TKI URBAN ENERGY
Topsector Energie

Smart Grid Ready Energy Storage

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DNV GL — Novy Francis, Rianne 't Hoen, Koen Broess
Technolution — Winifred Roggekamp, Wilbert Prinssen

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VOORWOORD

Flexibiliteit en opslag

Het elektriciteitssysteem komt door de energietransitie langzaam maar zeker onder druk te staan. Elektrificatie van de warmtevraag en mobiliteit leidt tot een toenemend elektriciteitsverbruik en creëert piekvraag naar energie op het elektriciteitsnet. Zonne- en windenergie worden met een fluctuerend karakter opgewekt. Daardoor raakt de balans van vraag en aanbod van elektriciteit verstoord en kan het elektriciteitsnet lokaal overbelast raken.

Een belangrijke oplossing is de inzet van 'flexibiliteit' – het veranderen of verschuiven van de vraag naar of het aanbod van elektriciteit. Met de inzet van flexibiliteit wordt het mogelijk om (lokaal) pieken en dalen in vraag en aanbod van energie af te vlakken en beter met elkaar in evenwicht te brengen. Dit draagt bij aan een betrouwbare, efficiënte en betaalbare elektriciteitsvoorziening. Flexibiliteit kan afkomstig zijn uit verschillende bronnen:

- Demand-side management (het veranderen van de energievraag van bestaande apparaten en machines).
- Curtailment (het afschakelen of afregelen van installaties voor duurzame opwek).
- Flexibele opwek (bijvoorbeeld het bij- of afregelen van conventionele energiecentrales).
- Conversie (bijvoorbeeld het omzetten van elektriciteit naar warmte).
- Opslag (bijvoorbeeld het tijdelijk opslaan van energieoverschotten in accusystemen of vliegwielen).

Opslag van elektrische energie in batterijsystemen wordt gezien als een veelbelovende ontwikkeling. De Topsector Energie heeft verschillende innovatieprojecten ondersteund die zich richten op opslag van elektrische energie in batterijsystemen. Noemenswaardige projecten zijn 'Enercons', 'Gridflex Heeten', 'Cooperative sustainable business models for storage' en 'Serieel geschakelde opslag van windenergie met onbalans regeling'. Daarnaast zijn er verschillende projecten waarbij innovatieve bedrijven werken aan de ontwikkeling van nieuwe materialen voor energieopslag, waaronder Dr. Ten in het project 'Grid2EVStorage', Exergy in de 'NaSTOR' projecten (1 en 2), Elestor in de 'FleXtore' projecten (1 en 2), Leyden Jar in het project 'Pure Silicon Li-ion' en Aqua Battery in de 'Blue Battery' projecten (1 en 2).

Interoperabiliteit – het gebruik van open standaarden en protocollen

TKI Urban Energy en RVO pleiten voor het gebruik van open standaarden/protocollen voor het flexibel aansturen van verschillende apparaten (zoals warmtepompen, elektrische auto's en ook batterijsystemen). Daarmee wordt de interoperabiliteit geborgd. Dat betekent dat het mogelijk wordt om gemakkelijk verschillende merken, typen en soorten apparaten (plug & play) op te nemen in een regelcircuit en op een later moment te veranderen. Ook ontstaat bij eigenaren en gebruikers van deze assets de mogelijkheid om te wisselen tussen leveranciers van 'flexdiensten'. Zo wordt een lock-in situatie voorkomen en dragen standaarden bij aan de opschaling en herbruikbaarheid van resultaten.

Eén van de grote voordelen van het gebruik van eenduidige standaarden en protocollen bij de aansturing van batterijsystemen, is de mogelijkheid om rollen en verantwoordelijkheden te scheiden. Dit maakt het uitgangspunt 'schoenmaker blijf bij je leest' mogelijk. In de praktijk betekent dat bijvoorbeeld dat een batterijleverancier zich kan richten op het produceren van een 'smart-grid ready' batterijsysteem, maar vervolgens de batterij met behoud van garanties kan overdragen aan derden. Hij hoeft zich niet te bemoeien met de installatie en operatie van het systeem bij (een breed scala aan) eindklanten, elk met een eigen use case en bijbehorende laad- en ontlaadstrategie.

Anderzijds hoeft de partij die de batterij aanstuurt – bijvoorbeeld een aggregator – zich niet te verliezen in de interne en veilige werking van een batterij.

