is analysed in order to get an understanding for how the FADR is operated today and how that corresponds with the specifications of operation according to national regulations.

2.4 Credibility

Credibility is considered through three main areas in this report and divided into; validity, objectivity and reliability (Björklund and Paulsson 2014).

2.4.1 Validity and Objectivity

Being a highly quantitative study eases the challenge of achieving high validity and objectivity. *Validity*, defined as to what extent results and conclusions in a study truly measure what is intended to measure is quite a straightforward challenge in this report due to the very concrete problem (Björklund and Paulsson 2014). In order to ensure high validity, a thorough requirement specification for the FADR is conducted in collaboration with SvkGT as well as Svk. This requirement specification is controlled, verified and approved by several people with different responsibilities within the two companies in order to confirm that the specification is accurate and correct. This approach also increases the objectivity of the specifications to be measured. The second major focus area of the report aside from the functional aspects to be measured for the two technologies is the economic perspective where validity and objectivity are considered as a lesser concern. Still, the report aims at using a limited number of sources for the economic comparison to attain consistency in the results, while these figures are also controlled and compared with other studies and interviews with the industry. This is further described below in the section discussing reliability.

2.4.2 Reliability

Reliability is defined as to what degree one can measure the result or conclusion repeatedly with a consistent outcome, meaning that repeated measurements would give the same result qualifies for good reliability (Björklund and Paulsson 2014). A common way of achieving high reliability is to use *Multiple Sources of Evidence.* This can be done in several ways as explained below.

Multiple Sources of Evidence - Triangulation

A commonly used strategy when researching a subject is the use of multiple sources of evidence to increase the spread of supporting information. Conclusions supported by several different sources of information is likely to be more convincing and accurate than those from a single one. Triangulation is a common and valuable example of using multiple sources of evidence that is applied throughout this study and simply demonstrated in figure 2.

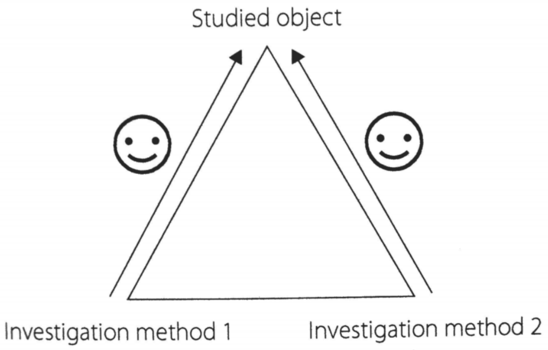


Figure 2: Triangulation

According to Patton(2002, cited in Yin 2009) there are four types of triangulation:

- Data triangulation - the use of several data collection methods(such as literature, interviews, observations etc.).
- Investigator triangulation - the use of several investigators or observers.
- Theory triangulation - using multiple theories or perspectives to analyse the same subject.
- Methodological triangulation - using a combination of different methods or approaches to the same problem.

Triangulation is used in this project in order to increase accuracy and validation to results and conclusions but also to ensure validation of specific sources of information not to let subjectivity or other factors be of to great of an impact on the final combined results. Data triangulation is applied through a collection of information from interviews and existing literature. Investigator triangulation is conducted by interviewing both suppliers and purchasers of different technologies. Triangulation is also achieved through the vast variety of cases studied throughout the project.

3 Frame of reference and theory

This chapter aims to provide a fundamental understanding of concepts and technologies discussed throughout the report as well as theory used for analysing attained information. Initially the Swedish power grid is described with the aim of giving a technical understanding of different requirements and services within power systems. The second part presents a range of different battery types suitable for grid applications. It is important to understand technical differences between battery types in order to understand why different facilities use different technologies. The third part of the chapter aims to present and describe different functions that BESS technology can provide and be applied for. Finally economic models used to evaluate the different technologies throughout the report are presented and described in more detail.

3.1 The Swedish Electrical Power grid

A power grid is the infrastructure constructed to handle the challenging and comprehensive task of electricity transmission and distribution. The concept of supplying electricity is unlike any other service due to the fact that supply has to correspond with consumption at all times. It can be considered as the ultimate "just in time" supply chain. The transmission needs to be flexible and durable to encounter the daily and seasonal changes, such as peaks and periods of low consumption as well as disruptions and faults in the power grid. Depending on the system and market structure, the actor responsible for development, maintenance and balancing of the power grid vary. In Sweden the governmental owned Transmission System Operator (TSO), Svenska Kraftnät is responsible for the power grid. The foundation of a power grid is the transmission lines connecting countries and regions. Figure 3 shows a map of the Scandinavian transmission lines forming highways for electricity to flow long distances. In Sweden, most electricity originates from hydropower situated in the north while the majority of the consumption occurs in the more densely populated south. The transmission line network merges on a smaller regional level with distribution lines and local power lines distributing the power locally. A potential problem when transporting electricity over long distances is bottlenecks that for example in Sweden occurs when demand in the south exceeds the capacity of the transmission lines supplying electricity from the north. The bottlenecks in Sweden are often concentrated to three main areas thus dividing the country into four main electrical regions as shown in Figure 4. In 2011 Sweden was divided into these so called *bidding zones*, between which electricity prices occasionally deviate from one another due to the limitations in the transmission system (Svk 2017). The three borders between the four bidding zones displayed in Figure 4 are called *cuts* and are named as follows:

- Cut 1, the border between SE1 and SE2
- Cut 2, the border between SE2 and SE3
- Cut 4, the border between SE3 and SE4

Figure 3: Transmission lines in Scandinavia

Figure 4: Bidding zones in Scandinavia

Svenska Kraftnät divides grid stability into three main components; *frequency stability*, *voltage stability* and *rotor angle stability* (Svk 2017). *Frequency stability* is the capability of keeping the grid frequency, also referred to as synchronous speed at a certain level which in the EU is set to 50 Hz. Electrical components are designed to operate at this frequency and larger deviations in frequency can cause failure of different components. Variations in frequency are caused by unbalance between production and consumption. If power production is higher than consumption, the frequency rises and if consumption exceeds productions the frequency drops. The Balance Service is a unit at Svenska Kraftnät controlling a range of reserves in order to balance production and consumption at all times (Svk 2017). Figure 5 shows the instantaneous frequency at a given moment and the accepted interval in which it is to be kept at all times (Svk 2018).

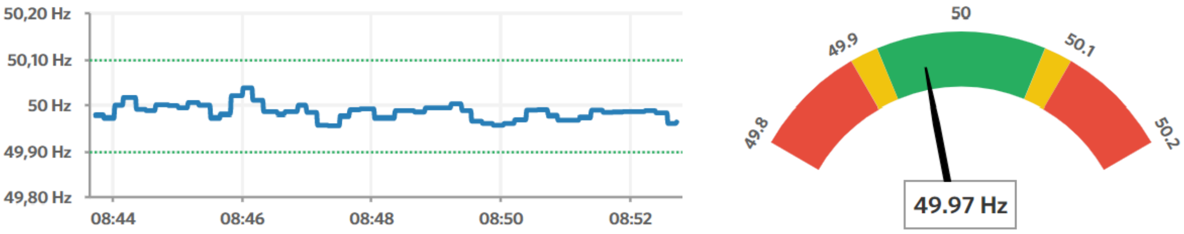


Figure 5: The instantaneous frequency at a given moment

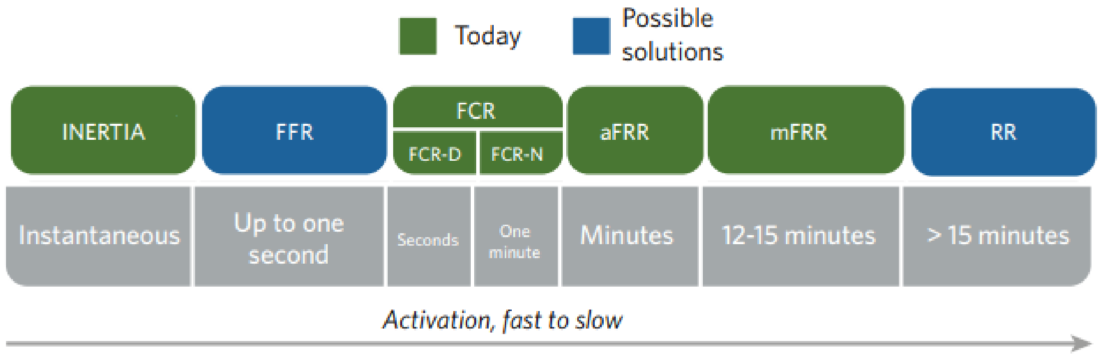
The power grid's different levels of voltage need to be in balance in order for the grid to maintain a proper *voltage stability.* This is a complex task thus voltage stability is affected by all components in different parts of the grid and requirements of reactive power. Due to difficulties in transmitting reactive power over long distances, reactance must be produced and consumed at specified places in the grid. Losing voltage stability may cause voltage collapses, leading to massive power failures (Svk 2017).

Synchronous generators that are connected to the power grid have individual specific rotor angle velocities when transmitting power. Correlation among these rotor angle velocities is essential to maintain rotor angle stability. Generators operating with deviating rotor angle velocities risks being disconnected from the grid. The term *Rotor angle stability* thus refers to the ability to dampen the mutual movement that exists between generator rotors (Svk 2017).

3.1.1 Ancillary services

The collective term *Ancillary services* is used to describe a range of services used to maintain balance and stability in power grids. According to Svenska Kraftnät these can be divided into four main categories, *Balancing services*, *Frequency control*, *Voltage Regulation* and *Inertia* (Svk 2017). These categories can be further divided into individual functions according to Table 2 (Svk 2017). mFRR is as aforementioned the ancillary service which is of special interest in this report as the FADR is part of it.

Table 2: The ancillary services of today and the future



INERTIA	FFR	FCR		aFRR	mFRR	RR
		FCR-D	FCR-N			
Instantaneous	Up to one second	Seconds	One minute	Minutes	12-15 minutes	> 15 minutes

Inertia

Energy production that involves rotating machinery such as turbines and generators supports power systems with inertia. Inertia is the rotating machinery's difficulty to change velocity and thereby acts as an instantaneous response to load variations. It is a vital capability which supports the power system in keeping the frequency close to 50 Hz. Renewable energy sources such as wind and solar power lack inertia and the integration of these into the grid decrease the proportion of inertia in the power system making it more fragile (Karlsson and Nordling 2016).

Frequency controlling

FFR, Fast Frequency Reserves are ancillary services yet to be introduced in Sweden and on the Nordic market. With a declining amount of inertia in the power system there is an increasing interest in Fast Frequency Reserves. *FCR*, Frequency Containment Reserves are the fastest reserves (excluding inertia) currently used in Sweden and it is most often supplied from hydropower. FCR is divided into two reserves based on when the reserves are activated; FCR-N and FCR-D. *FCR-N (Frequency Containment Reserve - Normal)* is activated at frequency deviations within 50 ± 0.1 Hz and *FCR-D (Frequency Containment Reserve - Disturbance* is activated in case of larger deviations of frequencies below 49.9 Hz and above 50.1 Hz (Svk 2017).

Balancing Services

FRR, Frequency Restoration Reserves are used to restore the frequency to its nominal value in case of a larger disturbance and thus unload FCR-D enabling FCR-D to recover and handle new disturbances. FRR is divided into two parts based on how they are activated, where *aFRR* is activated automatically and *mFRR* is activated manually from the control room at Svk. aFRR is categorised under secondary reserves and mFRR under tertiary reserves. *RR*, Restoration Reserves is yet to be introduced in Sweden. RR fills the same function for FRR as FRR does for FCR. It acts as a reserve to back up and unload FRR, enabling FRR to manage new disturbances. (Svk 2017). Apart from the reserves described so far there are several others that are demonstrated according to when they are used in Figure 6 (Karlsson and Nordling 2016). Most of these reserves are not described in this report considering the focus on batteries in comparison to gas turbines intended for FADR use.

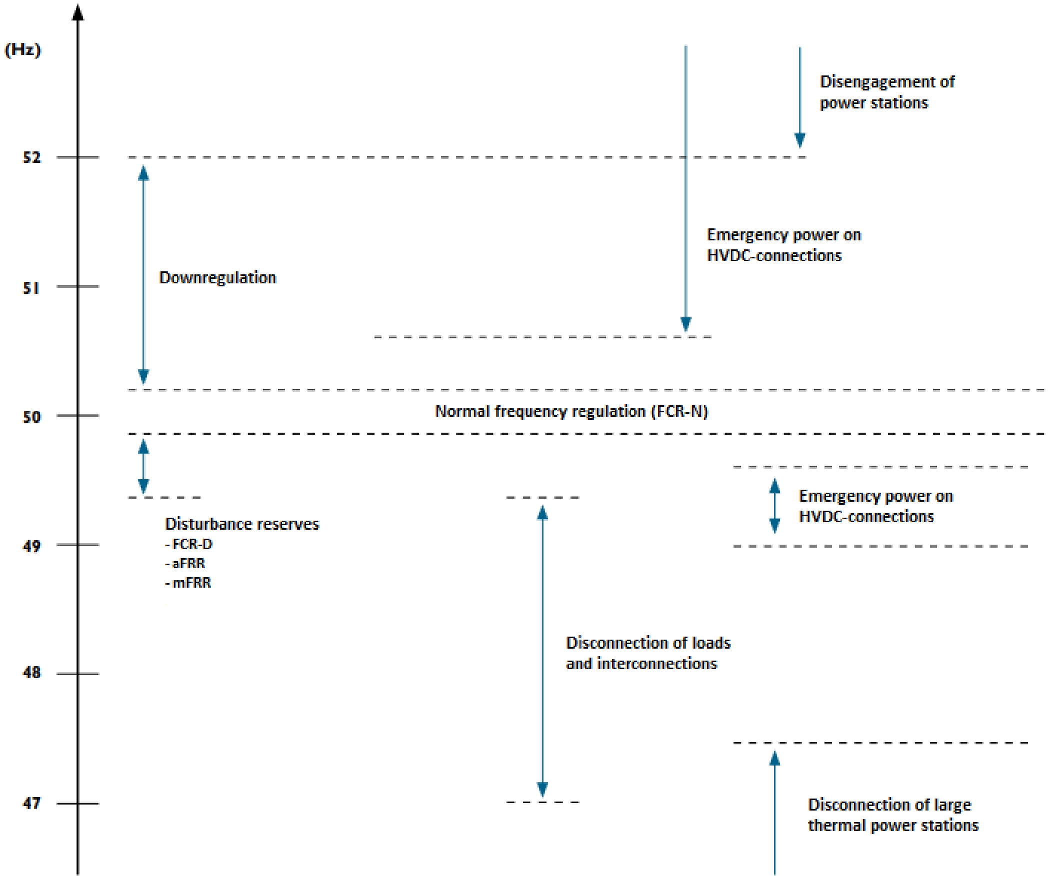


Figure 6: Reserves that are activated according to frequency level

3.2 Electrochemical Storage

Electrochemical storage, more often referred to as *batteries* are technologies enabling the transformation from electrical energy to chemical energy. Once transformed into chemical energy, power can be stored for later use when needed, the chemical energy is transformed back into electrical energy. The first ever battery was constructed by Alessandro Volta in the year 1800. Volta called his creation the Voltaic Pile which basically was a stack of copper and zinc plates separated by brine-soaked paper in between. The Voltaic Pile could produce a steady current for a considerable period of time. Since then batteries have gone through a dramatic development especially in regards to technical aspects. Today there are hundreds of types of batteries all better or worse suited for different applications. Economies of scale have reduced battery costs significantly and the development of materials and technology have greatly improved both capability and reliability (Science 2016).

Figure 7 shows an electrochemical cell in its most basic form. There are three fundamental components that are essential for all types of batteries. The anode, cathode and electrolyte. The anode and cathode are electrodes between which electrons can flow through an external circuit. The electrodes are usually made out of metals or chemical compounds of different sort. When electrons flow through the outer circuit chemical reactions occur at the anode and cathode. The dispatching of electrons creates positive and negative ions that flow through the electrolyte. The electrolyte can be of liquid, gel or solid substance and separates the electrodes from one another. Some batteries have an additional semi-permeable barrier in the electrolyte to prevent ions from coating the electrodes, stopping the electrochemical process (Science 2016).

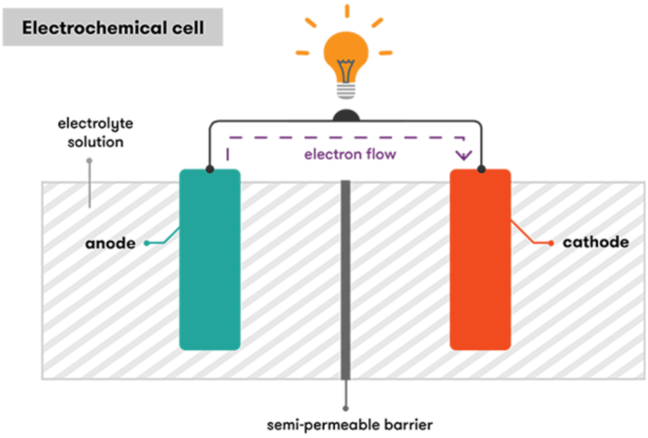


Figure 7: Battery components

For many batteries the process described above process is reversible, enabling recharging of the battery. However when reversing the process the electrons and ions end up in a less structured way compared to the initial state. Each charging cycle will slowly worsen the structure causing the battery to degrade over time of use. A battery also degrades naturally during off-use periods due to minor chemical reactions. This phenomenon is referred to as self-discharging. All these factors make it difficult to determine a battery's lifespan (Science 2016). The lifespan of a battery is of great importance, especially for grid scale batteries that are usually intended to operate continuously over a long period of time.

Aside from a battery's lifespan, different technologies can be evaluated in terms of a various of performance factors, six of them being *efficiency*, *specific energy*, *energy density*, *depth of discharge*, *cycle life* and *calendar life*. The *efficiency* of a battery is defined as the round trip efficiency, meaning the percentage of energy that is conserved after the transformation process from electrical energy to chemical energy and back again. *Specific energy* and *energy density* is a measure of how much capacity a battery can hold in comparison to its physical weight and size respectively. Energy density can be of utmost importance when it comes to mobile devices such as EVs and phones, where weight and space is a key concern. When designing batteries for grid application weight and space usually is not of the same importance but still worth considering. *Depth of discharge* is the rate to which a battery can be discharged without additional significant degradation. Li-ions for example suffers from great degradation when discharged fully and recommendations usually imply a maximum rate of discharge of approximately 80% to the full capacity. *Cycle life* is the number of cycles a battery withstands before the end of its lifespan and is usually expressed in equivalent full cycles which is the ratio of discharge capability according to the recommended depth of discharge. *Calendar life* is the lifespan of a battery operating according to recommendations in regards to depth of discharge (Science 2016).

Batteries are usually categorised by their working principle, classic batteries, flow batteries and hybrid capacitors as earlier demonstrated in Figure 1. Hybrid capacitors are mainly used for micro discharge operation, not suitable for comparison with gas turbines and therefore not considered in this project. The working principles of classical and flow batteries are further explained and subcategorised in the following sections.

3.2.1 Classical Batteries

Classical batteries are essentially the kind of batteries described above and shown in Figure 7, consisting of the three main parts; *anode* and *cathode* separated by the *electrolyte* which can be in liquid or solid form. Electrical charge travels through the external circuit and ions pass through the electrolyte. There are several classical battery types used for grid application. Lithium-ion, Lead-Acid, Nickel-Cadmium and Sodium-Sulfur are among the most common once. This report presents Li-ion batteries and NaS batteries thus they are the most suitable and widely deployed today for utility scale use.

Lithium-ion (Li-ion)

Lithium-ion batteries are the most well known batteries and were developed and commercialised in 1991. They are known for their high cell voltages and energy density. The term "Lithium-ion batteries" actually refers to a broad spectrum of different batteries constructed of a variety of chemistries. What unites them is that lithium ions are the ions travelling through the electrolyte between the electrodes. Lithium-ion batteries are frequently used in consumer products and other lightweight applications due to their high energy density. A recent prominent area of use is in EVs and for grid application. They have an efficiency ranging between 80-95%, an energy density between 250-690Wh/dm^3 and a specific energy of 100-265Wh/kg. (ESA 2018).

Sodium-Sulfur (NaS)

The sodium-sulfur battery was developed by Ford Motor Company in the 1960s to power early-model electric cars. NaS batteries are fabricated from inexpensive materials and have long cycle life. The batteries are often referred to as molten salt batteries which is exactly what they are. Molten sulfur acts as the anode and molten sodium as the cathode. The battery operates at 300-350 ° C making it a challenge to handle scarce use. However, when used continuously they are well suited for grid application. The electrolyte separating the electrodes is a solid ceramic and consists of sodium alumina. Today many NaS batteries reach an efficiency of approximately 80 % (ESA 2018).

3.2.2 Flow Batteries

Flow batteries can be considered as a mix between a conventional battery and a fuel cell. The main difference from an ordinary battery is that the electrolyte is circulated through the battery cell containing the electrodes. Additionally the cell is usually divided with a membrane through which ions flow, however the electrolyte is separated from one side of the membrane to the other. The separate circulating electrolytes are therefore referred to as anolyte and catholyte. Due to the circulating electrolytes energy can be stored outside the cell in tanks as opposed to traditional batteries where all energy is stored within the cell. Figure 8 demonstrates a simple flow battery (Pan and Wang 2015).

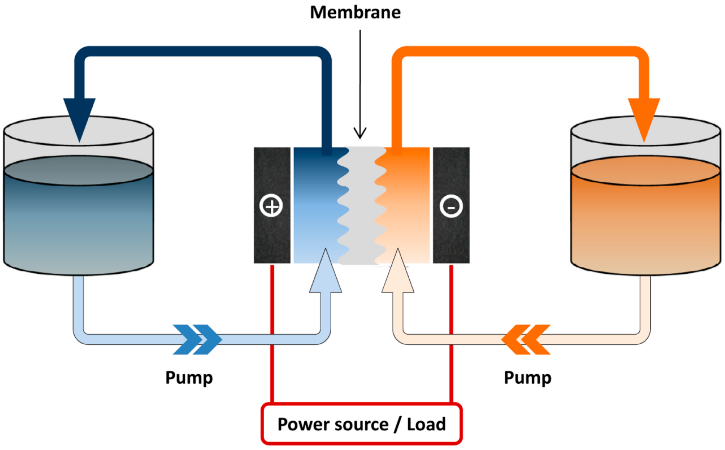


Figure 8: Flow Battery Working Principle

There are several advantages with flow batteries. Unlike for classic batteries, power is separated from energy, the storage capacity can easily be scaled up enlarging the electrolyte tanks, the flow can be controlled and stopped during a fault condition enabling a much more secure operation procedure with less risk for fires and other thermal accidents. Additionally flow batteries are much more durable and do not age like traditional batteries. Cycle life for flow batteries is estimated to exceed 15000 complete cycles. This is quite impressive in comparison to Li-ion batteries that usually can go through 1500 cycles during their life expectancy. Flow batteries can also handle a 100% depth of discharge without additional degrading which for instance lithium-ion batteries can not. A few disadvantages with flow batteries are their low energy density of about 15-25 Wh/dm^3, their low specific energy of 10-20 Wh/ kg and their slightly lower efficiency around 70-80%. Due to the low energy density flow batteries are not well suited for mobile uses and the main area of application is for utility functions. There are several types of flow batteries that are well suited for grid applications. Vanadium Redox Flow, Iron-Chromium and Zink-Bromine are among the most common ones and this report focuses on the Vanadium Redox Flow Battery thus it is the most deployed technology among utility scale batteries today.

3.3 Battery functions and applications in power grids

Batteries can provide a vast variety of services in a power system. The types of batteries previously mentioned all have advantages and disadvantages and different types of batteries are better suited for different applications. This part of the report aims to describe the most common and frequently discussed applications for utility scale batteries. Applications and functions are first categorised into application families after which one of the families, *ancillary services* and a few underlying functions, more interesting for this particular study are described in more detail. These particular functions lay the ground for the evaluation of different BESS facilities throughout the study.

Battery functions can be categorised into five main families of application when discussing utility scale batteries (Hesse et al. 2017).

- Ancillary services
- Grid support
- Behind the Meter
- Energy trade
- Combined applications

Several applications stretch out over more than just one of these families and can be considered as a contribution to several problems or challenges in a power system. Therefore applications are from now on only mentioned under one of these categories. An example is voltage support that can be categorised both under the *grid support* family as well as the *ancillary services* family (Hesse et al. 2017). This report mainly focuses on ancillary services and additionally, Svenska Kraftnät also considers voltage support as an ancillary service in their System Development Report(Svk 2017). Therefore, voltage support is subcategorised to ancillary services in this study. Similar approaches are used for other applications as well.

Behind the meter applications mainly refers to energy management at residential and industrial level which is not considered in this report. *Energy trade* focuses on fluctuations in electricity prices and opportunities to buy and sell energy according to market price variations, leading to arbitrage gains. This function is greatly dependent on the market structure and therefore neither considered in this project. The one interesting function provided by BESS when talking about *Grid support* that is not mentioned under any other category is the opportunity of using storage for deferral or even a permanent alternative to traditional grid reinforcements. For instance in Sweden where most power is generated in the north while the majority of the consumption occurs in the south, the most straightforward way to avoid so called bottlenecks in the transmission system is to upgrade the power lines. In regards to this matter, BESS located in the more densely populated south can fill a useful purpose in increasing the overall transmission capabilities. Finally the application called Island-Grid or Micro-Grid is shortly discussed under the *combined applications* family. Micro-Grid is a function based on several other functions and therefore hard to bind to one application family.

3.3.1 Ancillary services

Frequency regulation

Many utility scale batteries have the ability to react to variations in the grid on a millisecond timescale. This capability makes BESS well suited for *frequency regulation* especially considering the increasing amount of RES and the intermittent nature they bring to power systems. Facing out energy sources like nuclear power, contributing with inertia to the systems also increases the demand for fast acting reserves. Frequency response can be further subcategorised into many different functions and the most common one provided with utility scale batteries is called *Fast Frequency Response, (FFR)* or *Enhanced Frequency Response, (EFR)*. FFR is a faster reserve in comparison to aforementioned frequency regulation FCR and EFR is an even faster reserve with a response time in milliseconds (Svk 2017). When discussing operational time and patterns, frequency regulation is generally characterized by numerous small cycles per day and have very quick response time (Bussar 2013). Figure 9 aims to explain the challenge of maintaining balance in a power system where demand during a ramp up from 3600 MW to 4000 MW is demonstrated between 7 and 10 a.m. The increase from 3600 up to 4000 MW is considered as a macro change and represented by the blue line. The jagged green line represents the actual demand during the period and the red line is a scaled up representation of the difference between the blue and green line. The red line represents micro changes in a power system which are the kind of changes handled with frequency regulation services. Macro changes are handled with peak shaving abilities explained below.

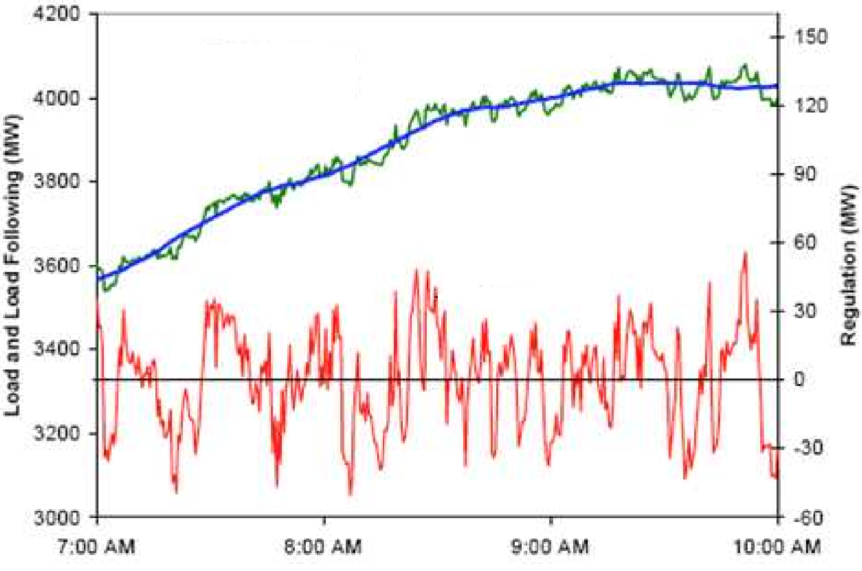


Figure 9: Frequency regulation

Peak shaving

Peak shaving is a form of load levelling, and involves storing power during periods of low consumption and delivering it during high demand peaks. Peak shaving differs from frequency regulation in the way that peak shaving is discussed when fluctuations in demand or supply are characterised by longer periods of change. Batteries suitable for peak shaving generally have higher energy capacity (kWh) with the intention of supplying power for longer periods. Batteries intended for peak shaving usually go through one to two cycles per day and the typical duration for operation is around two hours (Bussar 2013). The need for very fast or immediate response is not essential thus energy peaks are often predictable. However, many batteries intended for peak shaving use are capable of quick response and therefore also capable of enhancing frequency stability.

Ramping

Ramping or ramping control is similar to both frequency regulation and peak shaving. It is about smoothing out power generation, however ramping only refers to the production side. Ramping is especially beneficial when used to handle power from production units with strong supply fluctuations like wind turbines and solar PV generators. Evening out production from RES can be facilitated through the use of battery storage. There are other ways to achieve ramping but batteries are considered as the most efficient way today (Hesse et al. 2017). An example of a facility with ramping as the primary purpose is the AES Laurel Mountain facility where a 32 MW Lithium-Ion battery is co located with a wind farm with a total capacity of 97.6 MW. The procedure of ramping for this particular facility is demonstrated in Figure 10. The pattern of operation time for ramping is hard to describe in absolute terms considering the high dependency of the production facility but in general ramping operation ends up somewhere in between frequency regulation and peak shaving towards the pattern of the latter. This can vary extensively though depending on the site and production source.

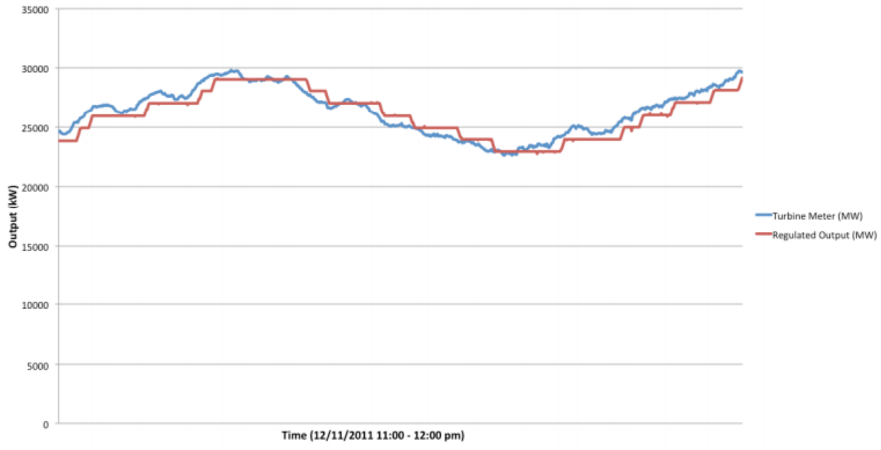


Figure 10: Ramping, AES Laurel Mountain

Black-Start

Black-start is the restart of a collapsed system or a particular part of a system. In the case of a blackout many types of BESS can facilitate a restart of decentralised power generation units. Black-start is usually conducted in a series of steps where units with ever higher power are activated until the main production can be started. Individual power stations are then gradually reconnected to each other. Depending on the size of the battery and power output the facility can take many positions in this type of reaction chain (NationalGrid 2018).

Voltage support

Managing voltage levels in grids is important and mainly requires management of reactance as stated earlier in section 3.1. Traditionally, *voltage support* has been provided by generation units able to produce reactive power which offsets reactance in the grid. There are several types of battery technologies that can provide voltage support. However, this application requires what is called "distributed" storage, meaning that the location of the battery is of great importance and in general it has to be placed close to the end consumer due to the fact that reactive power cannot be transmitted long distances in an efficient manner. Therefore, for a battery to provide voltage support it is essential that it is placed in a high density consuming power centre, like a major city where most reactance occurs.

Rotor Angle Support

Maintaining a constant rotor angle is essential in a power system as aforementioned. BESS can with the help of a so called static synchronous compensator (STATCOM) dampen the rotor angle oscillations. This kind of setup shows particular potential when co-located with wind farms, where the fluctuating production makes the rotor angle less stable (Datta, Kalam, and Shi 2018).

Island-Mode/Micro-Grid

A prominent use for battery storage is in so called *micro grids*. Microgrids are smaller grids, connected to larger grids(macro-grids) or completely isolated, with the ability to function independently. Many microgrids built today from scratch skip past conventional power production and go straight for renewable, meaning the need for ancillary services is of even greater importance. Defining microgrid use as a battery storage function is questionable due to the fact that storage is usable in microgrids but far from the most essential part of a micro-grid. A battery's suitability for micro-grid use also derives from several different functions provided by the battery, some of them mentioned earlier. However, it is a vital and prominent application area for batteries and therefore in this report dedicated separate attention.

3.3.2 Application stacking

Most BESS constructed today are built with the intention of handling several of the above mentioned applications. Batteries have many advantages and are therefore often used for multiple services. This is referred to as application stacking, the idea of using the same facility for several applications. The main advantage of a battery though is the quick response time. Most batteries are therefore intended for fast response operation, for example providing so called synthetic inertia or primary reserve capacity. For frequency regulation one wants to keep a battery roughly 50% fully charged in order to enable both a charge up when production exceeds consumption and a discharge when consumption exceeds production (Rahmann et al. 2017). Whether or not a battery can provide additional services is mainly a question of size and possible operational duration. Figure 11 simply describes the possible capabilities of a BESS facility depending on the possible duration of discharge (Effio 2018). Reserve as described in Figure 11 can be considered as peak shaving and generally requires slightly longer duration of operation in comparison to response that equals frequency regulation in the figure. Black start and transmission services usually require larger batteries with lower C-rates. An easy example to understand this practically is to consider a battery with a C-rate of 0.5(2-hour duration) intended for frequency regulation and peak shaving. The battery is then preferably kept half charged but always with enough capacity to cover local needs. Therefore, half of the total capacity must be sufficient to cover peaks of consumption. Figure 11 however is quite a rough estimate and should not be considered as definite. All situations are unique and a BESS is always designed according to specific local needs.

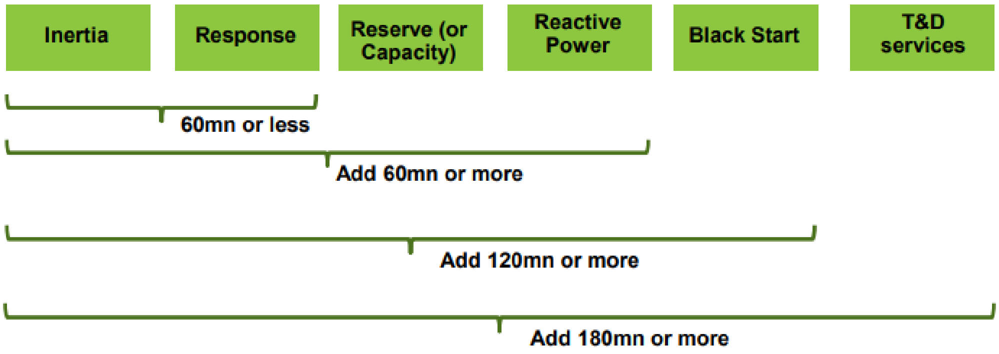


Figure 11: Application stacking with increasing durations of discharge

3.4 Financial models

There is no one way to evaluate financial aspects of energy supply. It is a complex task due to the many different types of existing energy sources, services and market structures. One major problem when comparing different types of energy technologies is to find common comparable values and variables for separate technologies. Additionally, depending on the market structure different types of functions are favoured revenue wise.

This report aims at giving a general, non regional dependent comparison between utility scale battery technology and gas turbines for tertiary reserves. Market structure varies among regions and is therefore not taken into consideration. Inflexions due to market structures are however discussed briefly for both technologies later in the report but is not compared between them. Additionally for many companies in Sweden and especially for Svk, balancing and means to stabilise the power system is mainly considered as a cost, not revenue due to the market structure and lack of capacity market as aforementioned. Therefore this report will only consider the costs and not revenue streams that could be generated through the different technologies. This part of the report describes a number of cost aspects on which the two technologies are compared with special emphasis on a certain concept called *Levelized Cost of Energy*.

The different technologies are mainly compared in terms of capital expenditures(CAPEX) and operational expenditures(OPEX) but with fuel costs separated from the OPEX. Fuel is an operational cost but is usually separated from OPEX when evaluating energy generating facilities because the need for fuel varies significantly among different energy sources (EIA 2013). A simple example is gas turbines in comparison to wind turbines where the latter is entirely independent of fuel. Costs according to this breakdown structure greatly depend on the type of facility as well as the intended use pattern of the asset. As stated earlier this report is to provide a comparison between BESS and gas turbines for the fast active secondary reserve in Sweden. This reserve is used rather rarely which lowers the operational and maintenance costs in comparison to the initial investment cost. Therefore a great focus lies on initial investment costs in terms of SEK/MW and SEK/MWh. Operational costs are still of great importance and discussed briefly through the *Levelized cost of energy*-method described below.

3.4.1 Levelized cost of energy, LCOE

Levelized cost of energy, or Levelized electricity cost is a traditional method for calculating costs for different types of energy generating facilities. It is initially intended for conventional dispatchable electricity generating technologies which today also is the most common application area for the method. Levelized cost of energy is defined as the net present value of the unit cost energy over the lifetime of a generating asset and simply explained in Figure 12 (Joskow and Sloan 2011).

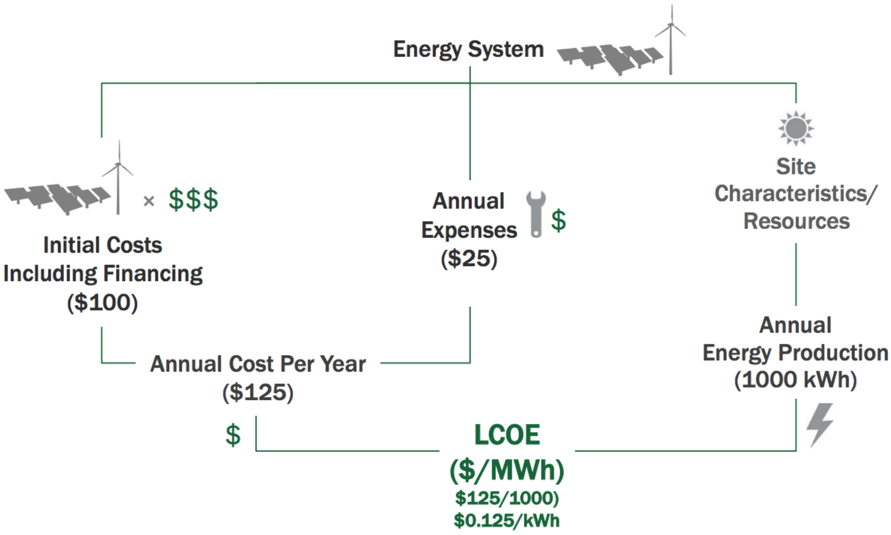


Figure 12: Levelized cost of energy, LOCE

LCOE is commonly used to calculate what average market price of electricity is needed for the asset to break even and generate revenue over its lifetime. However, it can also be used to compare cost competitiveness between different technologies. LCOE can be applied in different configurations but the most common arrangement of the method is to divide costs into CAPEX, OPEX, fuel-cost and dismantling costs. The dismantling cost term is not considered in this report. The purpose of the method is to incorporate all these expenses over the lifetime of a system: initial investments, capital costs, cost of fuel if necessary as well as other operational and maintenance costs. Total costs are then divided by the sum of energy produced over the lifetime of the asset in order to calculate the cost per unit produced energy from the facility. The method is briefly described in Equation 1 where terms are divided among CAPEX, OPEX and fuel-costs (Joskow and Sloan 2011).

$$LCOE = \frac{\sum_{i=1}^{n} \frac{I_i + OM_i + F_i}{(1+r)^i}}{\sum_{i=1}^{n} E_i} \tag{1}$$

- I_i = Investment expenditures in year i
- OM_i = Operation and maintenance expenditures in year i
- F_i = Fuel expenditures in year i
- E_i = Energy generated in year i
- r = Discount rate
- n = Lifespan or comparison time

3.4.2 Levelized cost of energy storage, LCOES

As mentioned earlier energy storage in itself is quite a new area and not much research on the technology exists, especially in regards to costs. However, the most common method used to evaluate the cost of energy storage is an extension of the Levelized cost of energy-method, conveniently called *Levelized cost of energy storage, LCOES*. The concept is basically the same as described above except for a few definitions that differ thus a battery is in fact a storage unit, not a production unit. The extended principle is simply explained in Equation 2 where quantities are the same as described above except for the fuel term that is replaced with a term for charging costs that is divided with the round trip efficiency of the battery described earlier (Belderbos, Delarue, and D´haeseleer 2017).

$$LCOES = \frac{\sum_{i=1}^{n} \frac{I_i + OM_i}{(1+r)^i}}{\sum_{i=1}^{n} E_i} + \sum_{i=1}^{n} \frac{P_{in_i}}{E_i \eta (1+r)^i} \tag{2}$$

- P_{in} = Charging electricity tariff
- η = Round trip efficiency

4 Empirical study and earlier research

This part of the report aims at presenting the gathered information throughout the project. Initially the requirements of the FADR is described after which the current assets of today's FADR are presented along with a brief presentation of a scenario of reinvestments in new gas turbines. The second part of the chapter describes the case study conducted throughout the project after which follows information on current status and predictions from previous studies of utility scale battery deployment, usage, performance and costs.

4.1 FADR: Desired characteristics

There is no unambiguous description of how the FADR should be used or what capabilities it should provide. The available information there is can be found in the "Nordic System Operation Agreement (SOA)". The SOA is an agreement between Nordic TSOs that provides the foundation of standards and regulations for balancing services within the Nordics (Moberg 2012). Specifications in the SOA are more or less explicit and vary in clarity making it more difficult to determine a distinct acquis for the requirements for balancing services and the fast active disturbance reserve.

There is also documentation on how the FADR have been used historically which has come to work as a benchmark or praxis on how the reserve is supposed to be designed. In general terms the FADR has two primary uses, to restore the electrical power system to normal operation in case of a disturbance or relieve transmission congestion after a disturbance. Secondary uses for the reserve is for voltage regulation, black start and island operation. This is partially confirmed in the SOA as well according to:

> "The fast active disturbance reserve shall exist to restore, relieve and unload FCR-N and FCR-D when these reserves have been activated and to return transmissions to acceptable limits after disturbances."

This part of the chapter aims at specifying the demands and standards that the FADR should fulfil based on information from the *SOA*, the report *Störningsreservens långsiktiga hantering* along with interviews with people responsible for the FADR in Sweden. The purpose of specifying these demands and standards is to facilitate an evaluation of both gas turbines suitability and BESS potential for FADR use. The major statements regarding the fast active disturbance reserve mentioned in the *SOA* and the report *Störningsreservens långsiktiga hantering* are interpreted and subcategorised in the areas below as well as summarised in bullet points for each category (Moberg 2012).

Size [MW]

The FADRs size in terms of power is today regulated by the SOA according to:

> "The fast active disturbance reserve shall exist in a size and location so that the system can be reset to normal operation after a disturbance. The size is determined by the individual subsystems evaluation of local needs accounting for production and transmission capabilities"

As mentioned earlier the single largest production unit in Sweden today is the nuclear reactor, O3 in Oskarshamn with a total power output of 1450 MW earlier referred to as the N-1 criteria. The FADR should be able to handle the failure of a single production or transmission unit. Therefore, information from the SOA is interpreted to that the size in terms of power output for the FADR should add up to 1450 MW (Moberg 2012).

- 1450 MW

Response Time

The response time is also regulated in the SOA and should be no longer than 15 minutes according to:

> "The fast active disturbance reserve is a manual reserve available within 15 minutes in the case of a failure of an individual main component (production unit, cable, transformer etc.). The fast active disturbance reserve resets the frequency containment reserve (FCR-D)."

- Maximum 15 minutes

Endurance

The endurance of the fast active disturbance reserve is not clearly specified in the System Operation Agreement. However, the agreement states that

> "If the power system is not restored to normal operation after a disturbance, normal operation should be achieved within 15 minutes."

This statement can be interpreted to that the fast active disturbance reserve should never need an endurance exceeding 15 minutes. An alternative not stated in any regulations is to consider that the FADR should be able to operate for as long as it takes to negotiate new bids on the regulatory market meaning a period of 36 hours (Nyberg 2018). A third alternative is to consider the agreements regarding current gas turbines that are contracted to have fuel for a running time of 100 hours disposable at all times. Finally one can investigate the actual operational pattern of the FADR which is discussed further in Section 4.2. Interviews with people responsible for the FADR however indicate that the 100-hour long endurance of current gas is essential for FADR use (Blomqvist 2018).

- Minimum 100 hours

Location

The SOA states that:

> "The fast active disturbance reserve shall exist in a size and location so that the system can be reset to normal operation after a disturbance. The size is determined by the individual subsystems evaluation of local needs accounting for production and transmission capabilities. ... If required, a subsystem can hold a certain amount of fast active disturbance reserve for another subsystem, as long as there is free transmission capacity for it. Such reservations are agreed upon between the subsystems TSOs."

The nuclear reactor, O3 in Oskarshamn is located in the bidding zone SE3. When accounting for transmission congestion and possible bottlenecks between the bidding zones the distribution of FADR becomes more complicated. Cut 2 between SE2 and SE3 is often used to its maximum capacity in the southern direction. Therefore the 1450 MW must be positioned in SE3 and SE4. The same goes for cut four between SE3 and SE4 which usually is fully loaded in the southern direction as well. Therefore the FADR primarily must be dimensioned according to the requirements in SE4. The biggest providing unit in SE4 is the transmission line "Nordbalt" with a capacity of 700 MW meaning that the fast active disturbance reserve requires a reserve capacity of 700 MW in SE4. As mentioned earlier the N-1 criteria equals 1450 MW thus leading to that SE3 requires the remaining 750 MW.

- 750 MW in SE3
- 700 MW in SE4

Availability

The availability of FADR is not stated in the SOA however the report *Störningsreservens långsiktiga hantering* implies that it is of utmost importance that the production units start when they are needed and that the uncertainty of the fast active disturbance reserves availability today is a key concern that must be minimised (Moberg 2012). An availability of 90% is considered acceptable but higher the strive should always be to achieve an availability of 100%(Blomqvist 2018).

- 90 %

Environment

The Swedish goal of having zero net emission by 2045 applies to the country as a whole but there are currently no regulations in the SOA associated with emissions for the FADR (Hermann 2018). In 2012 the gas turbines devoted for FADR use were considered as Svks third largest contributing factor to greenhouse gas emissions (Alterbeck 2014). This figure is quite high considering the scarce use of the turbines.

- Zero net emissions by 2045

Requirement specification

The desired characteristics for FADR are summarized in Table 3

Table 3: Desired characteristics for FADR

Size	Response	Endurance	Location	Availability	Environment
1450 MW	15 min	100 hours	750 MW in SE3 700 MW in SE4	90%	-

4.2 FADR: Current situation

This section presents current assets available for the FADR, how they are located geographically and operated today. Currently there are 21 gas turbines and two diesel engines in Sweden available for the FADR. The assets are owned by three different companies, SvkGT being one of them. The other companies are Uniper and Öresundskraft who operate their assets at the disposal of Svk. Table 4 shows a complete overview of the available assets. The total effect of the 23 units adds up to 1304,5 MW and with a 300 MW HVDC-link secured from Denmark the total disposable effect of the FADR is 1604,5 MW.

Table 4: Overview over the fleet of gas turbines in FADR

Owner	Units	Effect[MW]	Effect range/unit [MW]
SvkGT	11	690	60-70
Uniper	10	564	3-172
Öresundskraft	2	50.5	2,5-48
Total	23	1304.5	2,5-172

As stated earlier a majority of the energy produced in Sweden derives from hydropower in the north while most consumption occurs in the more densely populated south. In case of a disturbance in the grid it is more common that the southern parts suffer from deficiencies in production which is why it is vital that balancing assets are positioned in the southern regions. Therefore all assets available for FADR are located in bidding zones SE3 and SE4 as shown in Figure 13.

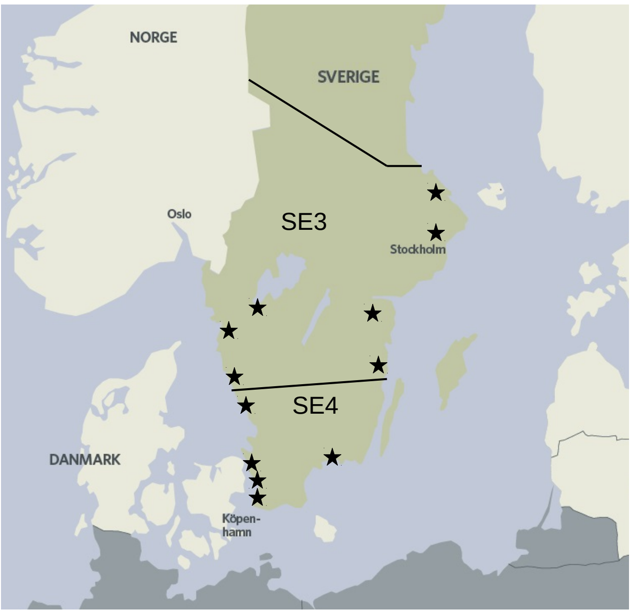


Figure 13: The 12 geographical sites of the 23 units in FADR, all in SE3 and SE4

4.2.1 Operation of current GTs

Most of these turbines were constructed and commissioned in the beginning of the 1970s meaning they are between 40-50 years old today. Svk have during the last decade continuously collected operational data on every hour for all assets devoted to the FADR which is summarised in Table 5, 6 and 7 (Nyberg 2018). These tables are intended to give an overview of the operational patterns of the FADR. Further calculations are based on the entire data which is available upon request but not included in the report. Table 5 shows the total amount of operational time for each year, number of stints (sessions) along with the average duration and maximum duration per stint for each year. Table 6 displays the total production of energy and the average and maximum output per stint in terms of energy [MWh]. Table 7 shows the power output in average and maximum per stint. The statistics presented in this report range from 2012-2016. In November 2011 Sweden was divided into the four current bidding zones earlier displayed in Figure 4 which changed the conditions for balancing dramatically. Therefore, the most representative data for today's situation is the one from 2012 and forth.

Table 5: Running time of current GTs in total and per stint

Year	Total [hh:min]	Stints [Nbr]	Average stint [hh:min]	Max stint [hh:min]
2012	11:59	17	00:42	01:20
2013	22:34	29	00:47	08:00
2014	01:55	5	00:23	00:31
2015	05:00	7	00:43	01:09
2016	02:55	8	00:22	00:47

Table 6: Energy produced by current GTs in total and per stint

Year	Total output [MWh]	Average output [MWh]	Max output [MWh]
2012	2580	152	396
2013	2801	97	519
2014	446	89	247
2015	789	113	274
2016	505	63	188

Table 7: Effect produced by current GTs per stint

Year	Average output [MW]	Max output [MW]
2012	192	356
2013	147	676
2014	232	700
2015	151	306
2016	140	240

4.2.2 Availability of current GTs

One disadvantage with today's FADR however is the *availability* of each unit earlier described in Section 4.1. Due to the complexity of a gas turbine with thousands of moving parts and heavy start up sequences, a specific unit is not guaranteed to start when needed. Quick and reliable availability are favoured characteristics for FADR and here, gas turbines bring a certain uncertainty. The assets available for FADR are obligated to have high availability but gas turbines are due to their nature unable to reach a 100% rate of reliability. All assets that are part of the FADR are therefore regularly tested and over the last years, statistics have been compiled on whether or not these test starts as well as necessary starts have been successful or not. The total availability considering all assets were estimated to 87% between 2008 (Jan) and 2011 (Aug). This number varies between years and is greatly dependent on reinvestments and upgrading of the turbines but still seldom reaches above 90% according to data provided by Svk.

4.2.3 Operational expenditures of current GTs

The operational expenditures for the current fleet of gas turbines is important to understand in order to compare it to the OPEX of BESS. Current business models where Svk buys the availability of gas turbines from Uniper, SvkGT and Öresundskraft are not fully presented in this report due to confidentiality reasons. As a government-owned company though SvkGTs annual financials are public and can be found in Appendix C. Discussions with Peter Blomqvist (Blomqvist 2018) concerning how to analyse SvkGTs OPEX have resulted in two approaches. SvkGT is funded by Svk with the sole purpose of supplying FADR. One can therefore consider the entire annual revenue of SvkGT as a turnkey concept at which Svk buys a certain amount of available power for FADR. Thereby the first approach results in considering the annual turnover for SvkGT as the annual operational costs for the business. The second approach implies considering the two cost items "Operation and maintenance expenses" & "Other external expenses" from the annual financial report as the total OPEX to manage SvkGTs fleet of 690 MW. A third external alternative is also considered based on a study by the Swedish research institution *Energiforsk* as a reference to the two internal alternatives (Nohlgren et al. 2014). The resulting operational expenditures for each of these cases are presented in Table 8.

Table 8: OPEX costs for gasturbines

Source	Effect [MW]	Cost [MSEK]	OPEX [MSEK/MW&YEAR]
SvkGT Turnover	690	114.2	0.165
SvkGT O&M	690	59.4	0.086
Energiforsk			0.050

4.3 GT: New Investment

An alternative to looking into new technologies is to continue with business as usual by upgrading or investing in new gas turbines. As mentioned earlier many of the current turbines owned by SvkGT are being refurbished and could reach the end of their lifetime in 15-20 years. Gas turbine technology has a high rate of maturity, are proven dependable and SvkGT have vast experience within the field. Throughout this project, SvkGT has provided several reference studies with figures on investment costs for new turbines, one of them from Fingrid, the Finish TSO. Along with the construction of the nuclear reactor Olkiluoto 3, which will be the largest single providing asset in the Nordics, Fingrid needed to extend their fast active disturbance reserve to meet the changed N-1 criteria. Therefor Fingrid invested in new turbines with a total capacity of 318 MW at the Forssa site shown in Figure 14 (Fingrid 2013).

Figure 14: The 318 MW gas turbine facility in Forssa, Finland.

The facility at Forssa consists of two 159 MW units and is intended to operate at similar conditions as the turbines available for FADR in Sweden. The turbines are capable of starting within 15 minutes and are expected to provide balancing power in case of disturbances approximately ten hours per year. It took three years to construct the facility and the investment costs were around 1000 million SEK meaning a cost of approximately 3,14 MSEK/MW. These figures are however considered as exceptionally low, thus the investment occurred under favourable circumstances and are therefore considered as a minimum in this study (Hermann 2018).

A study by Energiforsk, a Swedish research and development organisation within the energy field, presents a more holistic view of gas turbine investment costs. A particular part of the study focuses on simple-cycle gas turbines which frequently are used for peak shaving and in emergency situations like the once intended for FADR. The study shows declining investment costs per MW with increasing system size. The results of the study are shown in Figure 15 where a number of reference cases are marked out along with the trend line. Fingrids facility in Forssa was included in the study and is highlighted in yellow (Nohlgren et al. 2014). A general estimation of the deployment time for a gas turbine site is approximately two years, and the economic lifespan of a turbine is estimated to 25 years (Genrup and Thern 2014).