Doel van dit rapport: interoperabiliteit tussen coordinating EMS en storage EMS
Wil men opslag inzetten in het elektriciteitssysteem, dan betekent dit op technisch vlak dat er een slimme koppeling moet plaatsvinden tussen het energie managementsysteem van bijvoorbeeld een aggregator en het managementsysteem van het opslagsysteem.

In verschillende innovatieprojecten wordt het zichtbaar dat de ontwikkelaars en systeemintegratoren van batterijsystemen worstelen met het inrichten van een goed storage Energy Management Systeem (EMS) waar 'flexspelers' zoals aggregators goed mee uit de voeten kunnen. Interoperabiliteit is in dat geval niet goed geregeld. Daardoor ontstaat er enerzijds frustratie en vertraging, doordat de batterijontwikkelaar zich te veel gaat bemoeien met laadstrategieën, terwijl een aggregator niet de juiste handvatten krijgt om de batterij aan te sturen. Anderzijds ontstaan accidenten in batterijen door verkeerde aansturing hiervan door externe organisaties.

Daarom heeft TKI Urban Energy samen met RVO aan DNV GL en Technolution gevraagd om een leidraad op te stellen waaraan een storage Energy Management System (EMS) van stationaire batterijsystemen dient te voldoen om effectief en eenvoudig interoperabel geïntegreerd te kunnen worden binnen een 'smart-grid' regelsysteem. Dit helpt ontwikkelaars van batterijsystemen bij het vormgeven van een goed storage EMS, terwijl het flexpartijen helpt om inzicht te krijgen in de spelregels om een batterij goed te kunnen aansturen.

Over TKI Urban Energy en de Rijksdienst voor Ondernemend Nederland
TKI Urban Energy is een onderdeel van de Topsector Energie. De organisatie stimuleert bedrijven, kennisinstellingen, maatschappelijke organisaties en overheden om samen te werken op het gebied van energie-innovaties. TKI Urban Energy bevordert samen met RVO onderzoek naar energie-innovaties voor een snelle transitie naar een duurzaam, betrouwbaar en betaalbaar energiesysteem in de gebouwde omgeving en de infrastructuur door initiatieven financieel te steunen, betrokken partijen bij elkaar te brengen en kennis te delen. Hiermee versterkt zij de economische concurrentiekracht van betrokken Nederlandse bedrijven en kennisinstellingen.

Heeft u innovatieve ambities op het gebied van flexibiliteit? Mogelijk kan TKI Urban Energy of RVO u ondersteunen bij uw ambities. De medewerkers van TKI Urban Energy staan klaar om uw ideeën te toetsen en u te helpen bij het vinden van samenwerkingspartners en het opzetten van een consortium. Ook kunt u bij TKI UE of RVO terecht als u wilt toetsen of uw ideeën in aanmerking komen voor subsidie (cofinanciering) vanuit de Topsector Energie.

Maarten de Vries
Programmamanager Smart Energy Systems
06-16836490, maarten@tki-urbanenergy.nl

Nicole Kerkhof-Damen
Senior adviseur Smart Energy Systems
06 272 39 645, nicole.kerkhof@RVO.nl

Over DNV GL
De drijfveer van DNV GL is het waarborgen van leven, eigendommen en het milieu. Vanuit deze doelstelling helpt DNV GL organisaties de veiligheid en duurzaamheid van hun bedrijfsvoering te verbeteren. De 2500 energie-experts van DNV GL leveren wereldwijd diepgaande baanbrekende adviesdiensten en erkende testen in een snel veranderend energiewaardeketen met inbegrip van duurzame energie en energiebesparing. Op het gebied van energieopslag werken wij met fabrikanten, nutsbedrijven, projectontwikkelaars, overheid en regelgevers om systemen te identificeren, evalueren, testen en certificeren die naadloos integreren met het huidige net, en klaar zijn voor het net van morgen. We leveren ondersteuning over de gehele waardeketen; van haalbaarheidsstudies, testen, ontwikkeling en engineering tot constructie en exploitatie.

Over Technolution

Technolution realiseert als technologie-integrator de missiekritische innovaties. Innovaties die waarde creëren voor uw bedrijf. Samen met u werken we aan de beste oplossingen, van idee tot waardevol product of dienst. Dit doet Technolution met name op de markten energy, mobility, public safety & security en high tech. Technolution ontwikkelt elektronica, embedded software en (technische) software.