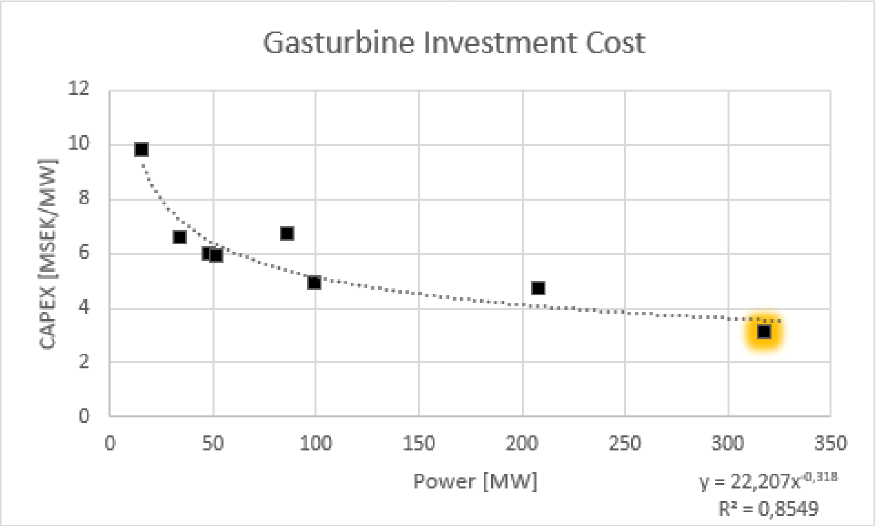


Figure 15: Investment costs for Simple-Cycle gas turbines

GT: Construction and Physical Properties

Both large scale battery storage facilities and gas turbines require a physical piece of land to put it on. Already at an early stage in a project this is of course something to take into account and plan for. This part of the thesis aims to provide a general estimation and practical feeling what a investment into a new gas turbine would mean today. Construction and Physical Properties for BESS is described in Section 4.6.

The facility in Forssa will act as a good reference as it is constructed recently and with similar use as the FADR. As aforementioned in took three years to construct the facility and it has a footprint of approximately 15 000 m^2. The highest point is its chimneys.

4.4 BESS: Case Study

One of the main purposes of this project is for SvkGT to attain information about BESS projects around the world that could be suitable for FADR use. Looking at BESS one must consider relatively large facilities for them to be measurable to gas turbines. Therefore a case study of the largest 100 facilities in terms of power [MW] conducted throughout the project is presented in Table 9. The case study includes an extensive amount of information that can be further studied in Appendix A most of which is not presented or discussed in more detail in the report. Table 9 includes key figures from the study that are further analysed to identify key drivers and incentives for BESS. The entire study includes all 100 facilities while only the top 74 with a minimum power output of 10 MW are presented in Table 9 in order to keep the basis of the analysis relevant in terms of size. The year presented for each facility represents the commissioning year of the facilities. For facilities under construction the expected commissioning year is stated. The main application area of each facility is presented according to the functions presented in Section 3.3.1. However, it is important to keep in mind that application stacking described in section 3.3.2 is very common especially for larger batteries. Most of the batteries in the study are not only intended for one type of use but many. All possible applications are presented in Appendix A.

Table 9: A portion of the information gathered in the BESS case study

Ref Nbr	Name (Short)	Power (MW)	Duration (h:mm)	Tech (Type)	Com. (Year)	Location (Country)	Application (Main)
1	Dalian	200	4:00	VRF	2019	China	Peak
2	Alamitos	100	4:00	Li-Ion	2020	United States	Peak
3	Kingsfisher	100	4:00	Li-Ion	2020	Australia	Ramping
4	Hornsdale	100	1:17	Li-Ion	2017	Australia	Frequency
5	Buzen	50	6:00	NaS	2016	Japan	Ramping
6	Roosecote	50	1:00	Li-Ion	2018	United Kingdom	Frequency
7	Jardelund	48	1:02	Li-Ion	2016	Germany	Peak
8	GimJe	48	n/a	Li-Ion	2017	South Korea	Frequency
9	Gyeongsan	48	0:15	Li-Ion	2016	South Korea	Frequency
10	Minami-Soma	40	1:00	Li-Ion	2016	Japan	Ramping
11	Glassenbury	40	0:41	Li-Ion	2017	United Kingdom	Frequency
12	Nishi-Sendai	40	0:30	Li-Ion	2016	Japan	Frequency
13	Notrees	36	0:22	Li-Ion	2013	United States	Peak
14	Non-Gong	36	0:22	Li-Ion	2016	South Korea	Frequency
15	Convergent	35	4:00	Li-Ion	2017	United States	Peak
16	Port of Tyne	35	n/a	Li-Ion	2018	United Kingdom	Frequency
17	Rokkasho	34	7:00	NaS	2008	Japan	Ramping
18	Ul-San	32	0:23	Li-Ion	2017	South Korea	Frequency
19	Laurel Mountain	32	0:15	Li-Ion	2011	United States	Frequency
20	Beech Ridge	31.5	0:23	Li-Ion	2015	United States	Frequency
21	Grand Ridge	31.5	0:23	Li-Ion	2015	United States	Frequency
22	Escondido	30	4:00	Li-Ion	2017	United States	Peak

Continuation of Table 9

Ref Nbr	Name (Short)	Power (MW)	Duration (h:mm)	Tech (Type)	Com. (Year)	Location (Country)	Application (Main)
23	Imperial	30	0:40	Li-Ion	2016	United States	Peak
24	Golden Hills	30	0:30	Li-Ion	2019	United States	Trans
25	Dalrymple	30	0:16	Li-Ion	2018	Australia	Frequency
26	SokCho	28	0:23	Li-Ion	2017	South Korea	Frequency
27	Seo-Anseong	28	0:15	Li-Ion	2015	South Korea	Frequency
28	GVEA BESS	27	0:15	Ni-Cd	2003	United States	Peak
29	Modesto	25	3:00	ZCF	2016	United States	Ramping
30	Tynemouth	25	0:30	Li-Ion	2018	United Kingdom	Frequency
31	Shin-Yongin	24	0:30	Li-Ion	2014	South Korea	Frequency
32	Shin-Gimje	24	0:23	Li-Ion	2016	South Korea	Frequency
33	Uiryeong	24	0:20	Li-Ion	2016	South Korea	Frequency
34	Shin-GyeRyong	24	0:15	Li-Ion	2016	South Korea	Frequency
35	Shin-WhaSun	24	0:30	Li-Ion	2016	South Korea	Frequency
36	UI-Ju	24	n/a	Li-Ion	2016	South Korea	Frequency
37	Pen y Cymoedd	22	0:45	Li-Ion	2018	United Kingdom	Frequency
38	Pomona	20	4:00	Li-Ion	2016	United States	Peak
39	Mira Loma	20	4:00	Li-Ion	2017	United States	Peak
40	Beacon	20	0:30	Li-Ion	2018	United States	Peak
41	Marengo	20	0:30	Li-Ion	2018	United States	Frequency
42	Broxburn	20	n/a	Li-Ion	2018	United Kingdom	Frequency
43	Angamos	20	0:15	Li-Ion	2011	Chile	Peak
44	Cochrane	20	0:20	Li-Ion	2017	Chile	Peak
45	Tait	20	n/a	Li-Ion	2013	United States	Frequency
46	Cape York	20	4:00	Li-Ion	2019	Australia	Ramping
47	IPL Advancion	20	1:00	Li-Ion	2016	United States	Frequency
48	Lee DeKalb	20	n/a	Li-Ion	2015	United States	Frequency
49	McHenry	19.8	0:24	Li-Ion	2015	United States	Frequency
50	Jake	19.8	0:24	Li-Ion	2015	United States	Frequency
51	Elwood	19.8	0:23	Li-Ion	2015	United States	Frequency
52	Meyersdale	18	0:30	Li-Ion	2015	United States	Frequency
53	Wyman	16.2	0:30	Li-Ion	2016	United States	Frequency
54	Shin-ChungJu	16	0:23	Li-Ion	2016	South Korea	Frequency
55	Lünen	15	1:30	Li-Ion	2016	Germany	Frequency
56	Walsum	15	1:30	Li-Ion	2016	Germany	Frequency
57	Bexbach	15	1:30	Li-Ion	2016	Germany	Frequency
58	Volklingen	15	1:30	Li-Ion	2016	Germany	Frequency
59	Weiher	15	1:30	Li-Ion	2016	Germany	Frequency
60	Herne	15	1:30	Li-Ion	2016	Germany	Frequency
61	Schwerin	15	1:00	Li-Ion	2017	Germany	Frequency
62	Daimler AG	15	1:00	Li-Ion	2016	Germany	Frequency
63	Minami Haya.	15	4:00	VRF	2015	Japan	Ramping

Continuation of Table 9

Ref Nbr	Name (Short)	Power (MW)	Duration (h:mm)	Tech (Type)	Com. (Year)	Location (Country)	Application (Main)
64	Kaua'i	13	4:00	Li-Ion	2017	United States	Peak
65	Lünen (2)	13	1:00	Li-Ion	2016	Germany	Bill
66	IESO Hecate	12.8	4:00	Li-Ion	2018	Canada	Frequency
67	Yeongyang	12.5	4:00	Li-Ion	2016	South Korea	Ramping
68	Flumeri	12	6:40	NaS	2015	Italy	Frequency
69	Ginestra	12	6:40	NaS	2015	Italy	Frequency
70	Los Andes	12	0:20	Li-Ion	2009	Chile	Peak
71	Auwahi	11	0:24	Li-Ion	2012	United States	Ramping
72	Scampitella	10.8	6:40	NaS	2015	Italy	Frequency
73	Green Mountain	10.4	1:00	Li-Ion	2015	United States	Frequency
74	Feldheim	10	1:00	Li-Ion	2015	Germany	Frequency

4.5 BESS: Current status and future predictions

This section aims at presenting secondary data collected regarding deployment of BESS today and the expected development of the BESS market. The information focuses on BESS deployment and uses in various applications, suitability in various applications, performance and cost of different technologies and is mainly presented with data from 2016 and expectations towards 2030. The current status of BESS deployment is first presented after witch outlooks towards 2030 are discussed. Finally costs, performance and development of different types of storage technologies are presented individually.

4.5.1 Current status of BESS deployment and usage

Pumped hydro storage is the major electricity storage technique today with a total installed capacity of 169 GW accounting for 96 % of the approximate 176 GW of total energy storage worldwide. The second largest technique is thermal storage after which comes electro-chemical storage that in this report is referred to as batteries. At a total of 1.9 GW, it only represents 1.1 % of electricity storage globally. However, it is the fastest growing market segment out of all storage techniques (IRENA 2017). The growth rate of electro-chemical storage from 1996-2016 has been exponential and is demonstrated in Figure 16.

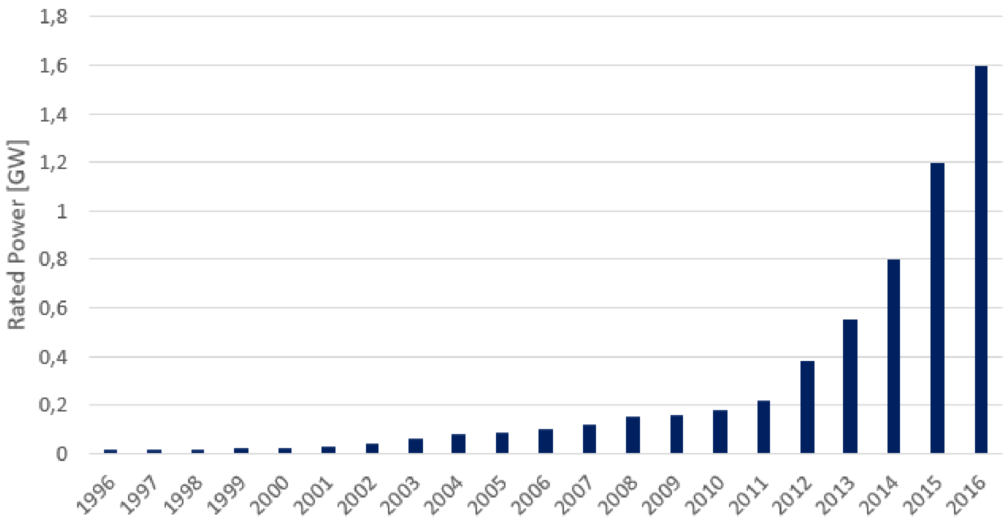


Figure 16: Global electro-chemical storage capacity, 1996-2016

Due to regulatory circumstances and market structures, the distribution of battery storage is yet concentrated to a rather small number of countries. Table 10 shows figures on the distribution of BESS up until 2016. Battery storage in the United States with approximately 680 megawatts of installed capacity accounts for almost half of the total amount and is also the fastest growing market. The US together with Korea and Japan accounted for 78% of total deployments in 2017. There are operational facilities outside of the countries stated in table 10 but to quite a limited extent. However, deployment is increasing worldwide and within the next few years, upcoming BESS projects (i.e. under construction or announced) are expected to add an additional 1.2 GW of capacity to the world market (IRENA 2017).

Table 10: BESS distribution by country, operatonal by mid-2017

Country	**Installed Capacity [GW]**
China	0.1
Japan	0.3
United States	0.7
Germany	0.1
Italy	0.1
Republic of Korea	0.4
Total	**1.6**

Out of the approximate 1.9 GW of BESS installed by mid-2017 worldwide the major main-use of application is for frequency regulation services accounting for about half of the usage. The second largest application is for peak shaving use accounting for about 18% and the third for renewables capacity firming at around 5%. Electric bill management at approximately 8% is another significant area of application but not discussed in this report and therefore categorised together with all other minor types of applications (IRENA

2017). Figure 17 describes the distribution of main-use cases for electro-chemical storage around the world by mid-2017.

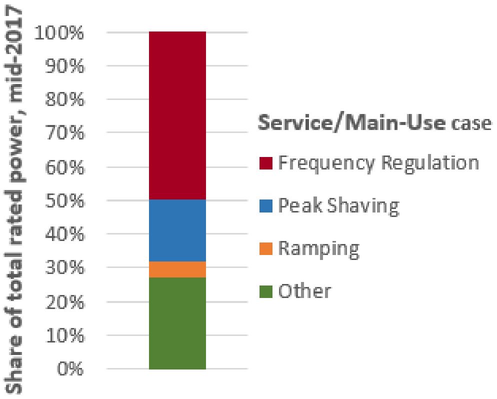


Figure 17: Global electro-chemical storage power capacity by main-use case, mid-2017

There are approximately 1.9 GW of installed electro-chemical storage for grid application today which is divided among a vast variety of technologies. The most commonly used technology today is the Li-ion battery accounting for about 59% of operational installed capacity by mid-2017. However, there are a number of emerging BESS-technologies showing great promise that are growing rapidly. Figure 18 shows the spread between different types of technologies in electro-chemical storage systems by mid-2017.

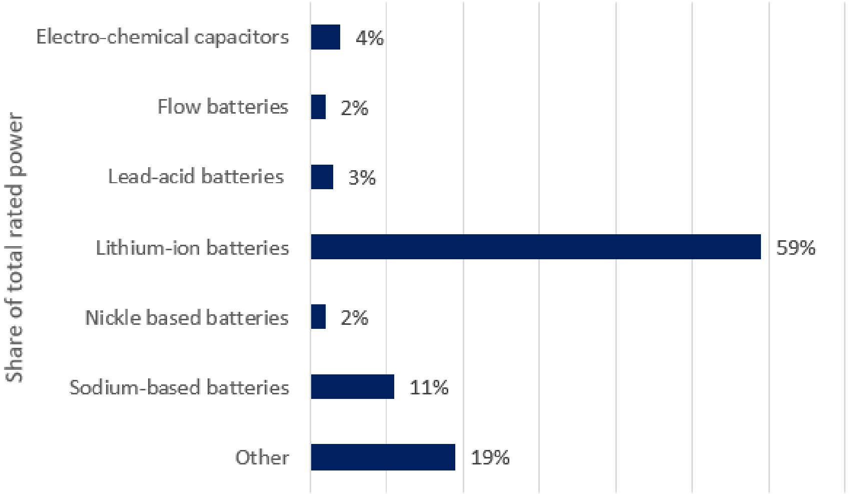


Figure 18: Global electro-chemical storage power capacity by technology, mid-2017

4.5.2 2030

The increasing amount of renewable production in energy systems directly drives the demand for storage solutions. Cost reductions for different storage technologies will boost this demand further. In the long run energy storage of longer duration will be necessary to compensate for the fluctuating production which enhances the demand even further. When predicting the future development of BESS it is first important to estimate the future deployment of renewable energy sources in power systems. The International Renewable Energy Agency uses a case referred to as the REmap Doubling case where the share of renewable energy in the global energy system is doubled by 2030 in comparison to 2014 levels which is the basis of the upcoming presented figures of this report as well (IRENA 2017). Doubling the share of renewable energy supply by 2030 is considered reasonable, however discussing this matter further is outside the scope of this report but can be furthered studied in *REmap 2030 - A Renewable Energy Roadmap* (2014).

Battery electricity storage capacity for utility and behind the meter applications is estimated to grow exponentially and increase from a current capacity of 11 GWh to between 181 GWh and 421 GWh in 2030. The major markets are expected to be the once where suitable regulatory structures are in place (e.g. Germany) and in places with excellent solar resources, high electricity prices and low grid feed-in remuneration (e.g. Australia) where storage co located with solar power is a promising option. Co located storage with renewable energy production is the application that shows the greatest promise and Figure 19 demonstrates high and low estimates of increasing deployment until 2030 by different application areas. This requires a simultaneous development of several power markets in regards to reimbursement for ancillary services.

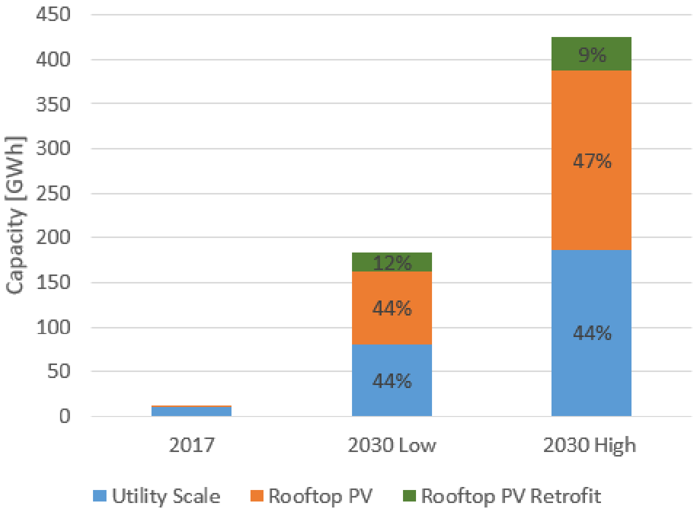


Figure 19: BESS capacity growth in stationary applications by sector, 2017-2030

BESS co located with new installations of solar power used for energy time shifting could increase with 79-198 GWh by 2030 and retrofitted batteries installed at sites with existing PV capacity could increase by 22-36 GWh. The BESS market for utility applications could increase from the current 10 GWh in 2017 to between 81 GWh and 187 GWh by 2030. Other major applications are for renewable capacity firming, frequency regulation and electric supply capacity. Figure 20 shows potential growth divided among different main-use cases in 2017 and 2030 where the major use for battery storage is for electricity time shifting operation accounting for 62-64%(115-269 GWh) of the total storage capacity in 2030 (IRENA 2017).

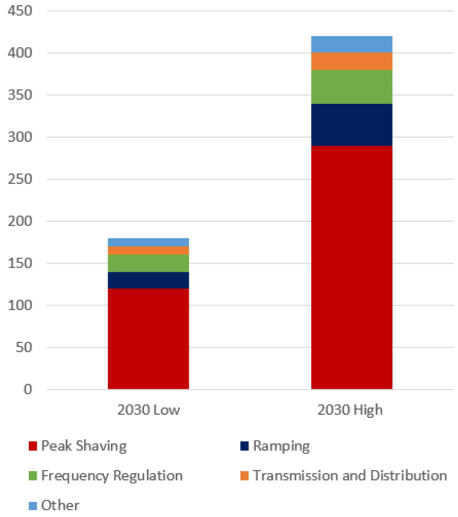


Figure 20: BESS growth in stationary applications by main-use case, 2017-2030

4.5.3 Costs and performance by technology, 2016-2030

This section presents information on installation costs and performance characteristics for different technologies and focuses on key figures necessary to compare technologies with one another. Installations costs are considered from a turnkey perspective meaning that they represent costs including everything from delivery to construction of a system to which point the project is completed and ready for operation. Operational cost is a more complex figure and is therefore presented in the following section. Performance characteristics that are presented includes

- Energy density
- Cycle life
- Calendar life
- Depth of discharge
- Round trip efficiency

These characteristics are earlier described in more detail and can be reviewed in Section 3.2. For some technologies additional information is provided as well but focus lies on the performance factors stated above.

Li-ion batteries

Lithium-ion batteries accounted for almost 60% of the BESS-market by mid-2017. The technology has benefited from great investments in recent years due to the vast variety of possible application areas. It is the most important technology for mobile applications mainly due to its high energy density which has enhanced the development of the technology. The recent history of declining prices for Li-ion systems have been impressive which has improved the economic aspects of using Li-ion batteries for stationary use and their presence in the grid market is increasing. Cost competitiveness of Li-ion batteries is expected to improve, driving down prices further. Li-ion batteries are characterised by high rates of discharge capability, relatively long life expectancy, low self-discharge rates and excellent round trip efficiency.

The depth of discharge rate for Li-ion batteries today ranges between 80-100% and the round trip efficiency varies between 92-96%. Energy densities for Li-ion battery cells range from 200 Wh/dm^3 to 735 Wh/dm^3. Current installation costs span between 2960 SEK/kWh and 8880 SEK/kWh with an average of approximately 4230 SEK/kWh in 2016. Expected calendar life and equivalent full cycles of a cell is greatly dependent on the application and operational conditions of the facility but also the cell design. Lifetime expectancy ranges from 5-20 years and equivalent full cycles between 500 and 12000.

A combination of improvements in performance and installation costs are expected towards 2030 for Li-ion batteries. Depth of discharge as well as energy density are expected to remain at the same level while the round trip efficiency is expected to rise by approximately 2%. Installation costs are expected to decrease to between 1230 SEK/kWh and 4850 SEK/kWh with an average of 3040 SEK/kWh. The central projection for costs of Li-ion batteries for stationary use represents a decline between 54-61% from 2016-2030. Self-discharge rates for Li-ion batteries are expected to remain unchanged at a range between 0.05-0.20%/day from 2016-2030. Figure 21 shows a summary of the costs and performance today as well as predictions towards 2030 for Li-ion batteries (IRENA 2017).

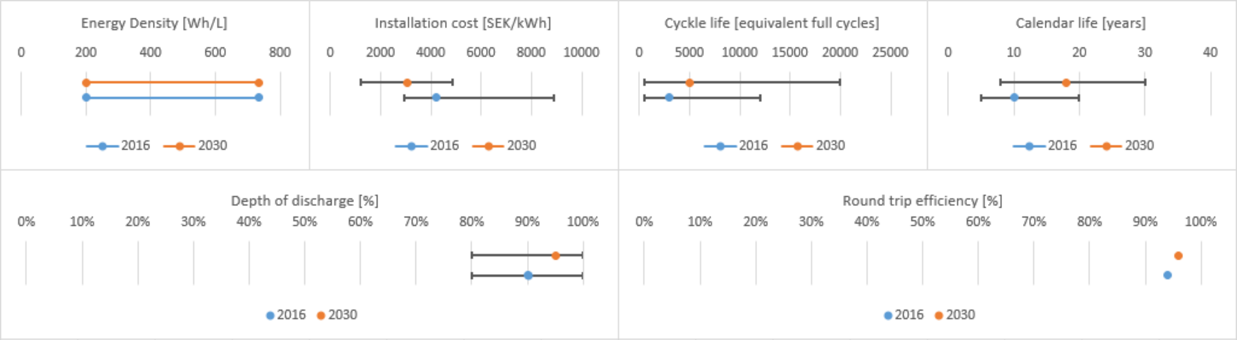


Figure 21: Cost and Performance of Li-ion battery storage systems, 2016 and 2030

Information regarding cost breakdown structures of BESS facilities is often scarce and difficult to obtain due to confidentiality restrictions. The distribution of costs also varies extensively depending on the type of application and differences in system design and sizing of facilities making the cost breakdown structure of facilities ever harder to generalise. Figure 23 demonstrates the results from a number of studies of the different installation costs associated with BESS and how they are expected to develop towards 2030. Material-related cost items account for almost half of the initial investment costs. In general the larger the system the less dominant becomes the material cost. When looking at the material costs isolated the contribution of cell costs also decreases with increasing system size, since for larger systems, power electronics and periphery costs become more relevant as demonstrated in Figure 22.

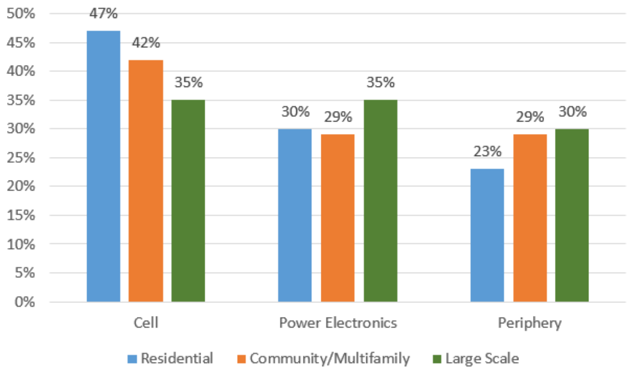
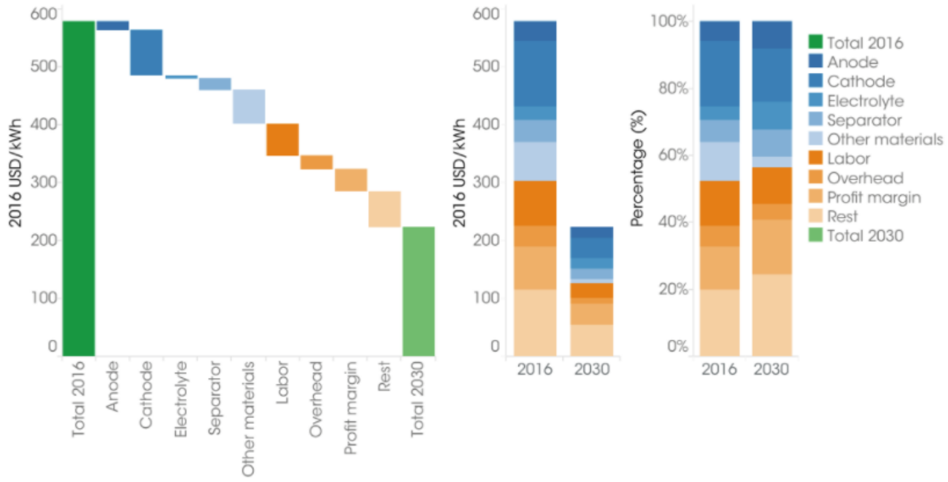


Figure 22: Cost component distribution of Li-ion BESS by storage size, 2016

For larger systems, cell costs represents approximately 35% of the total material costs while for residential systems it usually exceeds 45%. Figure 23 also demonstrates the total expected reductions in costs by cost component and in total. Total costs are expected to decrease by more than 50% quite equally divided between material-related costs and other costs. The contribution of material costs to the total system cost is expected to decrease from 47% to 43% by 2030 (IRENA 2017).



Source: International Renewable Energy Agency.

Figure 23: Cost breakdown structure and potential reductions, 2016-2030

Sodium sulphur(NaS) batteries

The sodium sulphur battery is a so called high-temperature battery. High-temperature batteries operate at high temperatures to keep the active material in a liquid state (sodium and sulfur in the NaS case). NaS batteries typically operate at a temperature between 300 °C and 350 °C and have so far only been commercialised in stationary applications. NaS batteries have been used extensively in Japan for grid applications since the 1990s. There is more than 300 MW of NaS capacity installed in more than 170 projects throughout the country. In recent years however deployment of NaS facilities have ceased being exclusive to Japan and is today commonly used for grid applications in other parts of the world as well. NaS Batteries are characterised by their relatively high energy density in the low end of the Li-ion range, suitable for daily cycling and dischargeable for long duration and high pulse of power.

The depth of discharge rate for NaS batteries is close to 100% and the round trip efficiency is approximately 80%. The energy density varies between 140 Wh/dm^3 and 300 Wh/dm^3. Self-discharge rate ranges between 0.05-1%/day depending on the application, location and technology. A general central value of self-discharge is closer to the lower end of the span. Current installation costs span between 2240 SEK/kWh and 6250 SEK/kWh with a central value of approximately 3400 SEK/kWh. Life expectancy of systems are like for other batteries greatly dependent on the type of use and application but ranges from 10-25 years and equivalent full cycles from 1000-10000. NaS batteries also have the advantage of high recyclability of around 99%. The main disadvantage of NaS batteries is that they are associated with high operating costs between 340-600 SEK/kW per year mainly due to the high operating temperature. The high-temperature operation requires a thermal enclosure that in itself can consume about 3% of the rated power of the facility.

The development of high-temperature batteries is not expected to progress as rapidly as for Li-ion batteries mainly due to lack of suppliers. Almost all NaS batteries on the market are manufactured by the Japanese company NGK. This dependency of a limited number of suppliers may impede a fast market growth. NaS batteries are still expected to improve in terms of performance, installation and operating costs but a key accelerator for this development is for new entrants to challenge and spur innovation in the market. Depth of discharge as well as energy density are expected to remain at the same level while the round trip efficiency is expected to rise by approximately 4%. Installation costs are expected to decrease to between 1020 SEK/kWh and 2800 SEK/kWh with an average of approximately 1530 SEK/kWh (IRENA 2017). Figure 24 shows a summary of the costs and performance today as well as predictions towards 2030 for NaS batteries.

Figure 24: Cost and Performance of NaS battery storage systems, 2016-2030

Vanadium Redox Flow Batteries

As mentioned earlier Vanadium Redox Flow Batteries(VRFB) differ from conventional batteries in the way that the electroactive materials are not stored within the electrode but instead dissolved in an electrolyte solution and can therefore be stored in tanks outside the cell. This enables a number of advantages including that they:

- Can operate at close to ambient temperatures.
- Can scale energy from power independently and vice versa.
- Offer cycle lifetimes that exceeds 10 000 full cycles.
- Support very deep discharge rates without degrading significantly.

The major disadvantages with flow batteries are their relatively low round-trip efficiencies and low energy density in comparison to Li-ion batteries for example.

The depth of discharge rate for VRF batteries is close to 100% and round-trip efficiency is approximately 70%. The energy density varies from 20 Wh/dm^3 up to 70 Wh/dm^3, but this figure is in most cases closer to the lower part of the span, with a central value of about 25 Wh/dm^3. Current installation costs span between 2680 SEK/kWh and 10 200 SEK/kWh. Life expectancy of systems ranges from 5-20 years with a central value of 15 and equivalent full cycles reaches beyond 15 000.

Because of good scalability and suitability for large scale grid applications, there has been a high focus on developing flow batteries over the last decade. While the possibility of improving energy density is limited, round-trip efficiencies for flow batteries are expected to increase from between 60-85% to between 67-95% by 2030. Installation costs are expected to decrease to between 920 SEK/kWh and 3910 SEK/kWh meaning a reduction of about two thirds of today's prices. Vanadium Redox Flow Batteries in particular are expected not to exceed 3060 SEK/kWh with a central value of approximately 1020 SEK/kWh. While round-trip efficiencies might not increase to comparable values with other technologies, VRFB typically exceeds 10 000 equivalent full cycles, which potentially compensates well for the slightly lower efficiency (IRENA 2017). Figure 25 shows a summary of the costs and performance today as well as predictions towards 2030 for flow batteries.

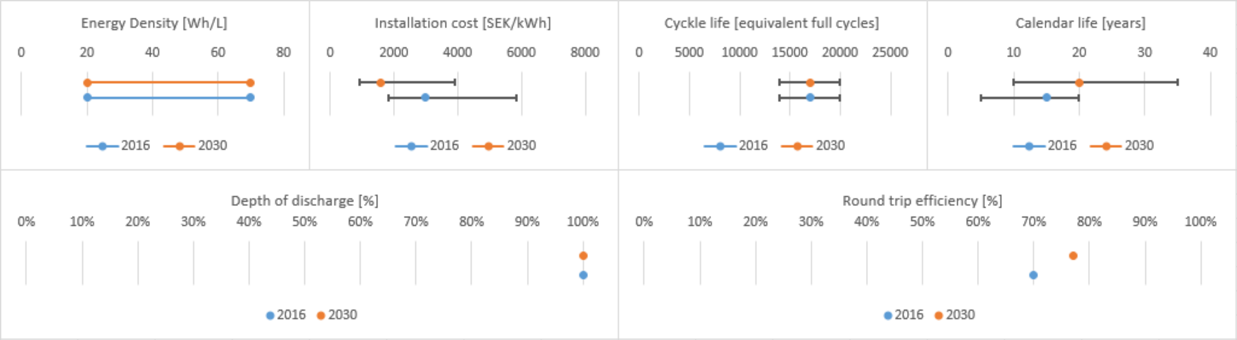


Figure 25: Cost and Performance of flow battery storage systems, 2016-2030

4.5.4 OPEX

As mentioned earlier, the operation of utility scale batteries is a quite young business and has developed a lot in recent years. There is limited information on how operation is handled and costs are in general hard to find due to confidentiality reasons. Depending on the battery provider there are several different options on how to run a battery. Some suppliers offer the alternative to operate the battery project for the customer while others provide energy management systems and other solutions for the utility company to run the batteries themselves. Therefore there are several uncertainties on what is actually included in different business models. Cost factors that should be considered at the initiation phase of a project are:

- Operational
- Maintenance
- Warranty
- Monitoring (Most often remote)
- Spare Parts

Table 11 demonstrates estimates based on a study conducted recently from a variety of sources providing figures on operation costs for different BESS technologies (Rahmann et al. 2017). The numbers are also in line with current industry standards which have been verified through interviews with several battery providers not mentioned in this report due to confidentiality reasons. Table 11 demonstrates central values for operational expenditures along with maximum and minimum values encountered in the study.

Table 11: Estimated OPEX percentages of CAPEX for all BESS Technologies

Technology	Low	Mid	High
Li-Ion	2 %	3 %	4 %
NaS	3 %	4 %	5 %
Flow	3 %	4 %	5 %

Aside from these costs one must consider charging costs for the battery facility based on current market prices and account for the round trip efficiency of the asset. Round trip efficiencies are presented earlier in Section 4.5.3. Current electricity costs are estimated at 0,4 SEK/kWh (Persson 2015).

4.6 BESS: Construction and Physical Properties

This chapter aims to present the different battery technologies physical space and overall construction information similar to Section 4.3 presenting GTs. Data of BESS facilities were provided from the industry with companies such as Tesla, Fluence, NGK and Rongke Power.

Lithium-Ion

Data have been collected both from Fluence and Tesla which both provide systems using Lithium-Ion. However what differs them is while Fluence uses a containerised solution, Tesla uses their modular Powerwall. Teslas facility at Hornsdale, Australia (Ref: 4) will provide an example with its 100 MW BESS. As mentioned uses Tesla a modular Powerwall solution which can be seen in Figure 26. The facility in Hornsdale is approximately 10 000 m^2 and it took only 60 days to construct the facility (NEOEN 2017).

Figure 26: The Hornsdale Power Reserve in Australia

Fluence is a merger between the energy storage divisions of Siemens and AES and are one of the leading providers of BESS globally. Their containerised solution is scalable and are despite the obvious technology inequality very similar to the one NGK uses which is described below (Wolfschmidt and Namyslo 2018).

NaS

NGK is an Japanese company which have specialised in NaS batteries and their facility in Buzen (Ref: 5) will provide a reference. NGK delivers their BESS facility containerised in 20-foot containers which can be seen in Figure 28. The 50 MW facility in Buzen (ref 5) which can be seen in Figure 27 uses 251 containers for storage. The rest of the facility is energy management systems. In total the 50 MW facility is 100 X 140m which is a footprint of 14000 m^2. The facility was constructed in just six months (not including permissions) (NgK 2018).

Figure 27: Buzen substation in Japan, 50 MW & 300 MWh

Figure 28: Four standard Ngk containers

Flow

Rongke Power is the supplier of VRF-batteries to the facility in Dalian, China (Ref: 1). Similar to Tesla does Ronge Power have a gigafactory providing them with VRF-batteries and the factory is conveniently placed in Dalian. Dalian will contain ten connected systems of 20 MW/80 MWh each. Ronge Power uses a containerised solution very similar to what NGK uses (Figure 28) for the power electronics. However being a flow battery is also requires tanks for the two electrolytes thus taking up more space. It is therefore quite difficult to estimate how much space such a system would take (Rongke 2018).

5 Analysis

A thorough analysis of the gathered information is carried out through this chapter. Initially the case study of the 100 largest facilities around the world is statistically evaluated and compared to earlier research presented in Section 4.5. As stated before, after looking at the 74 largest facilities one reaches sizes of 10 MW and therefore the final 26 facilities in the case study were sorted out and are not included in these statistic figures. The case study will still be referred to as a study of the 100 largest projects because 100 is a nicer number than 74. This part of the thesis aims to answer the first three questions of this thesis

- Can BESS fill the fast active disturbance reserves future needs for grid disturbance, balancing, voltage support, black start and island mode operation?
- What functions are existing or announced BESS facilities meant to handle?
- What are the economic key driving factors for BESS facilities?

The second part of the chapter focuses on a comparison between BESS and gas turbines primarily from a cost perspective analysing a number of possible investment situations.

5.1 FADR Suitability

Section 4.1 describes necessary and desired characteristics for assets devoted for FADR and Table 12 presents a summary of these figures along with the attributes of today's setup of gas turbines and the battery facilities studied throughout the project presented in Table 9.

Table 12: Desired characteristics for FADR and performance by technology

	Size	Response	Endurance	Location	Availability
Desired	1450 MW	15 min	100 h	750 MW in SE3 700 MW in SE4	90%
Current GTs	✓	10-15 min	100 h	✓	87%
BESS Case study	✓	0-1 s	0.05-6 h	✓	100%

As shown in Table 12 today's set up of gas turbines fulfils all necessary requirements with the exception of the availability. An availability of 90% however, is not stated in the System Operation Agreement and therefore not considered as an absolute requirement. Additionally, achieving a 90% rate of availability with gas turbines is not impossible. A new fleet of gas turbines would probably have a higher rate of availability than the current fleet of turbines and by increasing the accumulated power output by 3 % (0.9/0.87 = 1.03), the additional power exceeding the necessary criteria could be seen as a compensation for the occasional unsuccessful starts. Reaching a certain level of power output at the right location is only a matter of costs which is presented and discussed later in the report. From a purely technical point of view though, power output at the right location is of no concern for either of the technologies. The response time for the current fleet of gas turbines varies among the assets but they are all below the required maximum of 15 minutes. Endurance is for gas turbines due to their nature not a concern. Today's gas turbines are also capable of fulfilling secondary uses for FADR described in Section 12 mainly focusing on voltage support, black start and island mode operation.

Table 12 also shows that the studied BESS facilities fulfil all desired characteristics except for the endurance criteria. Batteries are able to exceed 15 min of operation which fulfils the absolute requirements of the FADR stated in the SOA, however depending on how endurance is evaluated batteries can be considered as deficient due to their limited discharge time. Batteries are far inferior to gas turbines when considering endurance and this is further compared in the discussion of the report but constructing a battery with a discharge duration exceeding 36 hours or 100 hours today would be absurd. The main advantages of BESS compared to gas turbines are their anticipated high rate of availability and quick response time. Appendix A includes all secondary applications of main-use for the studied BESS projects and shows that functions like voltage support, black start and island mode operation are all achievable functions with BESS technology. This however is also a question of capacity and possible duration of discharge, hence a question of costs and will be further discussed later in the report. From a purely technical perspective though batteries can handle all necessary requirements.

5.2 BESS: Case study

This section analyses content from table 9, the case study of the 100 largest facilities globally in a series of charts to demonstrate a fair image of larger BESS deployment today. The information is also compared to and discussed with the information in the previous chapter regarding earlier research which represents figures from BESS deployment around the world when considering all system sizes. A complete correspondence between these results are therefore not expected but a reasonable extent of correlation is.

Figure 29 and 30 demonstrates the deployment rate of the 100 largest BESS. As shown in the figures larger projects are mainly constructed in recent years and almost exclusively after 2010. These figures also correspond well with Figure 16 demonstrating the growth including all system sizes. A comparison between Figures 29 and 30 also demonstrates that the growth rate in terms of capacity is even more concentrated and significant in recent years than the one of power output which indicates that large BESS projects with longer duration show a faster individual growth than projects with higher C-rates. This is caused by the shift from using battery storage solely for short duration operation (e.g. frequency regulation) towards longer duration operation (e.g. peak shaving etc).

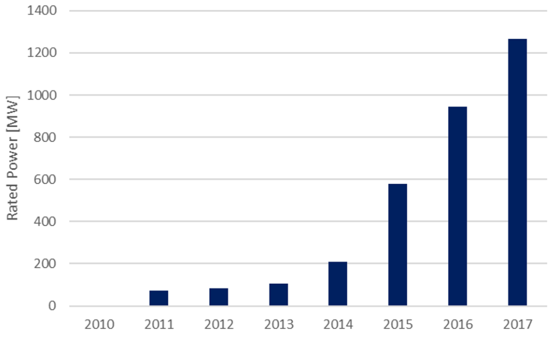


Figure 29: Installed rated power [MW], 2010-2017

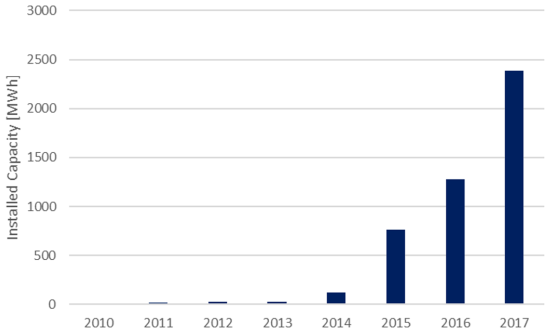


Figure 30: Installed capacity [MWh], 2010-2017

The largest BESSs in the world over 10 MW are found in only ten countries. 27 of the facilities are located in the US. South Korea and Germany with 13 and 12 facilities respectively represent the second and third largest markets. Australia, Italy, Japan, United Kingdom and Chile have 3-6 facilities each. China and Canada have one facility each. Figure 31 shows a map of these countries where a more intense colour represents larger amounts of facilities.

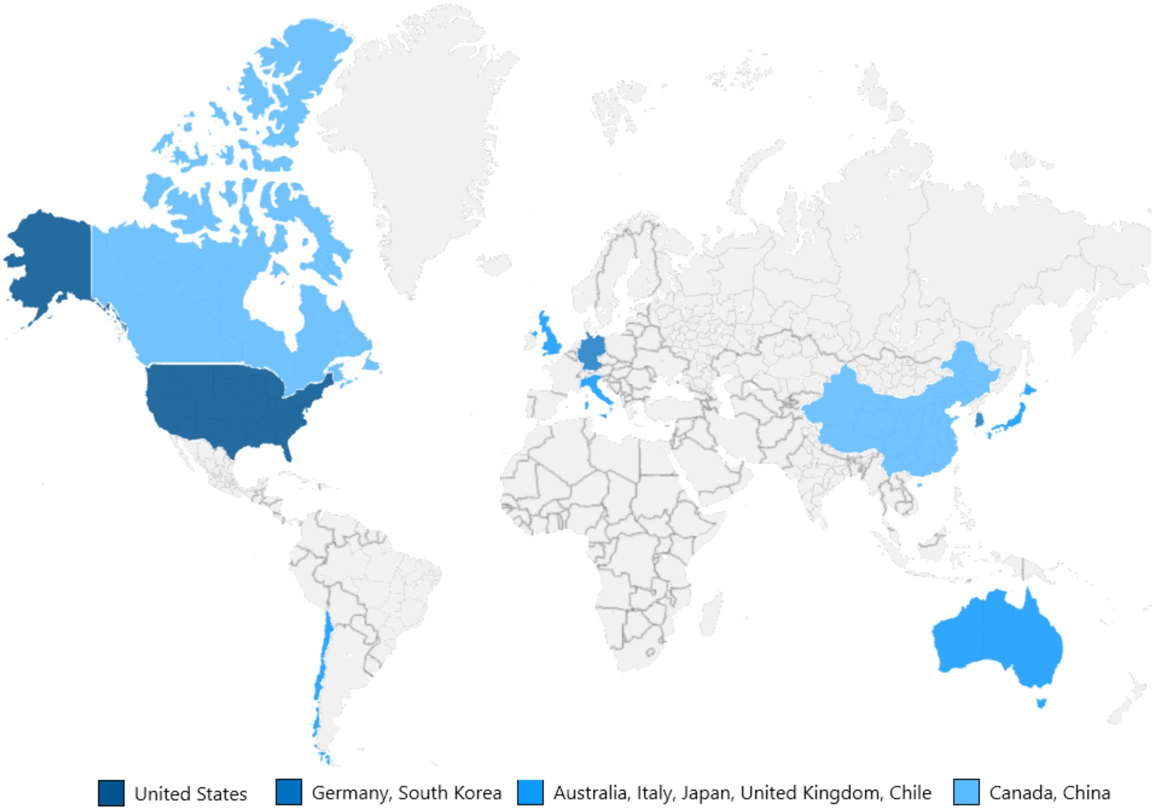


Figure 31: Geographical deployment of the top 100 BESS facilities

Investment costs for BESS facilities are in general hard to find. Most figures are strictly confidential and for the ones that are public, it is often difficult to determine what is included in the initial investment. Therefore the prices attained in the case study varies a lot and should be considered with a certain margin of error. The scope of the case study covers a lot of information not included in table 9 that only describes key characteristics and figures for each facility. Appendix A presents all further information about each asset including the initial investment cost for 27 of the facilities. Figure 32 displays the investment spread of these facilities according to commissioning year along with the price development from 2003 and fourth. These values correspond quite well with how battery prices have declined according to other studies. However, the extension to which these figures are verified varies among the projects and as mentioned earlier these results should be considered with a certain margin of error.

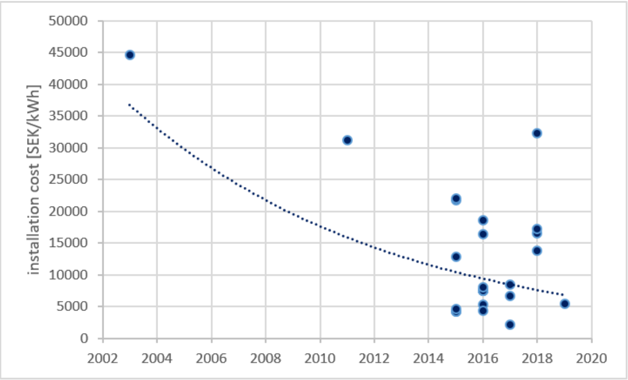


Figure 32: Initial investment and price decline, top 100

Figure 33 shows the distribution of BESS among the 100 largest facilities according to main-use case for each and every specific facility. Emerging capacity markets are great drivers for deployment of BESS and primary market reserves is in general a revenue stream with high potential well suited for battery operation due to their fast response time. Therefore frequency regulation clearly dominates the BESS market when solely looking at the number of facilities, with peak shaving and ramping as second and third. An almost negligible share of the facilities are constructed with a main purpose not including these three areas of application. When looking at an isolated segment of facilities like the larger ones, the number of facilities purposed for different uses are considered as suitable figure to review. However, another more common way to evaluate the deployment distribution of BESS is by power or capacity. A demonstration of the distribution of the top 100 BESS among application areas in regards to power and capacity instead of the number of facilities is shown in Figures 34 and 35. These figures can be considered as more representative due to the vast variety of projects sizes and are easier to find in other studies. The frequency regulation application appears less dominant in these sort of comparisons especially when solely looking at capacity where peak shaving is the clear dominant application. This is mainly due to the fact that peak shaving facilities require longer charge and discharge periods to cover the macro changes in supply and demand. Figures from the top 100 study correspond well with the distribution of applications in terms of rated power shown in Figure 17 in the previous chapter.

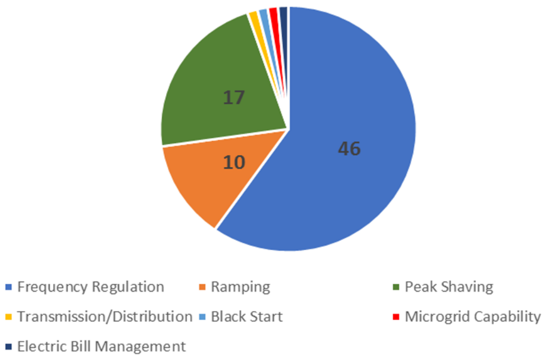


Figure 33: Number of BESS by main-use case, top 100

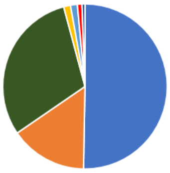


Figure 34: Rated power [MW] by application, top 100

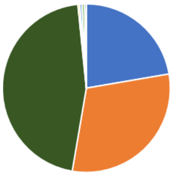


Figure 35: Capacity [MWh] by application, top 100

Figure 36 shows the distribution of BESS among the 100 largest facilities divided among different battery types for each and every specific facility. Li-ion is a well tried technology in both stationary as well as mobile application and the clear dominant technology in all cases. However, the share of Li-ion batteries shows a decrease in significance when evaluating the top 100 according to capacity. Other technologies such as NaS and flow batteries are well suited for longer duration operation and have as demonstrated in Table 9 mainly been constructed with lower C-rates. Li-ion facilities on the other hand are deployed with everything from a duration of 15 minutes up to several hours. Flow and NaS batteries suitability for larger scale batteries with longer duration operation results in a difference of the top 100 figures in comparison with Figure 18 considering all system sizes.

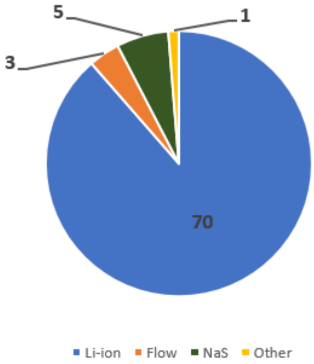


Figure 36: Number of BESS by battery type, top 100

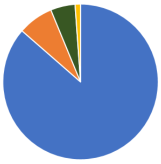


Figure 37: Rated power [MW] by battery type, top 100

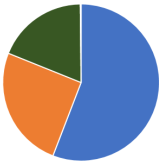


Figure 38: Capacity [MWh] by battery type, top 100

Figure 39 displays storage system size in terms of power output and capacity as well as C-rate of the 100 largest facilities. When looking at larger projects built recently, facilities tend to be constructed to operate for longer durations. BESS in general are mainly constructed with a C-rate of 1 when looking at all system sizes (Hesse et al. 2017) but as shown in Figure 39 average C-rates for larger facilities built recently tend towards C-rates of 0.25. This might appear strange at first when considering that frequency regulation and primary control reserves are the most common main-use cases for BESS but if one considers both first and second main-use services for facilities, a majority of BESS are built for peak shaving or similar operation in at least one of these main uses. This can be further studied in Appendix A containing all information gathering from the case study.

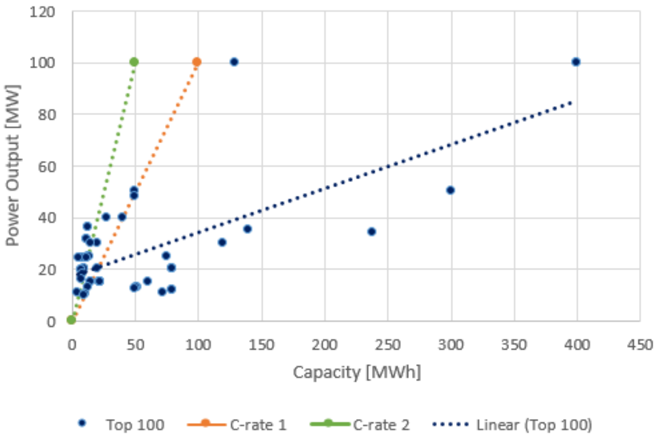


Figure 39: Power to energy ratio, top 100

Frequency Regulation Projects

As mentioned earlier BESS can be constructed to manage a series of tasks. Many of the facilities examined in the top 100 study are intended to provide a range of services. Most facilities however are constructed with one main operational purpose. By isolating facilities intended for a specific task one can evaluate the most commonly used technology for that specific application. Figure 40 shows all projects in the case study primarily intended for frequency regulation operation sorted by technology type. Out of the projects in the case study, 46 are intended for frequency regulation operation primarily. Out of these 46, 43 are Li-ion facilities and three are NaS projects as shown in the left chart. The middle chart shows the distribution of frequency regulation projects according to rated power and the right one displays the total capacity sorted among different technologies.

In this study, Li-ion batteries are the clear dominant technology regardless of measuring power, capacity or number of facilities. This is the usual case in all applications due to the vast deployment of Li-ion batteries in general. Li-ion batteries exceed all batteries in terms of total production potential today making them the most accessible batteries in the market. Their high discharge capabilities and quick response time are also a contribution to why they are well suited for primary reserves and have significant shares in the frequency regulation market.

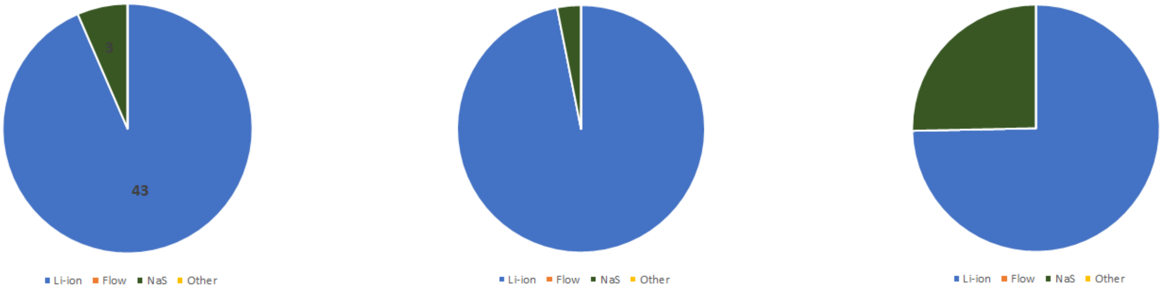


Figure 40: Frequency Regulation Projects by battery type, [Nbr] - [MW] - [MWh]

Peak Shaving Projects

When looking at peak shaving projects, Li-ion batteries still account for a majority of the number of facilities, rated power and capacity out of the top 100. Their dominance however is not as significant as in the previous case when looking at frequency regulation. Facilities with the main purpose of peak shaving operation are displayed in Figure 41 where the number of facilities are demonstrated in the first chart, rated power in the second and capacity in the third. Out of the largest 100 there are 17 with the main purpose of peak shaving operation of which 14 are Li-ion facilities. However, when measuring rated power and capacity, Li-ions are much less significant, especially in terms of capacity. Table 9 also shows that many of the facilities with ramping as main use case operate as peak shavers secondarily. These types of uses are similar, often demanding long periods of duration and especially flow and NaS batteries are well represented among these types of facilities. Therefore if secondary main service cases are considered the amount of Li-ion batteries used for peak shaving would be less significant than in Figure 41 and technologies such as flow and NaS batteries would represent greater shares.