PREFACE

Flexibility and storage

The energy transition is slowly but surely putting pressure on the electricity infrastructure. Electrification of heating and mobility leads to increased electricity consumption and creates peak demand for energy on the electricity grid. Solar and wind energy are being generated with a fluctuating nature. This disrupts the balance of supply and demand for electricity and might overload the electricity grid.

An important solution is the use of "flexibility" - adjusting or shifting the demand or supply of electricity. With the use of flexibility, it becomes possible to peak-shave and balance the supply and demand for electricity. This contributes to a reliable, efficient and affordable electricity supply. Flexibility can come from different sources:

- Demand-side management (changing the energy demand of existing devices and machines).
- Curtailment (switching off installations for sustainable energy generation or decreasing their production).
- Flexible power production (for example increasing or decreasing the energy production of conventional power plants).
- Conversion (for example, converting electricity to heat).
- Storage (the temporary storage of energy surpluses in, for example, battery systems or flywheels).

Storage of electrical energy in battery systems is considered a promising development. The *Topsector Energy* has supported various innovation projects that focus on the storage of electrical energy in battery systems. Notable projects are 'Enercons', 'Gridflex Heeten', 'Cooperative sustainable business models for storage', 'Cooperative sustainable business models for storage' and 'Serieel geschakelde opslag van windenergie met onbalans regeling'. In addition, there are various projects where innovative companies are working on the development of new materials for energy storage, such as Dr. Ten in the project 'Grid2EVStorage', Exergy in the 'NaSTOR' projects (1 en 2), Elestor in the 'FleXtore' projects (1 & 2), Leyden Jar in the project 'Pure Silicon Li-ion' and Aqua Battery in the 'Blue Battery' projects (1 & 2).

Interoperability – the use of open standards and protocols

TKI Urban Energy and RVO call for the use of open standards/protocols to be used for the flexible control of various devices (such as heat pumps, electric cars and battery systems). This ensures interoperability. This means that it is possible to easily incorporate different brands, types and kinds of devices (plug & play) into a control circuit and change them along the way. Owners and users of these assets then have the opportunity to switch between suppliers of "flex services", which prevents a lock-in situation. In this way standards contribute to the scaling up and reusability of results.

One of the major benefits of using unambiguous standards and protocols in controlling battery systems, is the ability to separate roles and responsibilities. This makes the principle "*let the cobbler stick to his last*" possible. In practice, this means, for example, that a battery supplier can focus on producing a smart grid-ready battery system, but can then transfer the battery to third parties while maintaining guarantees. He does not have to interfere with the installation and operation of the system at (a wide range of) end customers, each with its own use case and associated loading and unloading strategy. On the other hand, the party controlling the battery - for example an aggregator - does not have to lose itself in the internal and safe functioning of a battery.

Aim of this report: interoperability between coordinating EMS and storage EMS
When we want to incorporate Electricity Storage Systems in the Electricity System, this means on a technical level that we need to make a smart link between the coordinating Energy Management System (EMS) of, for example, an aggregator and the storage Energy Management System of the battery system.

In various innovation projects, it becomes apparent that the developers and system integrators of battery systems are struggling with the establishment of a good storage EMS with which 'flex players' like aggregators can use well. In this case the interoperability is not sorted out, which on the one hand leads to frustration and delay, because the battery developer is going to interfere too much with charging strategies, while an aggregator does not get the right tools to control the battery. On the other hand, accidents occur in batteries due to incorrect control by external organizations.

That is why TKI Urban Energy together with RVO has asked DNV GL and Technolution to prepare a guideline that a storage EMS of stationary battery systems must meet in order to be able to integrate effectively and easily integrally within a smart grid control system. This helps developers of battery systems in creating a good storage EMS, while it helps flex parties to gain insight into the rules of the game in order to manage a battery properly.

About TKI Urban Energy and Netherlands Enterprice Agency (RVO)
TKI Urban Energy is part of the Topsector Energy. The organization encourages companies, knowledge institutions, social organizations and governments to work together in the field of energy innovations. TKI Urban Energy promotes, together with RVO, research into energy innovations for a rapid transition to a sustainable, reliable and affordable energy system in the built environment and infrastructure by financially supporting initiatives, bringing stakeholders together and sharing knowledge. This strengthens the economic competitiveness of the Dutch companies and knowledge institutions involved.