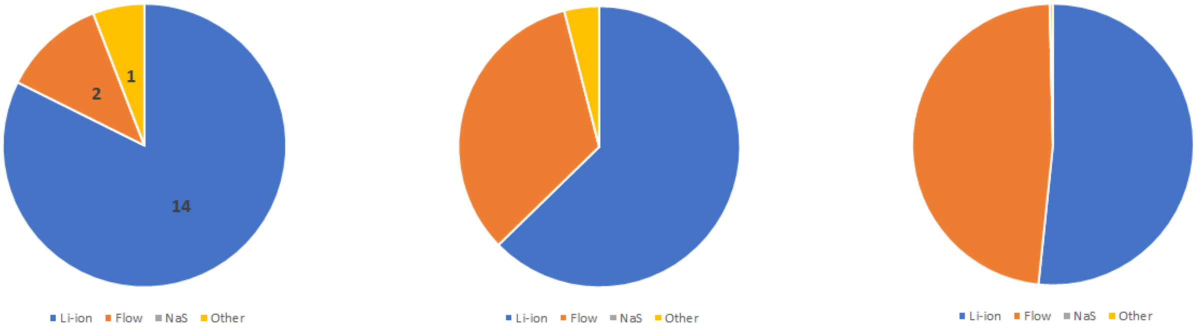


Figure 41: Peak Shaving Projects by battery type, [Nbr] - [MW] - [MWh]

5.3 BESS: Cost and performance overview

This part of the analysis presents costs and performance factors for different battery technologies in comparison to each other. Current statuses of different technologies are presented along with projections towards 2030. This part focuses on central values where key performance characteristics and costs are compared, unlike the individual technology sections where both central values and ranges are displayed. The idea of this approach is to provide a simplified overview of the technologies.

When comparing installation costs and cycle life in equivalent full cycle terms among the three different groups examined; *Li-ion*, *NaS* and *Flow*, the two classical batteries (Li-ion and NaS) are unable to reach the cycle life values of the flow batteries both looking at today's status and future projections. Flow batteries are also the cheapest ones today with Li-ions as the most expensive ones. The high-temperature NaS batteries currently represent a middle ground both when looking at cycle life and installation cost with the potential of advancing its cost competitiveness in 2030. Differences in costs however are far from as significant as the differences in life cycles. The general cost outlook for BESS is promising. NaS and flow batteries show a price decline potential around 50% by 2030, 55% for NaS and 47% for flow while prices for Li-ions are expected to decrease by 28%. Cycle life and cost for the three different battery categories are displayed in Figure 42

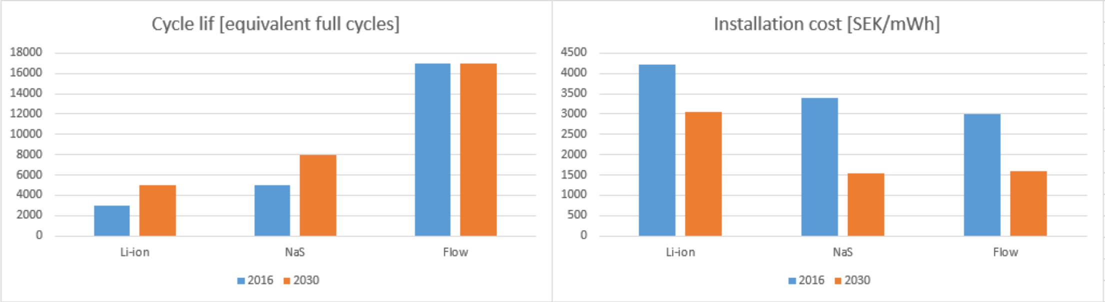


Figure 42: Central values of cycle life and installation costs by technology, 2017-2030

By only considering the properties displayed in Figure 42 flow batteries appears superior to the classical batteries and NaS batteries appears superior to Li-ion. An important aspect to keep in mind is the maturity of the Li-ion technology due to extensive deployment and usage in different applications like EVs or other mobile apparatus. Another aspect is the round trip efficiency (η) which is significantly higher for Li-ion batteries in comparison with any other technology. Figure 43 demonstrate current status and future projections of costs, cycle life and round-trip efficiencies for the three categories. As shown in the figure the Li-on technology is a more expensive alternative than other technologies with a far inferior lifespan. However, the round-trip efficiency of the Li-ion technology exceeds the others by far and is expected to do so in the future as well.

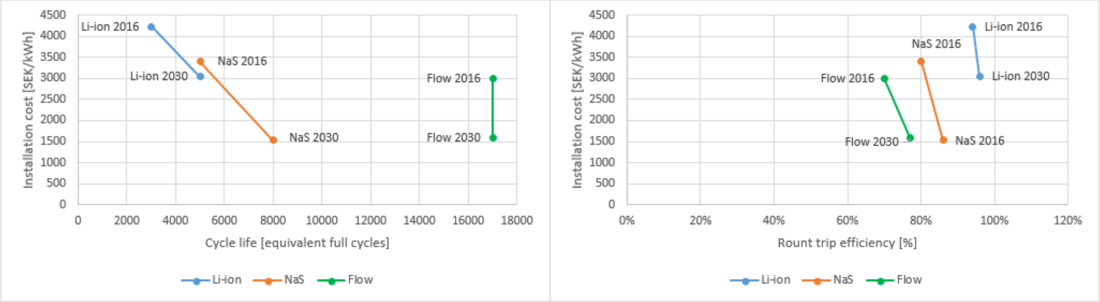


Figure 43: Energy installation cost, cycle life and round-trip efficiency by technology, 2017-2030

5.4 BESS vs GTs

This part of the analysis aims at comparing costs and functional characteristics of gas turbines and batteries. In order to accomplish that a number of standard facilities of specific power and capacity are constructed based on the information achieved through the empirical part of the study. Hypothetical facilities of the same power output but with the different technologies; gas turbines, Li-ion, NaS and flow batteries are constructed and economic aspects in terms of installation costs, operational and maintenance costs as well as the levelized cost of energy are compared to one another after which different attributes depending on technology is compared. The purpose of this section is to answer the questions stated in the purpose section of the report

- Can BESS fill the fast active disturbance reserves future needs for grid disturbance, balancing, voltage support, black start and island mode operation?
- How does BESS compare to gas turbines economically in terms of investment/MW, investment/MWh, operational and maintenance costs as well as levelized cost of energy?

5.4.1 Case: 50 MW, C-rate: 1 & 2

Considering the variation in installation costs it is necessary to compare capabilities and costs between GTs and BESS at specific reference points. Based on the results from the case study along with information on gas turbines currently intended for FADR a close estimate to the average power output for a specific asset is 50 MW. As stated earlier a battery could never fulfil the criteria of 100 hour endurance time for the FADR. However, with regards to data provided by Svk on the operation of current gas turbines, partly presented in Section 4.2, a battery with a duration of one hour of discharge could cover 85% of the necessary starts since 2012. A battery with an additional hour of possible discharge (C-rate 0.5) could cover 97% of the stints of operation for the same period. In order to cover the remaining 3% of disruptions, a battery facility with a possible discharge duration of 8 hours would be necessary. Considering these figures this report presents two sets of reference facilities. Both with a total power output of 50 MW but with different total capacities of 50 MWh and 100 MWh. The CAPEX for gas turbines is estimated by

Table 15 which indicates a cost of 6.4 MSEK/MW for a 50 MW unit which equals a total investment of 320 MSEK.

50 MW - 50 MWh

Figure 44 shows minimum, average and maximum installation costs for Li-ion, NaS and flow battery facilities with a 50 MW power output and 50 MWh capacity. The figures indicate that the initial cost for a 50 MW gas turbine exceeds the cost for the equivalent BESS in all cases except for the higher estimates of Li-ion and Flow batteries. For all calculations see Appendix B.

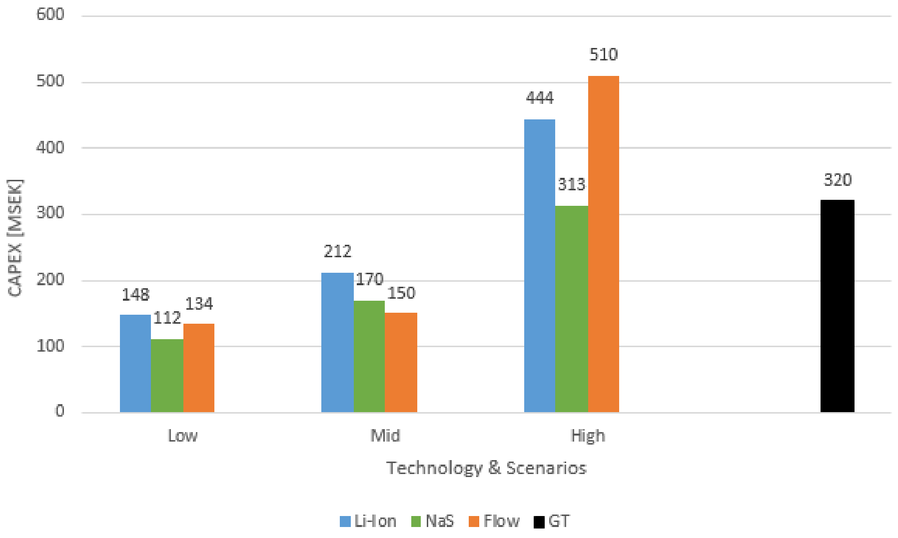


Figure 44: Installation costs, 50 MW - 50MWh by technology

Figure 45 shows central values of investment costs for 50 MW facilities in 2018 along with accumulated CAPEX and OPEX for a 25 year period. As mentioned in the Section 4.3 the life expectancy of gas turbines is estimated to 25 years and Li-ions to 10 years. The lifespan of NaS and Flow batteries are estimated to 15 years. Reinvestments in new facilities for the various battery types are included after each separate lifespan period shown by the gaps in accumulated costs. A reinvestment for the Li-ion facility is included in 2028 at the estimated prices in 2030 presented in Section 4.5.3. The same approach is used for NaS and Flow batteries but in 2033 and investments are accounted for according to 2030 price estimates. The remaining period to 2043 after the reinvestments are calculated according to improved life expectancies estimating a lifespan for Li-ions to approximately 18 years, NaS to 20 years and Flow to 25 meaning no further necessary investments before 2043. Figure 45 shows that initial investment costs for a gas turbine of 50 MW exceed all battery types. The life expectancy of gas turbines however is far superior in comparison to batteries which evens out the results by the end of the considered period of time. The approach for all calculations are found and described in more detail in Appendix B

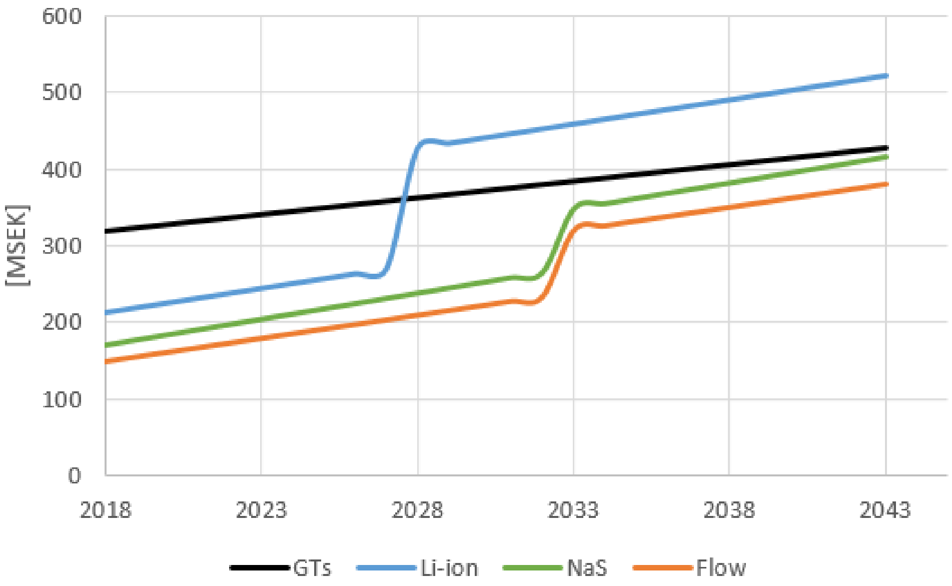


Figure 45: Accumulated CAPEX and OPEX by technology, 50 MW - 50 MWh, 2018-2043

The approach described above, accounting for reinvestments at improved prices and life spans, at the end of each technology's estimated initial life expectancy is also used to calculate the Levelized Cost of Energy for gas turbines and the Levelized Cost of Energy Storage for the battery facilities. Calculating LCOE and LCOES is described earlier in more detail and can be recapped in Section 3.4.1. The amount of energy supplied each year is estimated to 1424 MWh/year for all units available for FADR according to an average of data attained from Svk. The discount rate is approximated to 5% (Energimarknadsinspektionen 2016). Calculated LCOE and LCOES are presented in Table 13 which indicates that the different technologies are all in the same range. The LCOE for gas turbines and LCOES for Li-ion slightly exceeds the LCOES for NaS and Flow batteries for a 50 MW - 50 MWh facility. All calculations are found and can be viewed in detail in Appendix B.

Table 13: Levelized cost of energy and energy storage, 2018-2043

Technology	LCOE/LCOES [SEK/MWh]
GTs	10 420
Li-ion	10 819
NaS	8 358
Flow	7 539

50 MW - 100 MWh

Figure 46 shows minimum, average and maximum estimations for installation costs calculated according to price figures presented in Section 4.5.3 for Li-ion, NaS and flow battery facilities with a 50 MW power output and 100 MWh capacity. The resulting figures indicate that the initial cost for a 50 MW gas turbine is in the range of the average estimates for the battery types. Maximum estimates for BESS exceeds the cost of the gas turbine by far and low estimates are slightly lower than the cost of the equivalent turbine. Calculations are based on no extended need for power electronics in comparison to the 50 MWh case described above thus costs for PE increases with increasing power output. According to Section 4.5.3 power electronics for grid scale batteries accounts for approximately 35% for a facility with a C-rate of 1. Installation costs presented in Section 4.5.3 are therefore deducted by 17.5% in the calculations for the 50 MW - 100 MWh cases. All calculations are presented in more detail in Appendix B.

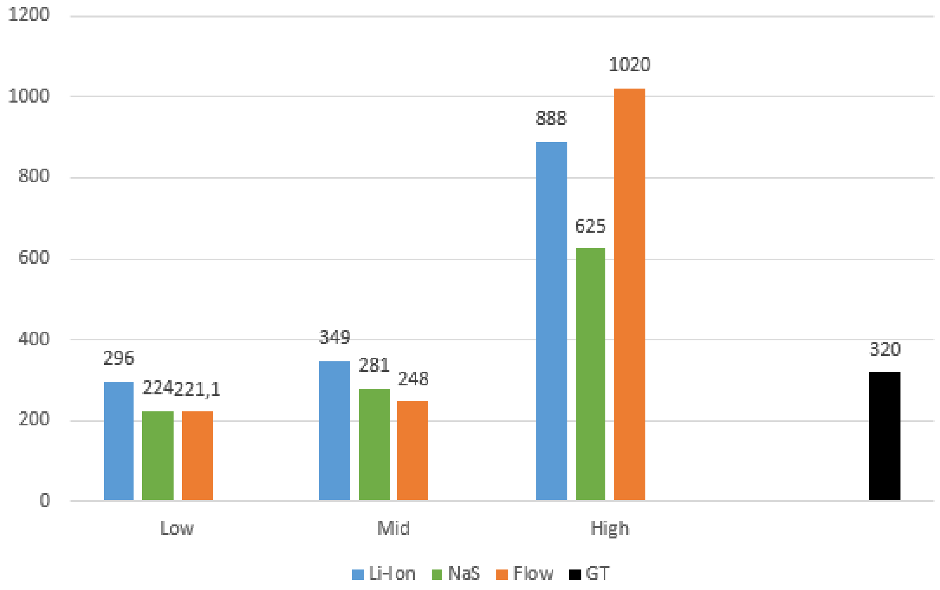


Figure 46: Installation costs, 50 MW - 100MWh by technology

Figure 47 shows central values of investment costs for 50 MW - 100 MWh facilities in 2018 along with accumulated CAPEX and OPEX for a 25 year period. Calculations are conducted according to the same approach as described for the 50 MWh facilities. Figures show that CAPEX is similar for the facilities but OPEX for the battery facilities exceeds the ones for the gas turbine. Reinvestments in batteries at the end of life expectancies increase the gap between accumulated costs between the alternatives further.

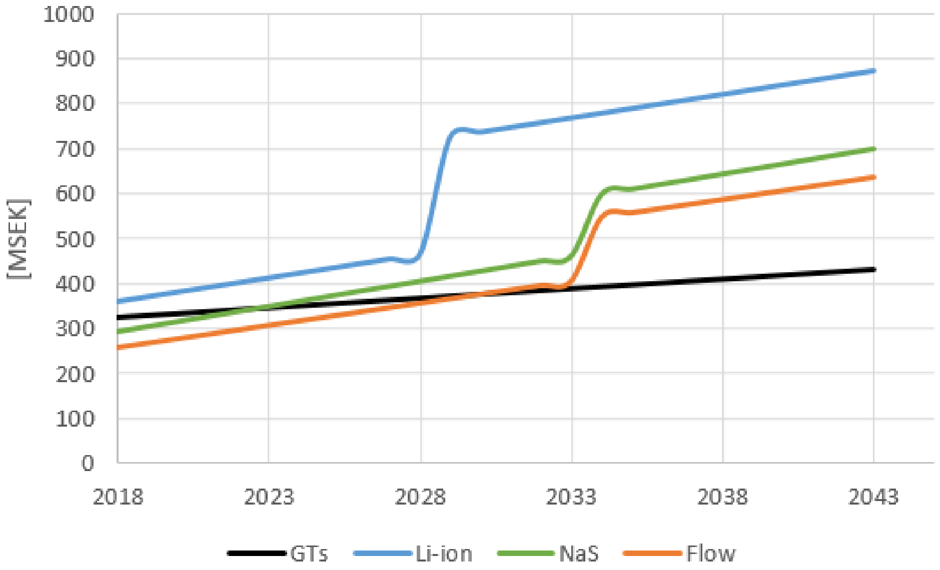


Figure 47: Accumulated CAPEX and OPEX by technoloy, 50 MW - 100 MWh, 2018-2043

Levelized Cost of Energy Storage for the 100 MWh battery facilities are calculated according to the same approach as described earlier. Calculated LCOE and LCOES are presented in Table 14 which indicates that the BESS facilities are all more expensive alternatives than the equivalent gas turbine. All calculations are found and can be viewed in detail in Appendix B.

Table 14: Levelized cost of energy and energy storage, 50 MW - 100 MWh 2018-2043

Technology	**LCOE/LCOES [SEK/MWh]**
GTs	10 420
Li-ion	17 850
NaS	13 790
Flow	12 437

5.4.2 Construction and Physical Properties

This part of the analysis aims to give comparisons and explain differences between the construction and physical properties described in Sections 4.3 and 4.6. The lead time for construction of a BESS compared to a GT is quite different and significant. While a GT takes between 2 to 3 years to construct a BESS takes around 6-12 months. It is always difficult to predict a exact constructing time as permissions and legal processes often can be a big part of the process. For an example it's typical that the site assembly itself of a containerised BESS facility just takes a few weeks. Teslas deployment of Hornsdale that took just 60 days is a extremely short lead time however and should not be considered as normal.

Concerning the physical properties it's quite difficult to make a fair analysis and comparison between the technologies because of a number of factors. The facilities described in Section 4.3 and 4.6 are of different sizes as it's difficult to find facilities sharing the same attributes with different technologies. It's also difficult to predict how strict the building rules were at the specific geographic site, perhaps was space not an issue thus the engineers saw no need to build compact. The footprint analysis of the facilities are therefore only meant to give a practical feeling towards a range in size. The GTs are quite small in their footprint considering their huge output. Concerning BESS is the footprint quite large seen to effect but lesser when looking as the energy.

Table 15: Construction and Physical Properties for GTs and BESS

Technology	**Facility**	**Footprint** [m^2/**Mw**]	**Footprint** [m^2/**Mwh**]
GTs	Forssa	47	-
Li-ion	Hornsdale	100	79
NaS	Buzen	280	46
Flow	N/A	N/A	N/A

GTs are however compared to BESS higher and more visible in that aspect. It's typical to construct a large containerised BESS two containers in height. This is considerably lower than a GT which chimneys can be seen from a long distance. Considering noise the BESS are in favour as the gas turbines can be quite loud.

6 Discussion

This part of the report aims to provide the author's thoughts and opinions on the analysis and the results. Ultimately future research areas are discussed briefly.

6.1 BESS: Case Study

The BESS case study presented in Table 9 and analysed in Section 5.2 gives a fundamental understanding of the deployment of BESS as of April 2018. The number of installed facilities globally has recently increased rapidly and the growth seems to continue exponentially. The growth is especially significant for facilities with longer possible durations of discharge which indicates a shift from short duration operation (e.g. frequency regulation) towards longer operation (e.g. peak shaving etc.). Tons of projects have been announced over the last few years and many have been carried out, but not all of them. This implies an uncertainty when considering projects yet to be constructed. Therefore the study focuses on facilities that are operational or projects where construction is already initiated. Many of the very recent announcements are not included in the case study unless sufficient confirming information about the facility is attainable. Market structures for ancillary services have a significant effect on the deployment of BESS. Many regions that have developed a capacity market like Germany and the US shows excellent progress in BESS deployment. A market for FFR is considered a possible solution in the Nordics which is believed to enhance the deployment rate of BESS in Sweden (Svk 2017).

The clear dominating application area for BESS today is for frequency regulation services with peak shaving and ramping as second and third. Regarding battery technologies, Li-ion is the most commonly used technology by far. There are two major reasons for the vast deployment of Li-ion utility scale batteries. The main one being the maturity of the technology partly due to the vast implementation of Li-ions in other applications. Secondly, the far superior round-trip efficiency of the Li-ion technology compared to other batteries enhances the competitiveness of the Li-ion batteries substantially. Many countries and regions have developed market structures that favour reserve capacity and especially primary reserve capacity. Primary reserves are usually the most advantageous services in terms of profit which is why many battery operators have chosen to focus on primary reserve capacity like frequency regulation. This sort of operation usually implies a great deal of charging and discharging where the round-trip efficiency of an asset becomes essential. NaS-and flow batteries are the main competitors to the Li-ion technology, with increasing shares on the BESS market, especially when considering facilities intended for longer operational durations. This correlation between battery technologies and applications is evident. Li-ion batteries are well suited and used for frequency regulation while NaS and flow technologies have higher shares in peak shaving and ramping applications. Flow and NaS batteries are expected to keep on growing especially considering the long term shift towards longer duration of operation for BESS presented in Section 4.5.2. This could possibly increase competition and drive down prices for flow and NaS batteries even further.

6.2 BESS: Cost and Performance

Prices for BESS have gone through vast changes over the last decade and are expected to keep on decreasing. The analysis mainly focusing on installation costs and performance factors for Li-ion, NaS and Flow batteries somewhat favours flow and NaS, considering them as cheaper alternatives than Li-ions. Due to the extensive current deployment of Li-ions, the technology is considered quite far along on the declining cost curve already and prices are not expected to decrease as much as for the other technologies. Therefore, the gap between the technologies is only expected to grow larger seen to the installation costs. Li-ions are also unlikely to catch up much when looking at cycle life and depth of discharge rate in the near future. However, Li-ion batteries have three significant advantages to flow and NaS batteries; their high energy density, the maturity of the technology and most importantly the round trip efficiency. Although, these advantages are of less importance when considering applying BESS for FADR use. *Energy density* is considered as a lesser concern in Sweden thus land area is not an issue in general. A BESS with a C-rate of 1 requires roughly the same amount of space as a gas turbine of equivalent size. Additional capacity for a BESS facilities requires more space though. BESS are also far superior in terms of delivery time with an estimation of six months for a turnkey concept in comparison to the estimated two years for gas turbines. The *round trip efficiency* is in most cases of great importance. Running a battery only a few hours a year though is not very common and through the case study and a variety of interviews with battery providers, the authors fail to encounter a similar project. A rough average operational pattern for a BESS facility is to complete one equivalent full discharge cycle per day meaning approximately 365 MWh of energy per MW power per year with a C-rate of 1. The usage of the fast active disturbance reserve earlier estimated to 1420 MWh per year in total would mean an equivalent of approximately one full discharge cycle per year. Considering the very limited running time of the FADR charging costs would be close to insignificant seen to the total operational costs. Therefore the round trip efficiency for the FADR is of less importance from an economic perspective. The same consideration goes for gas turbines where efficiency of the current turbines is a lesser concern. When using a battery for ordinary peak shaving or frequency regulation though, charging costs represents a much larger part of the total operational costs and the round trip efficiency becomes an essential parameter. The far superior round trip efficiency along with the maturity of Li-ion batteries compared to the NaS and flow technologies are considered as the most contributing factors to the much more extensive deployment of Li-ions for grid application. Thus many of the advantages with Li-ion batteries becomes close to irrelevant when applying the technology for FADR, flow and NaS are considered as more suitable alternatives for this specific use. The one disadvantage with NaS batteries is the operational temperature that would be a problem if the facility is to be used rarely. NaS batteries today are self heated by the chemical reactions in the cell and once commissioned they are kept running at 300-400 °C until the end of their calendar life. This would be a key concern if applying a NaS battery only for FADR use due to the scarce operation. In order to use a NaS battery for FADR one must consider application stacking of some kind in order to keep the battery operating continuously. This however is outside the scope of this report and would bring Li-ion back into the discussion as well. While considering only FADR use, flow batteries are considered as the most suitable option mainly due to their durability and resistance to degradation, high calendar life, low costs and their suitability for longer operational durations. The main disadvantages with flow batteries are their low energy density and their low round-trip efficiency and as described earlier these factors are of less concern when considering FADR usage.

6.3 BESS vs. GT

This Section aims at evaluating functional and economic aspects between BESS and GTs. The functional aspects are first separated from the economic discussion after which the comparison is discussed from an economic point of view with regards to functional aspects.

6.3.1 Functional aspects

Comparing gas turbines to batteries is like comparing apples with oranges but still the two technologies can provide similar services. In Section 5.1 it is concluded that both technologies are capable of meeting most of the requirements of the FADR according to the Nordic System Operational Agreement. These are the only absolute specifications to be found today regarding the fast active disturbance reserve. However, looking at a combination of these absolute criteria along with how the FADR is operated today, is from the authors point of view a better measurement and indication on what capabilities the FADR should provide. Section 4.1 presents the current 100 hour endurance time of the FADR as a key concern. A BESS facility could never accomplish this realistically. However, Section 4.2 presents that the FADR is most often run for quite short durations of approximately 20-40 minutes, seldomely exceeding one hour of running time. Section 5.2 describing the 100 largest BESS projects in the world shows that these kind of batteries are almost exclusively designed to handle at least one hour of discharge or longer. As shown in Figure 39 a very small number of the larger batteries have a C-rate exceeding one. Many of them have C-rates below 0.5 meaning a possible duration of discharge of more than two hours. Therefore, the majority of the batteries studied in the top 100 case study are capable and well suited to handle the current operational pattern of the FADR. To be more precise all batteries with a C-rate below 0.5 could handle more than 97% of the disruptions based on data since 2012 as stated in Section 5.4.1. These kind of batteries could be interesting to study in closer detail if considering initiating a project. An important aspect to keep in mind though is that almost none of these batteries are constructed only to provide peak shaving capabilities. As mentioned earlier, most of the top 100 projects primarily intended for peak shaving are constructed with a secondary use in mind, most often frequency regulation or ramping. Using a battery only for peak shaving purposes neglects its biggest advantage; the fast response time. Therefore, many of the BESS from the top 100 study primarily constructed for peak shaving, are sized up in terms of capacity to be able to provide primary regulation services as well. This configuration is referred to as application stacking and can be recapped in Section 3.3.2. Additionally batteries suffer from a certain amount of self discharge as described earlier and are not to be used to rarely. Therefore, they are seldomly used only for disruptions. Although, flow batteries with a near negligible rate of self discharge show great promise for scarce use.

There are two major areas where BESSs differs from gas turbines in regards to functional aspects. BESSs are far superior to gas turbines in terms of response time. This ability however is not favoured or necessary when only considering FADR use. The other aspect is that batteries are far inferior to gas turbines in terms of endurance. Initial investment costs for gas turbines are close to completely independent of desired endurance and the customer mainly pays for desired power output. Investment costs for batteries on the other hand are greatly dependent on both power output and capacity. The greater endurance that today's turbines provide enables the coverage of a vast variety of services like voltage support, black start, island mode operation etc. However, when looking at the statistics, this endurance is seldomly needed. For a battery to provide the same possible capabilities as a gas turbine one would need a battery with a possible duration of discharge of approximately eight hours, disabling the facility to compete with gas turbines on a cost basis. An eight-hour battery could provide functions like black start, voltage support, island mode operation and cover all necessary peaks based on data since 2012 but still could never compete with the 100 hours of fuel always available for current gas turbines. Interviews with people at Svk emphasises the importance of the so called, "100-hour electricity readiness" as an essential criterion for the FADR. Therefore, in order for batteries to be comparable to gas turbines one must look past the 100-hour electricity readiness and consider the actual FADR need today rather than considering what can be provided today. Whether or not this is possible is for Svk to decide.

6.3.2 Economical aspects

Installation costs for gas turbines of appropriate sizes for FADR use range between 3-7 million SEK/MW. If considering a battery with a C-rate of 1 and prices from 2016, installation costs are in the same range as gas turbines for all battery types studied in this report. Looking towards 2030 however, prices for batteries are expected to decline significantly enhancing the cost competitiveness of batteries compared to gas turbines.

Additional investment costs like reinvestments in batteries towards the end of the cycle life are difficult to determine. Few facilities have been operational long enough to explore different disposal alternatives for degraded batteries. Interviews with battery suppliers indicate that a battery has a significant value at the end of its lifespan but it is hard to determine and no precise figures are given. Residual values are therefore not considered in the analysis which leaves a certain room for error in the overall costs. At the same time the analysis estimates a 25-year life expectancy for gas turbines. This is mainly to attain an economic reference cycle life. Dialogues with the authors of the article from which these figures are collected (Genrup and Thern 2014), indicates a much longer technical life expectancy for gas turbines. This is also further confirmed based on the current fleet of turbines commissioned in the 1970s expected to operate until 2030.

Operational expenditures are difficult to determine for both technologies. For gas turbines OPEX ranges between 0.8-2.6%. The high end of the interval is based on the entire turnover of SvkGT. This includes many costs not directly associated with the operation of the turbines and is therefore considered as a slightly exaggerated estimate. This figure also differs significantly from approximations attained externally which further indicates the unreliability of the figure. Accurate levels of OPEX for gas turbines are therefore considered towards the lower half of the range. OPEX for batteries are estimated to range between 2-5%. These figures are considered more accurate. The figures are attained from sources considered reliable and correspond well with indications from interviews with the industry. However, a battery is quite a simple device compared to a gas turbine. The necessary maintenance appears to be minimal in comparison to gas turbines and the higher OPEX seems difficult to motivate. The author's image of the operational costs after conducting this project is that the high operational charges are mainly a consequence of the immature market. Even though batteries themselves have gone through price declines from increasing competitiveness, the service costs of operating a battery seem unchanged over the last few years. The authors find it hard to motivate the high charges for operation and therefore consider that the profit margin for operation charges to be quite significant. As mentioned earlier BESS facilities can be contracted to be remotely controlled by the battery supplier at a higher cost close to 5% OPEX. They can also be contracted to be controlled by the owner at a fee towards the lower part of the cost range which seems like a more reasonable business model at the moment due to the difficulty in motivating the high operational charges. This however is an area for further evaluation not included in this report.

The combination of ranging installation costs, operational expenditures and the uncertainty regarding necessary reinvestments makes it challenging to determine which technology is more expensive than the other. This is further evaluated through the two cases discussed below.

6.3.3 Case: 50 MW, C-rate: 1 & 2

An enhanced need for FADR is expected with the increasing amount of RES in the Swedish power system and new investments in balancing assets could be necessary in the near future. It is easy to think of new technologies as complete substitutes to current ones but this is not necessarily the case for the future FADR. A highly probable alternative in the near future is an expansion of the mFRR where new assets are added not intended to replace older equipment but as additional balancing means. The case facilities presented in the analysis are intended to give a fundamental understanding of the alternative of investing in a BESS facility compared to extending the current FADR with additional gas turbine assets. The economic comparison between the technologies is to be considered as a general indication of possible investment alternatives. Actual prices and costs attained from battery suppliers are excluded from the report due to confidentiality reasons but correspond well with the presented cases calculated according to public figures.

Functional

As mentioned earlier a battery can technically, but never in reality live up to the endurance standards of a gas turbine. Both reference facilities described in the analysis would cover most FADR needs though as presented in Section 5.4.1. The one-hour duration facility is limited to disruption operation while the second one could possibly be applied for other uses as well.

The lifespan of the different reference facilities have been estimated according to the market average. These estimations are most likely far below the actual lifespan of these facilities. Market average estimations are approximated according to normal use of a battery which would exceed the use of a battery devoted for FADR by far. Due to lack of reference cases and experience among BESS suppliers of operating a battery at SvkGTs desired needs a better figure is difficult to estimate. However, one should consider that reinvestments would be necessary less frequently in a real scenario lowering the overall costs for the BESS facilities.

Economical

It is easy to be astounded by the results showing that BESS, in a few cases are much cheaper than gas turbines both when considering investment costs isolated and accumulated CAPEX and OPEX. There are however a few things to keep in mind. A 50 MW system is far from the most favourable for the gas turbine technology thus investment costs per MW are significantly higher compared to a larger investment like the one Fingrid made. Battery prices used in the calculations are attained from the report *"Electricity storage and renewables: Costs and markets to 2030"* by the International Renewable Energy Agency which is considered a truly trustworthy source. It is worth mentioning though that interviews with the Li-ion industry indicates higher prices than the once presented in the IRENA-report. Prices attained from interviews with the industry are not presented in the report but the average Li-ion price of 4230 SEK/kWh can be considered as a bit optimistic. Still the Li-ion technology is considered as a less costly alternative than gas turbines for the 50MWh facility and flow and NaS technologies reaches the same cost levels as gas turbines even for the 100 MWh case. While considering a 25 year period seen from the initial investment, also accounting for operational costs and reinvestments the results even out for the 50MWh facility and the gas turbine investment is far superior to the 100 MWh facility. In a real scenario though, the possible lifespan of a hypothetical flow facility could be as long as the lifespan of a gas turbine. As mentioned earlier, operational expenditures are also considered unreasonably high and if these could be reduced a two-hour flow battery could truly compete with a gas turbine from a cost perspective.

The LCOE and LCOES are measurements of how much every MWh of balancing capacity costs over the lifetime of the different asset alternatives and can be recapped in Section 3.4.1. Calculations for the 50 MWh facilities shows that LCOE/LCOES for the gas turbine exceeds the ones for flow and NaS and is quite similar to the Li-ion LCOES. The LCOES of the sized up facilities all exceed the LCOE for the gas turbine. The Li-ion one by far whilst the flow and NaS facilities are more comparable to the gas turbine technology. Calculations are made accounting for a yearly production of 1424 MWh which is an average of 2012-2016. 2015 and 2016 indicates a lower production closer to 500 MWh/year but at the same time, the need for FADR is projected to increase which is why the amount is kept around 1500 MWh/year for the calculations. This figure does not affect the relative difference between the alternatives thus the costs barley changes due to variations in production. The amount of energy produced per MW available power is still minimal and does not affect the operational costs much. Therefore a change in production would only affect the price range of LCOE/LCOES but not how they relate proportionally to one another. The Levelized Cost of Energy or Energy Storage is a good indication on how different technologies relate to one another. Additionally one must consider what functions or characteristics the different alternatives can provide.

6.4 Future research

This thesis should be considered as a pilot study for SvkGT into the world of BESS. The focus of the report has been to provide a deep understanding of the basic functional and economic aspects of BEsS compared with the existing gas turbine technology. Due to time constraints, there are however a number of research areas that have been excluded in this initial study that should be researched in future studies. For instance, an investigation of the legal conditions and regulations for BESS in Sweden should be further explored, evaluating potential owners and operators of the facilities. Moreover, a deeper technical analysis on how BESS could be integrated into the power grid with surrounding power electronics, could be of benefit to SvkGT. Next, BESS application stacking is an area especially important to investigate, focusing on what possibilities there are within the legal framework. This area is of particular significance since FADR use does not utilise the quick response time of power supply that BESS can provide which is considered as the main advantage of batteries. In addition, supercapacitors abilities to replace inertia with virtual inertia is a relevant field of future research as well. For example, the company "Freqcon" claims to be able to replace the inertial response of 1500 MW power plant generators with a 1 MW ultracapacitor. Throughout the entire supply chain, the environmental impact of batteries should also be further investigated, as well as the BEES calender life and its degradation over the expected life cycle. The moral and humanitarian aspects of battery production are furthermore relevant to examine, especially since many minerals derive from conflict zones. Lastly, a detailed evaluation of the operational costs for both current gas turbines and batteries would provide a more thorough understanding of the different components of the two technologies.

7 Conclusion

Maintaining balance in the Swedish power system is a challenge that increases with the reduction of disposable energy sources and the vast introduction of RES. Historically the grid has been stabilised using production facilities but with increasing environmental demands and regulations it is of utmost importance to consider other more environmentally friendly alternatives than the current gas turbines used for tertiary balancing. This report presents three categories of batteries, the current performance and costs along with future projections of the different technologies in order to evaluate their suitability for FADR use compared to current gas turbines.

According to the case study conducted throughout the project of BESS facilities sized appropriately for mFRR use, current facilities are mainly intended for primary balancing services like frequency control. Batteries capability of providing power quickly unlike any other technology is the key driver for current deployment of BESS. Evolving capacity markets are great drivers for the deployment of BESS and Li-ion batteries dominate the market due to the maturity of the technology along with their far superior round-trip efficiency compared to other technologies. However, future predictions indicate a shift for BESS, from short duration operation towards longer periods of operation like peak shaving that is more comparable to the operation pattern of the current FADR. Other technologies such as NaS and flow batteries show great promise for these kinds of applications. Application stacking is a common setup which means sizing up the battery capacity in order to cover a series of application areas with the same facility. This sort of setup could show great promise in Sweden and is a possibility for further investigation.

The case study of the 100 largest facilities in the worlds also indicates that there are large BESS projects constructed to handle most types of disturbance problems in a power system. All BESS technologies evaluated throughout the report are technically capable of fulfilling current FADR requirements mainly focusing on grid disturbance, balancing, voltage support, black start and island mode operation, however none of the technologies could ever in practice meet the criteria of 100-hour operation duration like gas turbines can and does today. This endurance is referred to as electricity readiness and highly valued according to people responsible for the mFRR. Therefore this capability is a first concern when even considering implementing batteries for FADR use. 100 hours of discharge for a battery is not a realistic option but if one can bend the rules for electricity readiness and considers the statistics of operation for the FADR a battery can be considered a reasonable option. A one-hour battery could fulfil 85% of necessary services of the FADR based on data since 2012 and a two-hour battery could cover 97% of the FADR demand. Batteries of these sizes are comparable to gas turbines from a cost perspective. Based on the results of the report most one hour batteries are considered less costly than a gas turbine of the same power output. If scaling up the batteries to two hours of duration, battery prices exceed gas turbine prices for all alternatives. Some of the less costly alternatives though are well comparable to gas turbines even for batteries capable of a two hour discharge time. Finally it is concluded that the Vanadium Redox Flow battery is the technology that shows greatest promise for FADR use, mainly due to its low price, high robustness, low degradation rate and the fact that its poor round-trip efficiency is of smaller concern when the asset is intended for FADR operation. Future prices and performance for batteries are highly uncertain to discuss but performance is expected to increase and prices to decline to a level at which two-hour batteries are far superior to gas turbines from a cost perspective.

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A BESS Case Study

Number	Project Name	Techno	Rated	Duratio	Country	Service/Use Case 1	Service/Use Case 2
1	Dalian	VRF	200	4,00	China	Peak Shaving	Black Start
2	Alamitos Energy Storage Array	Li-Ion	100	4,00	United States	Peak Shaving	Frequency Regulation
3	Kingfisher Project (Stage 2)	Li-Ion	100	4,00	Australia	Ramping	Peak Shaving
4	Hornsdale Power Reserve	Li-Ion	100	1,29	Australia	Frequency Regulation	Ramping
5	Buzen Substation	NaS	50	6,00	Japan	Ramping	Frequency Regulation
6	Roosecote Energy Storage	Li-Ion	50	1,00	United Kingdom	Frequency Regulation	Ramping
7	Jardelund "EnspireMe"	Li-Ion	48	1,04	Germany	Peak Shaving	Frequency Regulation
8	GimJe Substation	Li-Ion	48	n/a	South Korea	Frequency Regulation	
9	Gyeongsan Substation	Li-Ion	48	0,25	South Korea	Frequency Regulation	Voltage Support
10	Minami-Soma Substation	Li-Ion	40	1,00	Japan	Ramping	Peak Shaving
11	Glassenbury Battery Storage Project	Li-Ion	40	0,69	United Kingdom	Frequency Regulation	Ramping
12	Nishi-Sendai Substation	Li-Ion	40	0,50	Japan	Frequency Regulation	Voltage Support
13	Notrees Battery Storage Project	Li-Ion	36	0,37	United States	Peak Shaving	Frequency Regulation
14	Non-Gong Substation	Li-Ion	36	0,36	South Korea	Frequency Regulation	Ramping
15	Convergent 35 MW / 140 MWh - SCE	Li-Ion	35	4,00	United States	Peak Shaving	Frequency Regulation
16	Port of Tyne	Li-Ion	35	n/a	United Kingdom	Frequency Regulation	
17	Rokkasho Village	NaS	34	7,00	Japan	Ramping	Peak Shaving
18	Ul-San Substation	Li-Ion	32	0,38	South Korea	Frequency Regulation	
19	AES Laurel Mountain	Li-Ion	32	0,25	United States	Frequency Regulation	Ramping
20	Beech Ridge Wind Storage	Li-Ion	31,5	0,38	United States	Frequency Regulation	Ramping
21	Grand Ridge Energy Storage	Li-Ion	31,5	0,38	United States	Frequency Regulation	
22	Escondido Substation	Li-Ion	30	4,00	United States	Peak Shaving	Frequency Regulation
23	Imperial Irrigation District BESS - GE	Li-Ion	30	0,67	United States	Peak Shaving	Black Start
24	Golden Hills - NextEra Energy	Li-Ion	30	0,50	United States	Transmission/Distribution	Peak Shaving
25	Dalrymple 30 MW / 8 MWh battery	Li-Ion	30	0,27	Australia	Frequency Regulation	Peak Shaving
26	SokCho	Li-Ion	28	n/a	South Korea	Frequency Regulation	
27	Seo-Anseong Substation	Li-Ion	28	0,26	South Korea	Frequency Regulation	Transmission/Distribution
28	Golden Valley Electric Association (GVEA) Batt	Ni-Cd	27	0,25	United States	Peak Shaving	Frequency Regulation
29	Modesto EnergyFarm	ZCF	25	3,00	United States	Ramping	Frequency Regulation
30	Enel S.p.A. Tynemouth	Li-Ion	25	0,50	United Kingdom	Frequency Regulation	
31	Shin-Yongin Substation	Li-Ion	24	0,50	South Korea	Frequency Regulation	Transmission/Distribution
32	Shin-Gimje Substation	Li-Ion	24	0,38	South Korea	Frequency Regulation	Transmission/Distribution
33	Uiryeong Substation	Li-Ion	24	0,33	South Korea	Frequency Regulation	Transmission/Distribution
34	Shin-GyeRyong Substation	Li-Ion	24	0,25	South Korea	Frequency Regulation	Transmission/Distribution
35	Shin-WhaSun Substation	Li-Ion	24	0,50	South Korea	Frequency Regulation	Transmission/Distribution
36	Ul Ju Substation	Li-Ion	24	n/a	South Korea	Frequency Regulation	
37	Pen y Cymoedd Storage	Li-Ion	22	0,75	United Kingdom	Frequency Regulation	Ramping

38	Pomona Energy Storage Facility	Li-Ion	20	4,00	United States	Peak Shaving	Frequency Regulation
39	Mira Loma Substation	Li-Ion	20	4,00	United States	Peak Shaving	Frequency Regulation
40	Beacon Battery Storage	Li-Ion	20	0,50	United States	Peak Shaving	Frequency Regulation
41	Marengo Project	Li-Ion	20	0,50	United States	Frequency Regulation	
42	Broxburn -RES	Li-Ion	20	n/a	United Kingdom	Frequency Regulation	
43	AES Angamos Storage Array	Li-Ion	20	0,25	Chile	Peak Shaving	Frequency Regulation
44	Cochrane Thermal Power Station Storage Syst	Li-Ion	20	0,34	Chile	Peak Shaving	Frequency Regulation
45	AES Tait Battery Array	Li-Ion	20	n/a	United States	Frequency Regulation	
46	Cape York Solar Storage 20MW / 80MWh - Lyc	Li-Ion	20	4,00	Australia	Ramping	Peak Shaving
47	IPL Advancion Energy Storage Array	Li-Ion	20	1,00	United States	Frequency Regulation	
48	Lee DeKalb Energy Storage - NextEra	Li-Ion	20	n/a	United States	Frequency Regulation	Ramping
49	McHenry Battery Storage Project	Li-Ion	19,8	0,40	United States	Frequency Regulation	
50	Jake Energy Storage Center	Li-Ion	19,8	0,40	United States	Frequency Regulation	
51	Elwood Energy Storage Center	Li-Ion	19,8	0,39	United States	Frequency Regulation	
52	Meyersdale Energy Storage - NextEra	Li-Ion	18	0,50	United States	Frequency Regulation	Ramping
53	Nextera Wyman	Li-Ion	16,2	0,50	United States	Frequency Regulation	
54	Shin-ChungJu Substation	Li-Ion	16	0,38	South Korea	Frequency Regulation	Transmission/Distribution
55	15 MW Energy Storage at Lünen Cogeneration	Li-Ion	15	1,50	Germany	Frequency Regulation	Voltage Support
56	15 MW Energy Storage at Walsum Cogeneratic	Li-Ion	15	1,50	Germany	Frequency Regulation	Voltage Support
57	15 MW Energy Storage at Bexbach Cogenerati	Li-Ion	15	1,50	Germany	Frequency Regulation	Voltage Support
58	15 MW Energy Storage at Volklingen-Fenne Cc	Li-Ion	15	1,50	Germany	Frequency Regulation	Voltage Support
59	15 MW Energy Storage at Weiher Cogeneratior	Li-Ion	15	1,50	Germany	Frequency Regulation	Voltage Support
60	15 MW Energy Storage at Herne Cogeneration	Li-Ion	15	1,50	Germany	Frequency Regulation	Voltage Support
61	WEMAG Schwerin Battery Park - Younicos	Li-Ion	15	1,00	Germany	Frequency Regulation	Black Start
62	Daimler AG 15 MWh	Li-Ion	15	1,00	Germany	Frequency Regulation	Peak Shaving
63	Minami Hayakita Substation Hokkaido Electric F	VRF	15	4,00	Japan	Ramping	Peak Shaving
64	Kaua'i Dispatchable Solar Storage - 13 MW / 52	Li-Ion	13	4,00	United States	Peak Shaving	Ramping
65	Daimler 2nd Life Storage - The Mobility House	Li-Ion	13	1,00	Germany	Electric Bill Management	Peak Shaving
66	12.8 MW / 52.8 MWh IESO Energy Storage Prc	Li-Ion	12,8	4,00	Canada	Frequency Regulation	Peak Shaving
67	GS E&R-LG Chem	Li-Ion	12,5	4,00	South Korea	Ramping	Peak Shaving
68	Terna SANC Flumeri	NaS	12	6,67	Italy	Frequency Regulation	Transmission/Distribution
69	Terna SANC Ginestra	NaS	12	6,67	Italy	Frequency Regulation	Transmission/Distribution
70	Los Andes Substation Battery Energy Storage S	Li-Ion	12	0,33	Chile	Peak Shaving	Frequency Regulation
71	Auwahi Wind Farm Storage	Li-Ion	11	0,40	United States	Ramping	Frequency Regulation
72	Terna SANC Scampitella	NaS	10,8	6,67	Italy	Frequency Regulation	Transmission/Distribution
73	Green Mountain Energy Storage - NextEra	Li-Ion	10,4	1,00	United States	Frequency Regulation	Peak Shaving
74	Feldheim Regional Regulating Power Station (F	Li-Ion	10	1,00	Germany	Frequency Regulation	Ramping

Number	Service/Use Case 3	Peak Shaving	Ramping	Voltage Support	Black Start	Transmission Congestion Relief
1	Ramping	TRUE	TRUE		TRUE	
2	Black Start	TRUE	TRUE	TRUE	TRUE	
3		TRUE	TRUE		TRUE	
4	Peak Shaving	TRUE	TRUE	TRUE		
5			TRUE			
6	Transmission/Distribution	TRUE	TRUE			
7	Ramping	TRUE	TRUE			
8						
9	Transmission/Distribution			TRUE		TRUE
10		TRUE	TRUE			
11			TRUE	TRUE		
12				TRUE		
13	Ramping	TRUE	TRUE	TRUE	TRUE	
14						
15		TRUE		TRUE		
16						
17		TRUE	TRUE			
18						
19			TRUE			
20	Renewables Capacity Firming		TRUE			
21						
22	Renewables Capacity Firming	TRUE	TRUE			
23	Frequency Regulation	TRUE	TRUE	TRUE	TRUE	
24	Renewables Capacity Firming	TRUE	TRUE			
25	Voltage Support			TRUE		
26						
27	Voltage Support			TRUE		TRUE
28	Grid-Connected Residential (Reliability)			TRUE		
29	Testing battery?		TRUE			
30						
31	Voltage Support			TRUE		TRUE
32	Voltage Support			TRUE		TRUE
33	Voltage Support			TRUE		TRUE
34	Voltage Support			TRUE		TRUE
35	Voltage Support			TRUE		TRUE
36						
37						

38		TRUE				
39		TRUE	TRUE			
40	Load Following (Tertiary Balancing)		TRUE			
41						
42						
43						
44		TRUE				
45						
46	Resiliency		TRUE			
47						
48			TRUE			
49				TRUE		
50						
51						
52			TRUE			
53						
54	Voltage Support			TRUE		TRUE
55	Black Start			TRUE	TRUE	
56	Black Start			TRUE	TRUE	
57	Black Start			TRUE	TRUE	
58	Black Start			TRUE	TRUE	
59	Black Start			TRUE	TRUE	
60	Black Start			TRUE	TRUE	
61	Voltage Support			TRUE	TRUE	
62						
63	Frequency regulation		TRUE			
64		TRUE				
65	Frequency Regulation	TRUE				
66	Voltage Support			TRUE		
67	Frequency Regulation		TRUE			
68	Voltage Support			TRUE		TRUE
69	Voltage Support			TRUE		TRUE
70	Ramping		TRUE			
71			TRUE			
72	Voltage Support			TRUE		TRUE
73						
74	Transmission upgrades due to wind		TRUE			

Number	Description
1	The battery arrays approved by the China National Energy Administration will be made up of ten (10X) 20MW/80MWh Vanadium Flow Battery (VFB)
2	AES Southland announced that it has been awarded a 20-year Power Purchase Agreement (PPA) by Southern California Edison (SCE), to provide 1
3	The Kingfisher Project will feature a solar PV plant and a battery storage facility that uses sophisticated system management processes and is conne
4	The world’s largest lithium-ion battery has officially been turned on in South Australia promising to usher in a revolution in how electricity is produced a
5	Mitsubishi Electric Corp. has delivered what it claims is the world’s largest energy storage system to Japanese power vendor Kyushu Electric Power C
6	
7	Project ‘EnspireME’ as it will be known, will allow the local community to optimise its growing use of wind and solar energy by supplying the reserve p
8	
9	
10	Tohoku Electric Power Company has deployed the battery energy storage system (BESS) in a power transmission substation in Minami-Soma, on Ja
11	
12	Tohoku-Electric Power Co Inc announced Feb 20, 2015, that it has started commercial operation of a large-size storage batter system installed at Nis
13	Notrees was updated with Samsung lithium Ion batteries in 2016 . Duke Energy has deployed a wind energy storage demonstration system at the 153
14	Korea Electric Power Corporation (KEPCO) (KEP), has awarded Kokam a contract to develop a 36-megawatt (MW) system / 13-megawatt hour (MW
15	Convergent Energy + Power is contracted to deliver a 35 MW, 140 MWh energy storage system to provide targeted electric capacity and other benefit
16	Foresight Group (“Foresight”), the independent infrastructure and private equity investment manager, is pleased to announce the acquisition of Port o
17	In May 2008, JWD completed construction of a wind farm near Rokkasho village in Aomori Prefecture, in northern Honshu. This smart grid wind farm
18	
19	AES installed a wind generation plant comprised of 98 MW of wind generation and 32 MW of integrated battery-based energy storage. The project is
20	The 31.5 MW Beech Ridge energy storage developed by Invenergy is located adjacent to its 100.5 MW wind farm in West Virginia. Beech Ridge will
21	Grand Ridge Energy Storage project is located approximately 80 mi southwest of Chicago, IL. It has a power rating of 31.5 MW and an energy rating
22	AES Energy Storage, has entered into two contracts with San Diego Gas and Electric. AES will install and commission two energy storage arrays total
23	Imperial Irrigation District (IID) is installing a large-scale battery system that will help integrate around 50 MW of solar generation capacity to the local
24	They include a 30-megawatt system from NextEra Energy at its Golden Hills wind farm near Livermore.
25	The $30 million, 30 MW battery will be built at the Dalrymple substation on the Yorke Peninsula, west of Adelaide. A partnership between the Australia
26	
27	KEPCO established a plan to build 500 MW of energy storage systems (ESS) for frequency regulation in stages over four years (2014-2017). In 2014,
28	Completed in December 2003, the BESS is one of GVEA's initiatives to improve the reliability of service to GVEA members. In the event of a generati
29	The EnergyFarm will displace a planned $73 million natural-gas-fired power plant intended to smooth (or firm) the output of intermittent wind and sola
30	The construction-ready project, which will be developed by Enel’s Global Thermal Generation division, uses a lithium-ion battery with a capacity of 25
31	KEPCO established a plan to build 500 MW of energy storage systems (ESS) for frequency regulation in stages over four years (2014-2017). In 2014,
32	KEPCO installed 24 MW (9 MWh) of Li-ion battery based energy storage system for frequency regulation in 2015. At the time of commissioning, Shin-
33	KEPCO installed 24 MW (6 MWh) of Li-ion battery based energy storage system for frequency regulation in 2015. Note: System testing before comm
34	6 MWh
35	
36	
37	