Do you have innovative ambitions in the field of flexibility? TKI Urban Energy and RVO might be able to support you in your ambitions. The employees of TKI Urban Energy are ready to assay your ideas and help you find cooperation partners and set up a consortium. You can also contact TKI UE or RVO if you want to check whether your ideas are eligible for funding (co-financing) from the Top Sector Energy.

Maarten de Vries
Programmamanager Smart Energy Systems
06-16836490, maarten@tki-urbanenergy.nl

Nicole Kerkhof-Damen
Senior adviseur Smart Energy Systems
06 272 39 645, nicole.kerkhof@RVO.nl

About DNV GL
DNV GL is a global quality assurance and risk management company. Driven by our purpose of safeguarding life, property and the environment, we enable our customers to advance the safety and sustainability of their business. The 2500 energy experts from DNV GL provide in-depth ground-breaking consulting services and recognized testing in a rapidly changing energy value chain including sustainable energy and energy saving. In the field of energy storage we work with manufacturers, utilities, project developers, communities and regulators to identify, evaluate, test and certify systems that will integrate seamlessly with today’s grid, while planning for tomorrow. Through our dedicated labs and expertise around the world, we have created an industry-leading combination of analytical and testing experience that gives us a unique advantage in finding energy storage solutions. We provide support across the entire energy storage value chain—feasibility, testing, development and engineering, construction and operation.

About Technolution

Technolution is the most trusted technology integrator of the Netherlands, focused on the development of electronics, embedded and technical software. We deliver the mission-critical innovations that deliver the most value to your company. You create your optimal solutions from ideation to implementation with us as trusted technology partner. Technolution's core markets are Energy, Mobility, Public safety & security and High tech.

1 SUMMARY

Energy storage systems (ESS) are in most cases connected to the grid and therefore part of a bigger system. There is a relation, interface and communication, between an ESS and the surrounding (IT-)systems. When an energy storage system is developed or requested to deliver flexibility, this surrounding, which is called the ecosystem, must be taken into consideration. This document provides good practices for developers and ESS system integrators, and recommendations for policy makers to strive for an optimal future-proof cooperation between storage systems and their ecosystems. Communication between different components is not only required for performance and functionality, but also essential for safety characteristics as evidenced by the occurrence of multiple safety incidents with ESS in recent years due to communication problems.

1.1 Smart grids and energy storage systems

A smart grid typically consists of multiple cooperating systems with various levels of hierarchy, further collectively referred to as ecosystem. Coordination of all energy flows within an ecosystem is done within one or more cooperating energy management systems (EMS's). In this report this overarching system is called coordinating EMS**.** The energy flows within an energy storage system are coordinated by the storage EMS, which connects to a battery management system (BMS) for control of the storage medium. The coordinating EMS is responsible for the performance and optimization (e.g. technical and or financial) of the ecosystem and the storage EMS is responsible for performance and system safety on ESS level (storage medium plus auxiliaries). The BMS is responsible for the safety and the control on the level of a (single or aggregated) storage medium.

A clearly delineated interface between the coordinating EMS and the storage EMS is critical to the implementation of storage in an energy ecosystem and hence the main subject of this report. A more standardized interface will also ensure the interoperability between (different actors providing a) coordinating EMS and storage EMS.

Storage units are commissioned to perform functions in an electricity ecosystem and/or in a (micro)grid. Such functions are referred to as use cases for example, arbitrage, congestion management, ancillary services or energy trading like FCR, FRR, intraday market. These diverse ESS services ask for different operating commands to the ESS. In general, there are two types of control strategies communicated over the interface:

- Non-real-time strategies, where the control decisions are made by the coordinating EMS.
- Real-time strategies, where the coordinating EMS issues a command to the storage EMS to execute a (real-time) function.

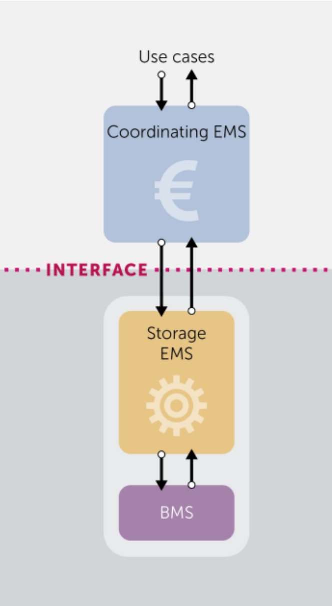


Figure 0. The interface between the energy storage system and the coordinating EMS.