38 The project will be constructed on a portion of the existing San Gabriel Energy Facility site located in Pomona, California. The system is designed to p
39 Tesla on Thursday announced that it had won a deal to provide 20 megawatts of batteries to the utility to plug into one of its substations and provide e
40 Los Angeles Department of Water and Power (LADWP) has selected Doosan GridTech and its partner, KTY Engineering, to deliver LADWP’s first ba
41 The Marengo plant will be interconnected to the local Commonwealth Edison Company (ComEd) electric grid and will provide RegD real-time frequen
42 National Grid, sole operator of Britain’s electricity transmission system, has contracted RES Renewable Energy Systems to install 20 MW of energy st
43 This project will utilize 20 MW of A123 lithium-ion batteries to supply a flexible and scalable emissions-free reserve capacity installation for AES Gene
44 The Cochrane facility being developed by AES Gener, will incorporate AES Energy Storage’s Advanced Reserves product. The advanced lithium-ion
45 AES has installed an additional 40 MW (+20/-20) of advanced energy storage resources to PJM Interconnection, which controls the power grid for 60
46 Lyon announced its next Solar + Battery project, to be built in Lakeland, Queensland. The grid- connected project will include 80MWh Solar PV and a
47 The IPL Advancion Array provides 20 megawatts (MW) of interconnected energy storage equivalent to 40 MW of flexible resource with unmatched op
48 NextEra Energy Resources’ 20 MW Frontier Battery Energy Storage System near the Lee DeKalb Wind Energy Center in Illinois went into commercia
49 EDF Group’s first battery storage project in North America, developed and built by EDF Renewable Energy, reached commercial operation on Decem
50 RES Americas will develop and construct two 19.8 MW energy storage systems, each having the ability to store 7.8 MWh of energy. The first project,
51 RES Americas will develop and construct two 19.8 MW energy storage systems, each having the ability to store 7.8 MWh of energy. The first project,
52 In 2015, NextEra Energy Resources commissioned the Meyersdale Battery Energy Storage System, an 18 MW facility located in Pennsylvania operat
53 16.2MW battery energy storage sysetm
54 6 Mwh
55 At the Lünen site, one of the six STEAG large battery systems was installed, which are used by STEAG for the provision of primary control capacity. E
56 Six large LG Chem lithium-ion battery storage units will be put into service at Steag power plants in Germany.The 100 million euro project will see 15
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58 Six large LG Chem lithium-ion battery storage units will be put into service at Steag power plants in Germany. The 100 million euro project will see 15
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60 Six large LG Chem lithium-ion battery storage units will be put into service at Steag power plants in Germany. The 100 million euro project will see 15
61 Europe's first commercial battery park, it will participate in Primary Frequency regulation market. Additional revenues/savings possible through black s
62 15 megawatt-hour energy storage system is being constructed by Daimler AG (with its subsidiary ACCUMOTIVE) and enercity (Stadtwerke Hannover
63 Hokkaido Electric Power Co Inc (HEPCO) and Sumitomo Electric Industries (SEI) Ltd announced Dec 25, 2015, that they have completed a large-sca
64 Kaua‘i Island Utility Cooperative (KIUC) has signed a power purchase agreement (PPA) with SolarCity for electricity from the first utility-scale solar arr
65 Daimler and The Mobility House under its joint venture Enbase Power announced a 13-megawatt-hour battery storage unit at the Remondis recycling
66 The Independent Electricity System Operator in the Canadian province of Ontario plans to install six energy storage systems to stabilize its grid. Lecla
67 South Korean battery-maker LG Chem said Tuesday that it has teamed up with GS E&R, a local power generator, to build the world’s largest win
68 NGK Insulators, Ltd.and Terna S.p.A, Italy's largest transmission system operator (TSO) came to a framework agreement for supply of a NaS battery
69 NGK Insulators, Ltd.and Terna S.p.A, Italy's largest transmission system operator (TSO) came to a framework agreement for supply of a NaS battery
70 The Los Andes project provides critical contingency services to maintain the stability of the electric grid in Northern Chile, an important mining area. T
71 An important component of this wind project is the 11-MW grid battery system. Energy from the battery system helps to regulate and sustain power to
72 NGK Insulators, Ltd.and Terna S.p.A, Italy's largest transmission system operator (TSO) came to a framework agreement for supply of a NaS battery
73 In 2015, NextEra Energy Resources commissioned the Green Mountain Battery Energy Storage System, a 10.4 MW facility located in Pennsylvania o
74 This innovative storage facility for renewable energy is being built in the energy self-sufficient village of Feldheim and functions as a ‘regulating power

Number	Commissioning Year	Lifetime	Performance	Capital Expenditure	CAPEX MSEK	CAPEX/MWh	Operating Expens
1	2019	20	Vanadium batteries have an expected lifetime of approximately 15,000 cycles, with zero degradation during				
2	2020	20	http://www.renewaesalamitos.com/AES-Alamitos-Fact-Sheet-2015.pdf				
3	2019			$250 Million	2150	5,375	
4	2017	15					
5	2016						
6	2018						
7	2017						
8							
9	2016						
10	2016						
11	2017						
12	2016						
13	2013						
14	2016						
15	2017						
16	2018						
17	2008	15	15 Years lifetime, 4 500 cycles, 85% Efficiency (DC-DC) , 2 milliseconds response, Minimal planned mainte				
18	2017						
19	2011		400,000 MWh of operational se	$29 Million	249,4	31,175	
20	2015						
21	2015						
22	2017	10					
23	2016			$38 million	326,8	16,34	
24	2019	10					
25	2018			$30 Million	258	32,25	
26							
27	2015						
28	2003	25	Prevented >60% of power-supp	$ 35 million (2003)	301	44,59259259	
29	2016	20		$ 46,7 million	401,62	5,354933333	
30	2018			20 million euros	172	13,76	
31	2014						
32	2016						
33	2016						
34	2016						
35	2016						
36	2016						
37	2018			£5000/MW	1320000		

38	2016	10	https://www.altagas.ca/our-infra	Mellan 321-369,45 M	345	4,3125	
39	2017						
40	2018			US$19.2 million?	165,12	16,512	
41	2018	10		20000000	172	17,2	
42	2018	15	RES’ battery storage systems will provide frequency response within one second of detection				
43	2011						
44							
45	2013		Performance metrics not availal	20000000	172		
46	-						
47	2016	10	Moves from a neutral state to fu	$ 26 million			
48	2015						
49	2015						
50	2015	10		20000000	172	21,7721519	
51	2015	10		20000000	172	22,05128205	
52	2015		N/A				
53	2016						
54	2016						
55	2016			€16.7 Million	167	7,422222222	
56	2016			€16.7 Million	167	7,422222222	
57	2016			€16.7 Million	167	7,422222222	
58	2016			€16.7 Million	167	7,422222222	
59	2016			€16.7 Million	167	7,422222222	
60	2016			€16.7 Million	167	7,422222222	
61	2017	20		€10 Million	100	6,666666667	
62	2016		N/A	€12 Million	120	8	
63	2015	3	N.A	$200 Million, osäker på om det är investering eller typ allt under hela livscyk			
64	2017	20	20-year power purchase agreen	13 Million (https://ele	111,8	2,15	
65	2016	10		0			
66	2017	15		$50 Million ??	430	8,3984375	
67	2016		NA				
68	2015	12	75 % efficency	100 million euros (S/	330	4,125	All info here: http:
69	2015	12	75 % efficency	100 million euros (S/	330	4,125	All info here: http:
70	2009						
71	2012	20					
72	2015	12	75 % efficency	100 million euros (S/	330	4,583333333	All info here: http:
73	2015		N/A				
74	2015			€12.8 Million	128	12,8	

Number	Utility	Utility Type	Paired Grid Resource	Ownership Model	Equity Owner 1	Energy Storage Technol
1		Federally Owned		Utility-Owned	China National Energy Administr	UET / Rongke Power
2			Combikraftverk	Third-Party-Owned	AES Southland	AES Energy Storage
3			100 MW of Solar PV	Third-Party-Owned	Lyon Group	AES Energy Storage
4			100 MW Hornsdale Wind Farm	Utility-Owned	Neoen	Tesla
5	Kyushu Electric Powe	Investor Owned	Solar	Utility-Owned	Kyushu Electric Power Co.	NGK Insulators
6						
7				Customer-Owned	Eneco	NEC
8						
9	Korea Electric Power	Public Owned		Utility-Owned	Korea Electric Power Corporation (KEPCO)	
10	Tohoku Electric Powe	Federally Owned		Utility-Owned	Tohoku Electric Power Company	Toshiba Corporation
11						
12	Tohoku Electric Powe	Investor Owned		Utility-Owned	Tohoku Electric Power Company	Toshiba
13	Duke Energy	Investor Owned	Wind	Utility-Owned	Duke Energy	Xtreme Power
14	Korea Electric Power	Public Owned		Utility-Owned	Korea Electric Power Corporatio	Kokam
15	Southern California E	Investor Owned		Utility-Owned	Southern California Edison	
16	National Grid (UK)			Customer-Owned	Foresight Group	RES (UK)
17	Tohoku Electric Power Company		51 MW Wind Farm (1.5 MW x :	Third-Party-Owned	Futamata Wind Development Cc	NGK Insulators Ltd.
18	Korea Electric Power	Public Owned		Utility-Owned	Korea Electric Power Corporatio	Samsung SDI battery
19			Grid	Third-Party-Owned	AES Wind Generation	A123 Systems
20			100.5 MW wind farm	Third-Party-Owned	Beech Ridge Energy Storage, LL	BYD
21			210 MW wind farm; a 20 MW s	Third-Party-Owned	Invenergy LLC.	BYD Company
22	San Diego Gas and E	Investor Owned	Escondido Substation	Utility-Owned	San Diego Gas & Electric (SDG&	Samsung SDI
23	Imperial Irrigation Dis	Public Owned	El Centro Power Plant; Midway	Customer-Owned	Imperial Irrigation District	Samsung SDI
24	Pacific Gas and Elec	Investor Owned	NextEra Golden Hills wind farm	Utility-Owned	Pacific Gas and Electric (PG&E)	
25				Third-Party-Owned	ElectraNet	
26						
27	Korea Electric Power	Public Owned		Utility-Owned	Korea Electric Power Corporatio	Kokam (16 MW), LG Ch
28	Golden Valley Electri	Cooperative (Customer Owned)		Utility-Owned	Golden Valley Electric Associatic	Saft
29	MID	Federally Owned	Wind	DOE/other		Primus Power
30	National Grid (UK)			Customer-Owned	Enel S.p.A	Renewable Energy Syste
31	Korea Electric Power	Public Owned		Utility-Owned	Korea Electric Power Corporatio	Samsung SDI
32	Korea Electric Power	Public Owned		Utility-Owned	Korea Electric Power Corporatio	Kokam
33	Korea Electric Power	Public Owned		Utility-Owned	Korea Electric Power Corporatio	LG CNS
34	Korea Electric Power	Public Owned		Utility-Owned	Korea Electric Power Corporatio	LG
35	Korea Electric Power	Public Owned		Utility-Owned	Korea Electric Power Corporation (KEPCO)	
36	Korea Electric Power	Public Owned		Utility-Owned	Korea Electric Power Corporation (KEPCO)	
37	National Grid (UK)		228MW Pen y Cymoedd onshore wind		Vattenfall	

38	Southern California E	Investor Owned	San Gabriel Energy Facility	Third-Party-Owned	AltaGas	
39	Southern California E	Investor Owned	Mira Loma Substation	Utility-Owned	Southern California Edison	Tesla
40	Los Angeles Departm	Public Owned	600 MW of solar power and 13	Utility-Owned	Los Angeles Department of Wat	Doosan GridTech
41	ComEd	Investor Owned	Grid	Third-Party-Owned	SGEM	Leclanché SA
42	National Grid (UK)			Third-Party-Owned	PPA	
43	AES Gener	Investor Owned	544 MW Thermal Power Plant	Third-Party-Owned	AES Gener	A123
44	AES Gener	Investor Owned	532 MW Coal-Hybrid Power Pla	Third-Party-Owned	AES Gener	GS Yuasa & Lithium Ene
45	Dayton Power & Ligh	Investor Owned	Grid	Third-Party-Owned	AES ES Tait	Fluence
46			55 MW Solar Photovoltaic	Third-Party-Owned	Lyon Group	AES
47	Indianapolis Power &	Investor Owned	Harding Street Thermal Genera	Utility-Owned	Indianapolis Power & Light, an A	Samsung SDI
48			217.5 MW Lee DeKalb Wind E	Third-Party-Owned	NextEra Energy Resources, LLC	LG Chem
49	ComEd	Investor Owned	Grid	Third-Party-Owned	EDF Renewable Energy	BYD America
50	Commonwealth Edis	Investor Owned	Grid	Third-Party-Owned	Prudential Capital Group	BYD America
51	Commonwealth Edis	Investor Owned	Grid	Third-Party-Owned	Prudential Capital Group	BYD America
52				Third-Party-Owned	NextEra Energy Resources, LLC	
53				Customer-Owned	Nextera Energy	
54	Korea Electric Power	Public Owned		Utility-Owned	Korea Electric Power Corporation (KEPCO)	
55	STEAG GmbH		Installed 507 MW Lünen Coger	Utility-Owned	STEAG GmbH	LG Chem
56	STEAG GmbH		560 MW Duisburg-Walsum Co	Utility-Owned	STEAG GmbH	LG Chem
57	STEAG GmbH		780 MW Bexbach Coal Power	Utility-Owned	STEAG GmbH	LG Chem
58	STEAG GmbH		466 MW Volklingen-Fenne Co	Utility-Owned	STEAG GmbH	LG Chem
59	STEAG GmbH		724 MW Weiher Cogeneration	Utility-Owned	STEAG GmbH	LG Chem
60	STEAG GmbH		960 MW Herne Cogeneration C	Utility-Owned	STEAG GmbH	LG Chem
61	WEMAG AG	Investor Owned	110-kV substation in Schwerin-	Utility-Owned	WEMAG AG	Samsung SDI
62	Enercity (Stadtwerke	Investor Owned		Customer-Owned	Daimler AG	
63	Hokkaido Electric Po	Investor Owned		Utility-Owned	Hokkaido Electric Power	Sumitomo Electric Indus
64	Kauai Island Utility C	Cooperative (Customer Owned)		Third-Party-Owned	SolarCity	Tesla
65				Third-Party-Owned	Daimler AG, GETEC Energie, The Mobility House	
66	Toronto Hydro Corp.	Investor Owned		Third-Party-Owned	Hecate Canada Storage II, LLP	Leclanche SA
67				Customer-Owned	GS E&R	
68	Terna S.p.A.	Investor Owned		Utility-Owned	Terna S.p.A.	NGK Insulators Ltd.
69	Terna S.p.A.	Investor Owned		Utility-Owned	Terna S.p.A.	NGK Insulators Ltd.
70	Centro de Dispacho Economico de Car		Grid	Third-Party-Owned	AES Gener	A123 Systems
71			21 MW wind farm	Third-Party-Owned	Sempra	A123 (NEC Energy Solu
72	Terna S.p.A.	Investor Owned		Utility-Owned	Terna S.p.A.	NGK Insulators Ltd.
73				Third-Party-Owned	NextEra Energy Resources, LLC	
74	50 Hertz (Transmission System Operat		Wind	Third-Party-Owned	Venture Capital	LG Chem Ltd.

Number	Power Electronics	Latitude	Longitude	City	State/Province	Web Link 1
1		38,914003	129,614582	Dalian	Liaoning	http://www.uetechnologies.com/news/72-unienergy-t
2		33,77005	-118,1937395	Long Beach	California	http://cleantechnica.com/2016/02/25/india-plans-750
3		-30,56206	136,9008815	Roxby Downs	South Australia	http://dev.essentialdigital.com.au/solar-projects-ann
4		-33,20528	138,601944	Jamestown	South Australia	https://www.reuters.com/article/us-australia-power-t
5		33,611511	131,130051	Buzen	Fukuoka Prefectu	http://electronics360.globalspec.com/article/6402/mi
6				Lancaster		
7	NEC	54,8253	9,20	Jardelund	Schleswig-Holstei	http://www.nec.com/en/press/201704/global_20170
8						
9				Gyeongsan		https://www.iere.jp/events/forum/2017-canada/Prese
10		37,642161	140,9572757	Minamisoma	Fukushima Prefe	https://www.toshiba.co.jp/about/press/2015_05/pr29
11				Glassenbury		
12		38,268215	140,8693558	Sendai	Miyagi Prefecture	http://techon.nikkeibp.co.jp/english/NEWS_EN/2015
13	Younicos	31,981939	-102,6147715	Goldsmith	Texas	http://www.duke-energy.com/commercial-renewable
14				Non-Gong Substa	N/A	http://www.prnewswire.com/news-releases/kokam-t
15		33,717471	-117,8311428	Orange County	California	http://www.elp.com/articles/2016/09/convergent-ene
16		54,974762	-1,4537178	Port of Tyne	Tyne and Wear	http://www.foresightgroup.eu/news/foresight-comple
17		40,967344	141,3745522	Rokkasho	Aomori	http://www.cleanenergyactionproject.com/CleanEne
18						http://www.lsis.com/edm/2017/0424/ESS_E_Leaflet_
19	Parker SSD	39,002039	-79,887705	Elkins	West Virginia	http://aesenergystorage.com/deployments/
20		37,963173	-80,6895314	Rupert	West Virginia	http://www.utilitydive.com/news/invenergy-adds-315-
21		41,330867	-88,7081293	Marseilles	Illinois	http://www.invenergyllc.com/ProjectsbyCountry/Unit
22	Parker Hannifin	33,119207	-117,086421	Escondido	California	https://www.theguardian.com/sustainable-business/
23	GE Brilliance MW	32,792	-115,5630514	El Centro	California	http://www.iid.com/Home/Components/News/News/
24		37,681875	-121,7680088	Livermore	California	http://www.greentechmedia.com/articles/read/pges-
25		-35,01847	137,5981723	Yorketown	South Australia	
26						
27	LS IS (Kokam ES	37,096941	127,2218324	84 Jangseo-ri, Ya	Gyeonggi-do	http://www.koreaherald.com/view.php?ud=2015071
28	ABB	64,837778	-147,7163889	Fairbanks	Alaska	http://www.gvea.com/energy/bess
29				Modesto	California	https://www.smartgrid.gov/project/primus_power_co
30		55,017587	-1,4255818	Tynemouth	Tyne and Wear	https://www.enel.com/media/press/d/2017/05/enel-b
31	EN Tech, LG CN	37,243749	May 6, 1900	218-1 Jigok-dong	Yongin-si, Gyeon	http://portal.koreascience.kr/article/articleresultdetail
32	Woojin Industrial	35,759032	127,0021437	86 Yongbok-ri	Geumgu-myeon,	http://kokam.com/kokams-56-megawatt-energy-stor
33	LG CNS			Daeui-myoen	Uiryeong-gun, Gy	http://home.kepco.co.kr/kepco/main.do
34						https://www.iere.jp/events/forum/2017-canada/Prese
35						https://www.iere.jp/events/forum/2017-canada/Prese
36						https://www.iere.jp/events/forum/2017-canada/Prese
37		51,710135	-3,566221	Pen y Cmoedd	Wales	https://corporate.vattenfall.co.uk/contentassets/9d63

38		34,058936	-117,7754029	Pomona	California	http://www.greensmithenergy.com/greensmith-altag
39		34,007449	-117,5609574	Ontario	California	http://insideevs.com/tesla-lands-worlds-largest-batte
40		35,493727	-118,8596804	Kern County	California	http://www.ladwpnews.com/ladwp-steps-up-utility-sc
41		42,248633	-88,6084269	Marengo	Illinois	https://www.mjelectric.com/project/marengo-battery-
42		55,378051	-3,435973	Broxburn	Scotland	http://www.greentechmedia.com/articles/read/UK-De
43	ABB	-23,65	-70,4	Mejillones	Antofagasta	http://www.aesenergystorage.com/deployments/
44	Mistubishi Corpor	-23,08859	-70,411558	Mejillones	Antofagasta	http://www.gs-yuasa.com/en/newsrelease/article.ph
45		39,725618	-84,2113632	Moraine	Ohio	http://www.aesenergystorage.com/2013/09/30/aes-
46		-15,84155	144,8494034	Lakeland	Queensland	http://dev.essentialdigital.com.au/projects/cape-york
47	Parker Hannifin	39,711314	-86,1903191	Indianapolis	Indiana	https://www.pjm.com/-/media/committees-groups/ta
48		41,929474	-88,7503647	DeKalb	Illinois	http://www.nexteraenergy.com/energynow/2015/051
49		42,303999	-88,4016041	McHenry County	Illinois	https://www.edf-re.com/edf-renewable-energy-anno
50		41,487738	-88,0997601	Joliet	Illinois	http://www.prnewswire.com/news-releases/res-anno
51		41,897852	-88,2230626	West Chicago	Illinois	http://www.res-group.com/en/portfolio/?ProjectID=2
52		40,022493	-78,9288242	Somerset County	Pennsylvania	http://www.nexteraenergy.com/energynow/2016/021
53		43,800621	-70,1867227	yarmouth	Maine	http://www.transmissionhub.com/articles/2016/09/ne
54					Shinchungju	http://www.lsis.com/edm/2017/0424/ESS_E_Leaflet_
55	Nidec ASI	51,610483	7,5285074	Lünen	North Rhine-Wes	http://www.pv-magazine.com/news/details/beitrag/ge
56	Nidec ASI	51,527869	6,7238275	Walsum	North Rhine-Wes	http://www.energymatters.com.au/renewable-news/
57	Nidec ASI	49,356023	7,2553745	Bexbach	Saarland	http://www.energymatters.com.au/renewable-news/
58	Nidec ASI	49,248978	6,8793865	Volklingen-Fenne	Saarland	http://www.energymatters.com.au/renewable-news/
59	Nidec ASI	49,296452	7,3470213	Weiher	Saarland	http://www.energymatters.com.au/renewable-news/
60	Nidec ASI	51,536895	7,2009147	Herne	North Rhine-Wes	http://www.energymatters.com.au/renewable-news/
61		53,635359	11,401654	Schwerin	Mecklenburg We	https://www.younicos.com/case-studies/schwerin/
62		52,408942	9,6693916	Herrenhausen	Hanover	http://media.daimler.com/dcmedia/0-921-657589-1-
63	Sumitomo Electri	43,064615	141,3468074	Abira-Chou	Hokkaido	http://renewables.seenews.com/news/japan-s-hepc
64		21,966108	-159,5737912	Kaua'i	Hawaii	http://www.solarcity.com/newsroom/press/kaua%CA
		51,61662	7,46635	Lünen	North Rhine-Wes	http://mobilityhouse.com/en/huge-media-response-t
66		43,653226	-79,3831843	Toronto	Ontario	http://www.hecateenergy.com/projects/ieso-storage
67				Yeongyang	North Gyeongsan	http://www.koreaherald.com/view.php?ud=20151124
68	Nidec	41,076049	15,1519998	Flumeri	Campania	https://www.terna.it/en-gb/sistemaelettrico/progettipi
69	Nidec	41,299399	15,0852503	Miscano	Campania	https://www.terna.it/en-gb/sistemaelettrico/progettipi
70	Parker SSD	-27,36636	-70,332237	Copiapo	Atacama	http://www.aesenergystorage.com/deployments/
71	Dynapower	20,79097	-156,3269338	Kula	Hawaii	http://www.a123systems.com/smart-grid-storage.htn
72	Nidec	41,091134	15,2998521	Scampitella	Campania	https://www.terna.it/en-gb/sistemaelettrico/progettipi
73		40,022493	-78,9288242	Somerset County	Pennsylvania	http://www.nexteraenergyresources.com/what/energ
74	Enercon	52,011579	12,819405	Feldheim	Brandenburg	http://cleantechnica.com/2015/09/21/new-10-mw-st

B Calculations

C Annual Financial Report SvkGT 2017

ÅRSREDOVISNING

2017-01-01--2017-12-31

för

Svenska Kraftnät Gasturbiner AB

556451-0260

Årsredovisningen omfattar: **Sida**

ÅRSREDOVISNING
FÖR SVENSKA KRAFTNÄT GASTURBINER AB

Styrelsen och verkställande direktören för Svenska Kraftnät Gasturbiner AB avger härmed årsredovisning för räkenskapsåret 2017-01-01--2017-12-31.

FÖRVALTNINGSBERÄTTELSE

Verksamhetens art och inriktning

Svenska Kraftnät Gasturbiner AB har till uppgift att äga, driva och underhålla gasturbinanläggningar. Bolaget äger sammanlagt 11 gasturbiner som finns i Varbergs kommun (Lahall), Norrköpings kommun (Kimstad), Trollhättans kommun (Stallbacka), Norrtälje kommun (Hallstavik) samt Göteborgs kommun (Arendal). Gasturbinerna har en sammanlagd kapacitet om 690 MW. Samtliga 11 gasturbiner ingick under år 2017 i Svenska kraftnäts snabba aktiva reserv för att klara fel i kraftsystemet (störningsreserven) samt för elberedskapsändamål.

Drift och underhåll av gasturbinanläggningarna sköts av Vattenfall Services Nordic AB enligt det entreprenörsavtal som tecknades 2004-11-22. Detta avtal har förlängts 2008, 2011, 2013, 2016 och 2017 till att gälla till och med december 2018.

Ägarförhållanden

Samtliga aktier i Svenska Kraftnät Gasturbiner AB ägs av Staten och förvaltas av Affärsverket Svenska kraftnät med org.nr 202100-4284.

Väsentliga händelser under räkenskapsåret

Bolagets gasturbinanläggningar är omkring 40 år gamla och närmar sig i nuvarande status slutet på sin tekniska livslängd. 2015 påbörjades därför ett omfattande reinvesteringsprogram som beräknas pågå fram till och med 2022. Reinvesteringsprogrammet syftar till att förlänga anläggningarnas tekniska livslängd.

Under året har bolaget investerat i ytterligare nyrenoverade AVON-motorer, renoverade kraftturbiner och generatorer, nya skorstenar, nytt skalskydd, förbättrat miljöskydd, uppgraderat kontrollsystem och nytt bränslereglersystem.

Utveckling av verksamhet, ställning och resultat

Bolagets omsättning härrör i huvudsak från försäljning av system- och elberedskapstjänster till Svenska kraftnät.

(Tkr)	**2017**	**2016**	**2015**	**2014**	**2013**
Nettoomsättning	114 231	101 193	90 382	81 634	82 550
Rörelseresultat	27 309	16 511	19 029	12 943	19 707
Resultat e. finansiella poster	26 356	15 768	18 462	11 730	17 786
Investeringar	104 096	85 558	45 058	22 515	2 108
Balansomslutning	432 803	438 418	304 565	303 649	280 849
Soliditet (1)	50,9%	46,0%	61,5%	56,9%	58,3%
Avkastning på eget kapital (2)	12,0%	7,9%	9,8%	6,8%	10,8%
Starttillgänglighet	80%	71%	85%	93%	68%

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(1) Justerat eget kapital / Balansomslutning. Med justerat eget kapital avses eget kapital + obeskattade reserver med avdrag för uppskjuten skatteskuld.

(2) Resultat efter finansiella poster / justerat eget kapital.

Andra viktiga förhållanden

Återanskaffningsvärdet av oljelagret beräknas till 127,8 miljoner kronor som är bokfört till 83,1 miljoner kronor, vilket innebär ett övervärde uppgående till 44,7 miljoner kronor.
I slutet av 2017 införlivades bolaget i Svenska kraftnäts koncernkonto och avtal avseende kreditutrymme tecknades. Det får till följd att saldon på bolagets transaktionskonton ej längre redovisas såsom likvida medel utan fordran/skuld till koncernföretag. För 2017 uppgick den avtalade krediten i koncernkontot till 135 miljoner kronor.

Väsentliga risker och osäkerhetsfaktorer

Bristerna som uppdagats i statusinventeringen visar på osäkerhet kring anläggningarnas förmåga att nå efterfrågad drift- och starttillgänglighet. Risken möts i investeringsprogrammet.

Förväntad framtida utveckling

För att förbättra anläggningarnas förmåga till efterfrågad drift- och starttillgänglighet har ett reinvesteringsprogram påbörjats vilket leder till en period av ökade investeringar som förväntas pågå till 2022.

Forskning och utveckling

Forskning- och utvecklingsinsatser fokuserar bl.a. på förutsättningar för användande av biobränsle i gasturbiner.

Personal

Bolaget har inga anställda utan verksamheten bedrivs med upphandlade tjänster. Bolagets verkställande direktör, Peter Blomqvist är inhyrd konsult och hans tjänster faktureras bolaget. Konsultuppdraget löper till den 31 januari 2019. Bolaget har förstärkt organisationen med inhyrd personal i rollerna teknisk chef, HMS-chef, ekonomiansvarig samt projektchef. Inga arvoden har utgått till styrelsens ledamöter.

Miljö

	2017	**2016**	**2015**	**2014**	**2013**
Svavel (kg)	1 070	1 316	1 386	1 443	1 803
Kväveoxider (kg)	8 608	9 792	11 102	6 942	10 626
Koldioxid (ton)	3 276	3 318	3 860	3 042	4 236

Bolagets gasturbinverksamhet är miljöcertifierad enligt ISO 14001:2015.
Under 2017 har bolaget köpt 4 000 (2 000) utsläppsrätter, vilket innebär en rättighet att släppa ut 4 000 (2 000) ton koldioxid. Elförbrukningen i samtliga anläggningar uppgick till 3 788 (4 920) MWh. Under året uppgick förbrukningen av bränsle till 1 257 (1 263) Nm3.

Tillstånds- eller anmälningspliktig verksamhet enligt miljöbalken

Samtliga anläggningar i bolaget är tillståndspliktiga enligt miljöbalken. Bolaget ingår också i EU:s system för handel med utsläppsrätter.

Resultatdisposition (tkr)

Förslag till dispositioner beträffande vinst

Till årsstämmans förfogande står följande vinstmedel	
Balanserat resultat	63 375
Årets resultat	8 211
	71 586
Styrelsen föreslår att	
i ny räkning balanseras	71 586
	71 586

Med anledning av kommande års höga investeringsvolym föreslår styrelsen att årets resultat balanseras i ny räkning och att ingen utdelning sker.

Beträffande företagets resultat och ställning i övrigt hänvisas till efterföljande resultat-och balansräkning, rapport över förändringar i eget kapital, kassaflödesanalys samt noter. Alla belopp uttrycks i svenska kronor där ej annat anges.

RESULTATRÄKNING

(kr)	Not	2017-01-01 2017-12-31	2016-01-01 2016-12-31
Rörelsens intäkter			
Nettoomsättning	4,5	114 231 300	101 192 702
		114 231 300	**101 192 702**
Rörelsens kostnader			
Underhålls och driftskostnader		-37 474 919	-36 324 402
Övriga externa kostnader	6	-21 936 530	-22 218 151
Avskrivningar och nedskrivningar av materiella och immateriella anläggningstillgångar		-27 374 777	-23 976 130
Övriga rörelsekostnader	7	-135 782	-2 162 864
Rörelseresultat		**27 309 292**	**16 511 155**
Resultat från finansiella poster			
Övriga ränteintäkter och liknande intäkter	8	118 553	6 127
Räntekostnader och liknande kostnader	9	-1 072 238	-749 430
Resultat efter finansiella poster		**26 355 607**	**15 767 852**
Bokslutsdispositioner			
Förändring av periodiseringsfond		-3 531 830	-2 568 168
Förändring överavskrivningar		-12 281 623	-5 529 000
		-15 813 453	-8 097 168
Resultat före skatt		**10 542 154**	**7 670 684**
Skatt på årets resultat	10	-2 331 008	-1 694 990
ÅRETS RESULTAT		**8 211 146**	**5 975 694**

BALANSRÄKNING (kr)	**Not**	**2017-12-31**	**2016-12-31**
TILLGÅNGAR			
Immateriella anläggningstillgångar			
Utsläppsrätter	11	104 816	32 738
		104 816	**32 738**
Materiella anläggningstillgångar			
Byggnader och mark	12	46 591 675	22 750 075
Maskiner och andra tekniska anläggningar	13	254 237 139	220 438 901
Pågående nyanläggningar och förskott avseende materiella anläggningstillgångar	14	40 978 446	21 962 974
		341 807 260	**265 151 950**
Summa anläggningstillgångar		**341 912 076**	**265 184 688**
Omsättningstillgångar			
Varulager m m			
Råvaror och förnödenheter		83 073 558	83 746 349
		83 073 558	**83 746 349**
Kortfristiga fordringar			
Kundfordringar		0	636 900
Aktuella skattefordringar		17 393	653 411
Övriga fordringar		7 211 677	5 480 093
Förutbetalda kostnader och upplupna intäkter	15	588 051	146 500
		7 817 121	**6 916 904**
Kassa och bank	20	**0**	**82 570 470**
Summa omsättningstillgångar		**90 890 679**	**173 233 723**
SUMMA TILLGÅNGAR		432 802 755	438 418 411

Svenska Kraftnät Gasturbiner AB

556451-0260

BALANSRÄKNING

(kr)	Not	2017-12-31	2016-12-31
EGET KAPITAL OCH SKULDER			
Eget kapital			
Bundet eget kapital			
Aktiekapital		9 000 000	9 000 000
Reservfond		10 376	10 376
		9 010 376	**9 010 376**
Fritt eget kapital			
Balanserad vinst eller förlust		63 374 908	57 399 214
Årets resultat		8 211 146	5 975 694
		71 586 054	**63 374 908**
Summa eget kapital		**80 596 430**	**72 385 284**
Obeskattade reserver	16	**178 829 595**	**163 016 142**
Långfristiga skulder	17		
Skulder till koncernföretag		132 866 668	154 633 334
		132 866 668	**154 633 334**
Kortfristiga skulder			
Leverantörsskulder		16 135 083	23 236 067
Skulder till koncernföretag	18	23 094 523	22 977 084
Övriga kortfristiga skulder		511 241	0
Upplupna kostnader och förutbetalda intäkter	19	769 215	2 170 500
		40 510 062	**48 383 651**
SUMMA EGET KAPITAL OCH SKULDER		**432 802 755**	**438 418 411**

RAPPORT ÖVER FÖRÄNDRINGAR I EGET KAPITAL

(Tkr)

	Bundet eget kapital		*Fritt eget kapital*		
	Aktie- kapital	Reserv- fond	Balanserad vinst eller förlust	Årets resultat	**Summa eget kapital**
Ingående balans per 1 januari 2016	**9 000**	**10**	**50 578**	**6 821**	**66 409**
Disposition av föregående års resultat			6 821	-6 821	0
Årets resultat				5 976	5 976
Utgående balans per 31 december 2016	**9 000**	**10**	**57 399**	**5 976**	**72 385**

Aktiekapital 900 aktier á kvotvärde 10.000 kr

	Bundet eget kapital		*Fritt eget kapital*		
	Aktie- kapital	Reserv- fond	Balanserad vinst eller förlust	Årets resultat	**Summa eget kapital**
Ingående balans per 1 januari 2017	**9 000**	**10**	**57 399**	**5 976**	**72 385**
Disposition av föregående års resultat			5 976	-5 976	0
Årets resultat				8 211	8 211
Utgående balans per 31 december 2017	**9 000**	**10**	**63 375**	**8 211**	**80 596**

Aktiekapital 900 aktier á kvotvärde 10.000 kr

KASSAFLÖDESANALYS

(Tkr)	Not	2017-01-01 2017-12-31	2016-01-01 2016-12-31
Den löpande verksamheten			
Rörelseresultat		27 309	16 511
Justeringar för poster som inte ingår i kassaflödet:			
Avskrivningar		27 375	23 976
Realisationsvinst		0	2 073
Erhållen ränta		119	6
Erlagd ränta		-1 072	-749
Betald inkomstskatt		-1 695	-1 695
Kassaflöde från den löpande verksamheten före förändringar av rörelsekapital		**52 036**	**40 122**
Kassaflöde från förändringar i rörelsekapital			
Minskning(+)/ökning(-) av varulager		672	-324
Minskning(+)/ökning(-) av övriga kortfristiga fordringar		-1 537	1 548
Minskning(-)/ökning(+) av övriga kortfristiga skulder		-7 877	16 480
Kassaflöde från den löpande verksamheten		**43 294**	**57 826**
Investeringsverksamheten			
Försäljning/förvärv av immateriella anläggningstillgångar		-72	117
Förvärv av materiella anläggningstillgångar		-104 096	-85 558
Kassaflöde från investeringsverksamheten		**-104 168**	**-85 441**
Finansieringsverksamheten			
Upptagna lån		106 304	125 067
Amortering av lån		-128 000	-21 767
Kassaflöde från finansieringsverksamheten		**-21 696**	**103 300**
Årets kassaflöde		**-82 570**	**75 685**
Likvida medel vid årets början		**82 570**	**6 885**
Likvida medel vid årets slut	20	**0**	**82 570**

NOTER

Not 1 Allmän information

Svenska Kraftnät Gasturbiner AB med organisationsnummer 556451-0260 är ett aktiebolag registrerat i Sverige med säte i Stockholms län. Adressen till huvudkontoret är Sturegatan 1, Sundbyberg. Företagets verksamhet omfattar att äga, driva och underhålla gasturbinanläggningar.

Moderföretag i koncernen som Svenska Gasturbiner AB är dotterföretag till, är Affärsverket Svenska kraftnät (Svenska kraftnät), org.nr. 222100-4284, med säte i Stockholms län.

Not 2 Redovisningsprinciper och värderingsprinciper

Företaget tillämpar Årsredovisningslagen (1995:1554) och Bokföringsnämndens allmänna råd BFNAR 2012:1 *Årsredovisning och koncernredovisning* ("K3").

Intäkter

Intäkter redovisas till det verkliga värdet av den ersättning som erhållits eller kommer att erhållas, med avdrag för mervärdeskatt, rabatter, returer och liknande avdrag.

Svenska Kraftnät Gasturbiner ABs intäkter består i huvudsak av försäljning av reservkraft till moderbolaget Svenska kraftnät.

Ersättning för störningsreserven utgår i en fast och en rörlig del. Den fasta delen faktureras månadsvis i förskott och redovisas som intäkt i den period leverans sker. Den rörliga delen faktureras i efterskott.

Utländsk valuta

Företagets redovisningsvaluta är svenska kronor (SEK).

Omräkning av poster i utländsk valuta

Vid varje balansdag räknas monetära poster i utländsk valuta om till balansdagens kurs. Icke-monetära poster, som värderas till historiskt anskaffningsvärde i en utländsk valuta, räknas inte om. Valutakursdifferenser redovisas i rörelseresultatet eller som finansiell post utifrån den underliggande affärshändelsen, i den period de uppstår, med undantag för transaktioner som utgör säkring och som uppfyller villkoren för säkringsredovisning av kassaflöden eller av nettoinvesteringar.

Låneutgifter

Låneutgifter redovisas i resultaträkningen i den period de uppkommer.

Inkomstskatter

Skattekostnaden utgörs av summan av aktuell skatt och uppskjuten skatt.

Aktuell skatt

Aktuell skatt beräknas på det skattepliktiga resultatet för perioden. Skattepliktigt resultat skiljer sig från det redovisade resultatet i resultaträkningen då det har justerats för ej skattepliktiga intäkter och ej avdragsgilla kostnader samt för intäkter och kostnader som är skattepliktiga eller avdragsgilla i andra perioder. Aktuell skatteskuld beräknas enligt de skattesatser som gäller per balansdagen.

Uppskjuten skatt

Uppskjuten skatt redovisas på temporära skillnader mellan det redovisade värdet på tillgångar och skulder i de finansiella rapporterna och det skattemässiga värdet som används vid beräkning av skattepliktigt resultat.

Svenska Kraftnät Gasturbiner AB har inga temporära skillnader därav redovisas ingen uppskjuten skatt.

Aktuell och uppskjuten skatt för perioden

Aktuell och uppskjuten skatt redovisas som en kostnad eller intäkt i resultaträkningen, utom när skatten är hänförlig till transaktioner som redovisats direkt mot eget kapital. I sådana fall ska även skatten redovisas direkt mot eget kapital.

Immateriella tillgångar

Utsläppsrätter

Immateriella tillgångar består av innehavda utsläppsrätter och redovisas till anskaffningsvärde. I samband med att koldioxidutsläpp sker, uppstår ett åtagande att leverera in utsläppsrätter, vilket reducerar innehavda utsläppsrätter. Kostnaden redovisas bland produktionskostnader. Om innehavda utsläppsrätter inte täcker åtagandet redovisas nettoåtagandet som avsättning och värderas till marknadsvärde.

Borttagande från balansräkningen
En immateriell anläggningstillgång tas bort från balansräkningen vid utrangering eller avyttring eller när inte några framtida ekonomiska fördelar väntas från användning eller utrangering/avyttring av tillgången. Den vinst eller förlust som uppkommer när en immateriell anläggningstillgång tas bort från balansräkningen är skillnaden mellan vad som eventuellt erhålls, efter avdrag för direkta försäljningskostnader, och tillgångens redovisade värde. Detta redovisas i resultaträkningen som en övrig rörelseintäkt eller övrig rörelsekostnad.

Materiella anläggningstillgångar
Materiella anläggningstillgångar redovisas till anskaffningsvärde efter avdrag för ackumulerade avskrivningar och eventuella nedskrivningar.
Anskaffningsvärdet består av inköpspriset, utgifter som är direkt hänförliga till förvärvet för att bringa den på plats och i skick att användas.
Tillkommande utgifter inkluderas endast i tillgångens redovisade värde (eller redovisas som en separat tillgång) när det är sannolikt att framtida ekonomiska fördelar som är förknippade med posten kommer att tillfalla koncernen, och att anskaffningsvärdet för densamma kan mätas på ett tillförlitligt sätt.

Alla övriga kostnader för reparationer och underhåll samt tillkommande utgifter redovisas i resultaträkningen i den period då de uppkommer.

Då skillnaden i förbrukningen av en materiell anläggningstillgångs betydande komponenter bedöms vara väsentlig, delas tillgången upp på dessa komponenter.

Avskrivningar på materiella anläggningstillgångar kostnadsförs så att tillgångens anskaffningsvärde, eventuellt minskat med beräknat restvärde vid nyttjandeperiodens slut, skrivs av linjärt över dess bedömda nyttjandeperiod. Om en tillgång har delats upp på olika komponenter skrivs respektive komponent av separat över dess nyttjandeperiod. Avskrivning påbörjas är den materiella anläggningstillgången kan tas i bruk. Materiella anläggningstillgångars nyttjandeperioder uppskattas till:

Byggnader:	
Stomme	30 år
Tak	30 år
Brunnar, förråd, brygga	20 år
Markanläggningar	
Stämpelavgift	20 år
Inskrivningsbevis	30 år
Vattenanläggningar	10 år
Maskiner och andra tekniska anläggningar:	
Cisterner	20 år
Cisterninvallning	30 år
Elkraftsutrustning	10-20 år
Gasturbiner Industri	20 år
Gasturbiner Jet	15 - 20 år
Generatorer	15 - 20 år
Kontrollsystem (kontrollutrustning, datorer, elektronik)	5 - 15 år
Övrig kringutrustning (torkar, traverser, övrigt)	15 - 30 år

Nyttjandeperioden för mark är obegränsad och därför skrivs mark inte av.

Bedömda nyttjandeperioder och avskrivningsmetoder omprövas om det finns indikationer på att förväntad förbrukning har förändrats väsentligt jämfört med uppskattningen vid föregående balansdag. Då företaget ändrar bedömning av nyttjandeperioder, omprövas även tillgångens eventuella restvärde. Effekten av dessa ändringar redovisas framåtriktat.

Borttagande från balansräkningen
Det redovisade värdet för en materiell anläggningstillgång tas bort från balansräkningen vid utrangering eller avyttring, eller när inte några framtida ekonomiska fördelar väntas från användning eller utrangering/avyttring av tillgången eller komponenten. När tillkommande utgifter räknas in i anskaffningsvärdet (se ovan) tas det redovisade värdet på de delar som byts ut bort från balansräkningen.

Den vinst eller förlust som uppkommer när en materiell anläggningstillgång eller en komponent tas bort från balansräkningen är skillnaden mellan vad som eventuellt erhålls, efter avdrag för direkta försäljningskostnader, och tillgångens redovisade värde. Den realisationsvinst eller realisationsförlust som uppkommer när en materiell anläggningstillgång eller en komponent tas bort från balansräkningen redovisas i resultaträkningen som en övrig rörelseintäkt eller övrig rörelsekostnad.

Nedskrivningar av materiella anläggningstillgångar och immateriella tillgångar
Vid varje balansdag analyserar företaget de redovisade värdena för materiella anläggningstillgångar och immateriella tillgångar för att fastställa om det finns någon indikation på att dessa tillgångar har minskat i värde. Om så är fallet, beräknas tillgångens återvinningsvärde för att kunna fastställa värdet av en eventuell nedskrivning. Där det inte är möjligt att beräkna återvinningsvärdet för en enskild tillgång, beräknas återvinningsvärdet för den kassagenererande enhet till vilken tillgången hör.

Vid varje balansdag gör företaget en bedömning om den tidigare nedskrivningen inte längre är motiverad. Om så är fallet återförs nedskrivningen delvis eller helt. Då en nedskrivning återförs, ökar tillgångens (den kassagenererande enhetens) redovisade värde. Det redovisade värdet efter återföring av nedskrivning får inte överskrida det redovisade värde som skulle fastställts om ingen nedskrivning gjorts av tillgången (den kassagenererande enheten) under tidigare år. En återföring av en nedskrivning redovisas direkt i resultaträkningen.

Finansiella instrument
En finansiell tillgång eller finansiell skuld redovisas i balansräkningen när företaget blir part till instrumentets avtalsenliga villkor. En finansiell tillgång bokas bort från balansräkningen när den avtalsenliga rätten till kassaflödet från tillgången upphör, regleras eller när företaget förlorar kontrollen över den. En finansiell skuld, eller del av finansiell skuld, bokas bort från balansräkningen när den avtalade förpliktelsen fullgörs eller på annat sätt upphör.

Vid det första redovisningstillfället värderas omsättningstillgångar och kortfristiga skulder till anskaffningsvärde. Långfristiga fordringar samt långfristiga skulder värderas vid det första redovisningstillfället till upplupet anskaffningsvärde. Låneutgifter periodiseras som en del i lånets räntekostnad enligt effektivräntemetoden (se nedan).

Varulager
Varulager värderas till det lägsta av anskaffningsvärdet och nettoförsäljningsvärdet på balansdagen. Anskaffningsvärdet beräknas genom tillämpning av först- in-först-ut-metoden (FIFU). Nettoförsäljningsvärde är försäljningsvärdet efter avdrag för beräknade kostnader som direkt kan hänföras till försäljningstransaktionen.

Likvida medel
Likvida medel inkluderar kassamedel och disponibla tillgodohavanden hos banker och andra kreditinstitut samt andra kortfristiga likvida placeringar som lätt kan omvandlas till kontanter och är föremål för en obetydlig risk för värdefluktuationer. För att klassificeras som likvida medel får löptiden inte överskrida tre månader från tidpunkten för förvärvet.
I slutet av 2017 införlivades bolaget i Svenska kraftnäts koncernkonto och avtal avseende kreditutrymme tecknades. Det får till följd att saldon på bolagets transaktionskonton ej längre redovisas såsom likvida medel utan fordran/skuld till koncernföretag.

Avsättningar
Avsättningar redovisas när företaget har en befintlig förpliktelse (legal eller informell) som en följd av en inträffad händelse, det är sannolikt att ett utflöde av resurser kommer att krävas för att reglera förpliktelsen och en tillförlitlig uppskattning av beloppet kan göras.

En avsättning omprövas varje balansdag och justeras så att den återspeglar den bästa uppskattningen av det belopp som krävs för att reglera den befintliga förpliktelsen på balansdagen, med hänsyn tagen till risker och osäkerheter förknippade med förpliktelsen. Avsättningen redovisas till nuvärdet av de framtida betalningar som krävs för att reglera förpliktelsen.

Där en del av eller hela det belopp som krävs för att reglera en avsättning förväntas bli ersatt av en tredje part, ska gottgörelsen särredovisas som en tillgång i balansräkningen när det är så gott som säkert att den kommer att erhållas om företaget reglerar förpliktelsen och beloppet kan beräknas tillförlitligt.

Kassaflödesanalys
Kassaflödesanalysen visar företagets förändringar av företagets likvida medel under räkenskapsåret. Kassaflödesanalysen har upprättats enligt den indirekta metoden. Det redovisade kassaflödet omfattar endast transaktioner som medfört in- och utbetalningar.

Not 3 Viktiga uppskattningar och bedömningar

För att kunna upprätta årsredovisning enligt K3 måste företagsledningen göra bedömningar och antaganden som påverkar redovisade tillgångar, skulder, intäkter och kostnader. Dessa bedömningar baseras på såväl historiska erfarenheter som andra faktorer som bedömts som rimliga under rådande omständigheter. Faktiskt utfall kan skilja sig från dessa bedömningar om andra antaganden görs eller andra förutsättningar föreligger. Bedömningar och antaganden ses över regelbundet. Ändringar av bedömningar redovisas i den period ändringen görs om ändringen endast påverkar denna period, eller den period ändringen görs och framtida perioder om ändringen påverkar både aktuell period och framtida perioder. För väsentliga uppskattningar och bedömningar hänvisas till relevanta noter.

Not 4 Nettoomsättningens fördelning kr

Nettoomsättning per geografisk marknad	2017	2016
Sverige	114 231 300	101 192 702
Summa	**114 231 300**	**101 192 702**

Not 5 Uppgift om inköp och försäljning inom samma koncern

	2017	2016
Inköp	12,0%	12,0%
Försäljning	99,0%	94,0%

Not 6 Upplysning om ersättning till revisorn kr

	2017	2016
Deloitte AB		
revisionsuppdrag	110 000	91 550
Summa	**110 000**	**91 550**

Med revisionsuppdrag avses revisorns ersättning för den lagstadgade revisionen. Arbetet innefattar granskningen av årsredovisningen och bokföringen, styrelsens och verkställande direktörens förvaltning samt arvode för revisionsrådgivning som lämnats i samband med revisionsuppdraget.

Not 7 Övriga rörelsekostnader kr

	2017	2016
Kursdifferenser	-94 321	-70 403
Utrangering av maskiner & inventarier	0	-2 072 806
Utbildning samt konferenser styrelse och ledningsgrupp	-41 461	-19 655
Summa	**-135 782**	**-2 162 864**

Not 8 Övriga ränteintäkter och liknande intäkter kr

	2017	2016
Ränteintäkter	896	23 868
Värdeförändring utsläppsrätter	117 657	-17 741
Summa	**118 553**	**6 127**

Not 9 Räntekostnader och liknande kostnader kr

	2017	2016
Räntekostnader	-2 711	-3 507
Räntekostnader, koncernföretag	-1 069 527	-745 923
Summa	**-1 072 238**	**-749 430**

Not 10 Skatt på årets resultat kr

	2017	2016
Aktuell skatt	-2 331 008	-1 694 990
Skatt på årets resultat	**-2 331 008**	**-1 694 990**

Avstämning årets skattekostnad

	2017	2016
Redovisat resultat före skatt	10 542 154	7 670 684
Skatt beräknad med skattesats 22 %	-2 319 274	-1 687 550
Skatteeffekt av ej avdragsgilla kostnader	-176	0
Skatteeffekt av ej skattepliktiga intäkter	197	5 251
skatteeffekt av schablonränta periodiseringsfond	-11 755	-12 691
Summa	**-2 331 008**	**-1 694 990**
Årets redovisade skattekostnad	**-2 331 008**	**-1 694 990**

Not 11 Utsläppsrätter kr

	2017-12-31	2016-12-31
Ingående anskaffningsvärden	32 738	149 976
Inköp	199 953	99 247
Försäljningar/utrangeringar	-243 273	-216 485
Utgående ackumulerade anskaffningsvärden	**-10 582**	**32 738**
Årets uppskrivningar	115 398	0
Utgående ackumulerade uppskrivningar	**115 398**	**0**
Utgående redovisat värde	**104 816**	**32 738**

Bolaget innehar utsläppsrätter för koldioxid, vilka hanteras som en tillgång, då rättigheterna överstiger åtagandet och vice versa. När koldioxidutsläpp sker uppstår ett åtagande, vilket reducerar innehavda utsläppsrätter. Om innehavda utsläppsrätter inte täcker åtagandet redovisas nettoåtagandet som en avsättning.

Antalet utsläppsrätter vid årets utgång var 4 687 (4 005) stycken.

Not 12 Byggnader och mark kr

	2017-12-31	2016-12-31
Ingående anskaffningsvärden	30 676 617	19 528 921
Inköp	24 873 120	11 147 696
Försäljningar/utrangeringar	-66 125	0
Utgående ackumulerade anskaffningsvärden	**55 483 612**	**30 676 617**
Ingående avskrivningar	-7 926 542	-7 319 283
Årets avskrivningar	-965 395	-607 259
Utgående ackumulerade avskrivningar	**-8 891 937**	**-7 926 542**
Utgående redovisat värde	**46 591 675**	**22 750 075**
Varav anskaffningsvärde för mark	**7 350 000**	**7 350 000**

Not 13 Maskiner och andra tekniska anläggningar kr

	2017-12-31	2016-12-31
Ingående anskaffningsvärden	439 428 575	390 687 019
Inköp	60 207 621	53 316 244
Försäljningar/utrangeringar	0	-4 574 688
Utgående ackumulerade anskaffningsvärden	**499 636 196**	**439 428 575**
Ingående avskrivningar	-218 989 674	-198 122 686
Försäljningar/utrangeringar	0	2 501 882
Årets avskrivningar	-26 409 383	-23 368 870
Utgående ackumulerade avskrivningar	**-245 399 057**	**-218 989 674**
Utgående redovisat värde	**254 237 139**	**220 438 901**

Not 14 Pågående nyanläggningar och förskott avseende materiella anläggningstillgångar kr

	2017-12-31	2016-12-31
Ingående anskaffningsvärden	21 962 974	868 825
Investeringar	19 015 472	21 962 975
Överfört från påg arbeten	0	-868 826
Utgående redovisat värde	**40 978 446**	**21 962 974**

Not 15 Förutbetalda kostnader och upplupna intäkter kr

	2017-12-31	2016-12-31
Upplupna intäkter	0	146 500
Förutbetalda kostnader	588 051	0
Summa	**588 051**	**146 500**

Not 16 Obeskattade reserver

	2017-12-31	2016-12-31
Periodiseringsfond besk år 2013	5 135 821	5 135 821
Periodiseringsfond besk år 2014	4 217 153	4 217 153
Periodiseringsfond besk år 2015	2 921 021	2 921 021
Periodiseringsfond besk år 2016	2 568 168	2 568 168
Periodiseringsfond besk år 2017	3 531 830	0
Ackumulerade överavskrivningar	160 455 602	148 173 979
Summa	**178 829 595**	**163 016 142**

Not 17 Långfristiga skulder

	2017-12-31	2016-12-31
Skulder till moderföretag som förfaller inom 5 år	70 533 346	87 066 664
Skulder till moderföretag som förfaller senare än 5 år efter balansdagen	62 333 322	67 566 670
Summa	**132 866 668**	**154 633 334**

Not 18 Skulder till koncernföretag

Kortfristig skuld på de två lånen till moderföretaget vid årets utgång uppgår till 45 333 332 kr (21 766 666). Beloppet har reducerats med tillgodohavandet i Svenska kraftnäts koncernkonto som vid årets utgång uppgår till 21 696 200 kr.

Not 19 Upplupna kostnader och förutbetalda intäkter kr

	2017-12-31	2016-12-31
Upplupna drifts och underhållskostnader kostnader	709 194	1 796 500
Övriga poster	60 021	374 000
Summa	**769 215**	**2 170 500**

Not 20 Likvida medel i kassaflödet tkr

	2017-12-31	2016-12-31
Disponibla tillgodohavanden hos banker och andra kreditinstitut	0	82 570
Medel på koncernkonto	21 696	0
Summa	**21 696**	**82 570**

I slutet av 2017 införlivades bolaget i Svenska kraftnäts koncernkonto och avtal avseende kreditutrymme tecknades. Det får till följd att saldon på bolagets transaktionskonton ej längre redovisas såsom likvida medel utan mot fordran/skuld koncernföretag. För 2017 uppgick den avtalade krediten i koncernkontot till 135 mnkr.

Not 21 Ställda säkerheter och eventualförpliktelser

	2017-12-31	2016-12-31
Ställda säkerheter	inga	inga
Eventualförpliktelser	inga	inga

Svenska Kraftnät Gasturbiner AB
556451-0260

Not 22 Disposition av företagets vinst

Styrelsen föreslår att i ny räkning balanseras 71 586 tkr

Stockholm den

Ann-Marie Gelius
Styrelsens ordförande

Magnus Lindholm

Karin Rådström

Thomas Tagesson

Thomas Tagesson

Peter Blomqvist
Verkställande direktör

Vår revisionsberättelse har avgivits den 9/3-2018
Deloitte AB

Daniel de Paula
Auktoriserad revisor