This report provides some insights for use in an ecosystem where ESS are used. In the current state of the market, the economic incentives for energy storage as well as energy storage technologies are swiftly developing and improving. Consequently, making the right choices for the implementation of an ecosystem with storage or for the development of a storage product that fits well into ecosystems is far from trivial. Hence, this report strives to give guidance to developers of ecosystems or energy storage systems by describing good practices and recommendations.

1.2 Good practices for developers/system integrators

Underlying all good practices for developers/ESS system integrators as outlined in this report is the understanding that an energy ecosystem (as coordinated by a coordinating EMS) has fundamentally different characteristics from an ESS (as controlled by a storage EMS). Developers should make explicit choices in terms of modularization and interfacing.

A clear separation of tasks between the economic oriented coordinating EMS and the performance oriented storage EMS allows:

- clear allocation of responsibilities: safety, stability and performance of storage versus economy, stability and performance of ecosystem, information security shared between both, interoperability.
- fit-for-purpose development: develop and produce exactly what you specialize in, leading to the best product at the optimal cost, made with the highest motivation and focus;
- risk mitigation for uncertain future conditions: as nobody knows the requirements and economics of future use cases, the best technology mix within an ecosystem or the exact lifecycle of assets, a clearly defined interface ensures that you can operate in a wide diversity of future scenarios.

This separation of tasks between a coordinating EMS and a storage EMS can be attained by adhering to an interface that is as simple as possible. Guidelines from this report include:

- Start with well-defined grid service(s) and separation of responsibilities to define the required control strategy.
- Communicate only what is required (i.e. actionable) for the receiving system. This is a very limited subset of the information you have available.
- Communicate the status in energy terms (e.g. Watt, Joule). The consequences for the ecosystem (e.g. €, $\%_{uptime}$) or for the energy storage system (e.g. degree Celsius, Volt) are not relevant to the other system.

1.3 Recommendations for policy makers

The adoption of the above good practices may well be accelerated by stimulating the development and adoption of open standards and interface specifications that enable the separation of tasks and responsibilities, with special attention to the safety aspects. Developments of open source standards should be endorsed and fostered.

2 INTRODUCTION

2.1 Energy Storage Systems in the Electricity System

The energy transition is characterized by the rapid growth of renewable energy and the electrification of heat and mobility. Intermittent energy sources, such as solar and wind, cause imbalances between energy demand and supply, while the balance between energy production and energy demand is necessary for a stable electricity system.

Energy storage systems (ESS) can support the balance of supply and demand in the electricity system and support congestion management for the electricity grid. For example, by charging and thus storing energy at moments of overproduction, while discharging when the demand is higher than the energy production (Figure 1). In this way the energy storage system can provide flexibility and contribute to a reliable, affordable and sustainable electricity system. Also, at shorter subsecond timescales, energy storage can support the stability of the electricity system (Figure 2). In case of a power plant failure, an energy storage system can compensate the loss of production and contain and/or restore the grid frequency.

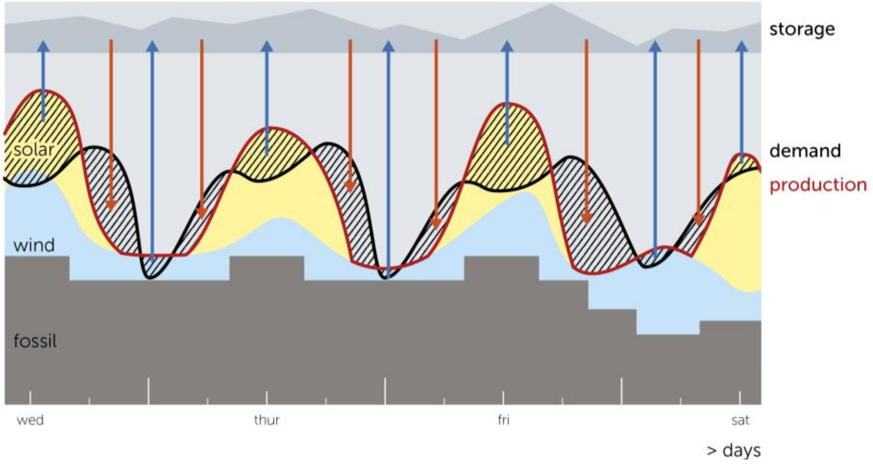


Figure 1. Energy storage can support balancing energy demand and supply. At moments of overproduction the ESS charges energy, while the ESS discharges when the demand is higher than the energy supply.

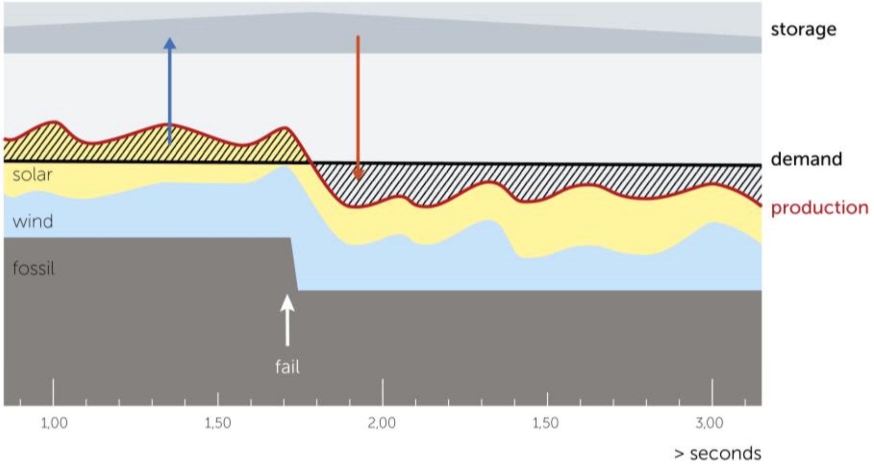


Figure 2. Energy storage can support the balancing of supply and demand also at short timescales. For example, when a failure of a power plant causes a drop in the grid frequency, an energy storage system can deliver power and stabilize the electricity system.

Energy storage technologies are maturing. The first commercial projects are being rolled out in the Netherlands and future-proof business cases are in development. One of the challenges for efficient deployment and technical development of (new) storage technologies is a well-defined interface between the energy storage system and the aggregator, where both focus on their own tasks, key competences and responsibilities. Or in short: interoperability should be ensured.

In order to efficiently bring (battery) energy storage technologies to the next level, it is important to share good practices and get insight in the most important challenges of the protocols for communication between the coordinating energy management system and storage management system. In the past several communication errors between the aggregator and the battery storage system did cause safety and efficiency issues resulting in battery fires in the worst cases. This report aims to give an overview of the best practices and gives recommendations and clarifies the open questions on the interface.

2.2 Reading guide

A smart grid typically consists of multiple cooperating systems with various levels of hierarchy, further collectively referred to as ecosystem. Coordination of all energy flows within an ecosystem is done within one or more cooperating energy management systems (EMS). In this report this overarching system is called coordinating EMS**.** The energy flows within an energy storage system are coordinated by the storage EMS, which connects to a battery management system (BMS) for control of the storage medium. The coordinating EMS is responsible for the performance and optimization (e.g. technical and or financial) of the ecosystem and the storage EMS is responsible for performance and system safety on ESS level (storage medium plus auxiliaries). The BMS is responsible for the safety and the control on the level of single or aggregated storage medium. Please note that there is often a miscommunication about the exact terminology of energy management systems. What we define in this report as storage EMS is often referred to as BMS, while the functionality of a storage EMS includes also performance aspects, such as temperature control, HVAC, inverter efficiency, etc.

Figure 3 shows the interface between the coordinating EMS and the storage EMS. At one side of the interface is the flexibility provider, for example an aggregator, which provides flex services and optimizes the different use cases. This is usually economic optimization, but the coordinating EMS can also optimize for self-consumption or sustainability. On the other side is the energy storage system located, with the physical storage medium and the storage EMS. This system is described in more detail in chapter 3.

We have approached the essential ingredients for the interface from two directions: top-down are the use cases that need to be controlled/optimized (as described in paragraph 3.2) and bottom-up the requirements of an energy storage system (see paragraph 3.3). Chapter 4 summarizes the tasks and responsibilities of both management systems, and describes the coordinating EMS – storage EMS interface. The fifth chapter summarizes the recommendations of good practices for the developers and ESS system integrators, while the last chapter describes the most important open questions for policy makers.

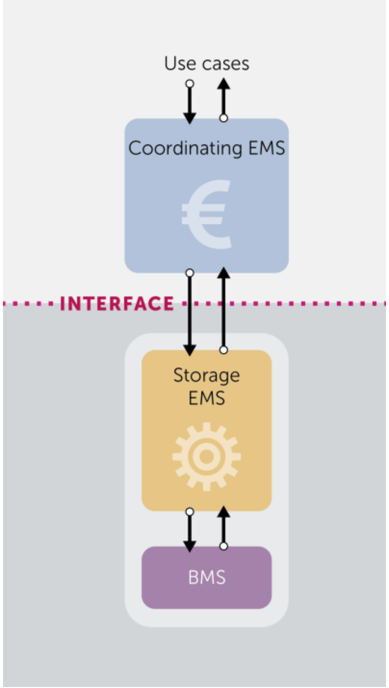


Figure 3. The interface between the energy storage system and the coordinating EMS.

3 SYSTEM DESCRIPTION

3.1 Ecosystem

Within an ecosystem, flexibility can be provided by one or multiple devices. A heat pump and other devices can adjust the time-of-use and/or their level of operation, and energy storage systems can charge or discharge when requested to provide flexibility. The economic value of flexibility depends on the relevant use cases, for example frequency support, trade on the electricity markets, improve power quality of the grid, capacity management, congestion management, etc. A standardized interface between an energy storage system and an energy management system will make it possible to optimize the energy management for a specific location or for an aggregator/flex provider to use the flexibility of an ESS for one or more use cases, without altering the energy storage system itself. Clear separation of tasks and responsibilities will make devices interchangeable and stimulate the development of the flex market as well as new (storage) technologies.

Figure 4 shows a variety of ecosystems of the energy storage systems and the energy management system. The coordinating energy management system (coordinating EMS) optimizes the different use cases and matches the flexibility solutions from energy storage systems and devices, for example electric vehicles (EV) and photovoltaics (PV). The coordinating EMS can be the responsibility of an aggregator, who makes economic optimization, or can be responsible for the optimization at a specific location, building or industrial park, in which case optimization might be an economic decision or optimization of self-consumption. At the other side of the interface (bottom), the energy storage system or other devices providing flexibility are located. The energy storage system consists of a storage EMS, optimizing the operation of the ESS in the most efficient way, and the BMS, responsible for the safety of the physical storage medium.

The interface between coordinating EMS and storage EMS, indicated with a red dotted line, is approached from two directions. Paragraph 3.2 describes the top-down approach, the use cases for flexibility providers who need to steer the energy management system, and paragraph 3.3 the bottom-up approach with the requirements of an energy storage system. Note that the storage system always has its storage EMS only connected to one (external) coordinating EMS. For a coordinating EMS it is optional to be connected to another coordinating EMS. Some energy storage systems run standalone without a high-level (aggregator) coordinating EMS and/or a connection to the energy markets.

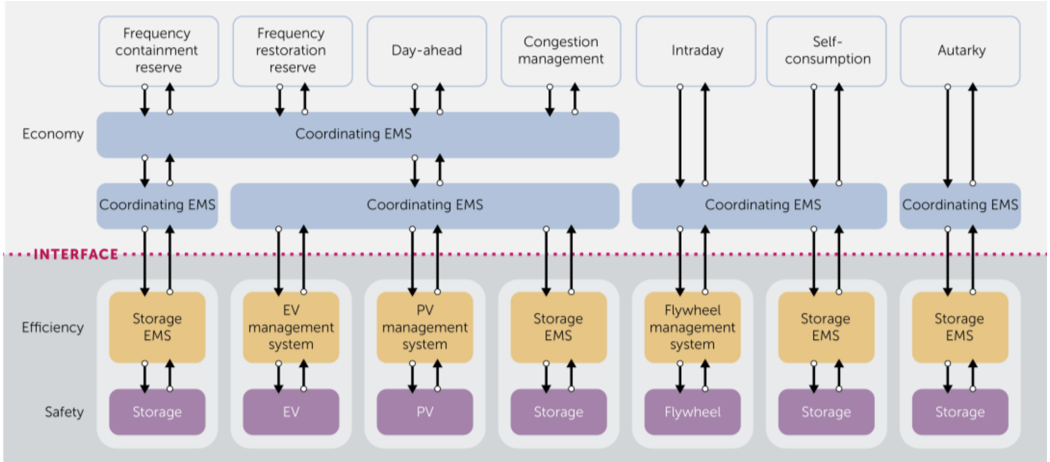


Figure 4. The ecosystem with interface indicated between the coordinating Energy Management System and the ESS with a storage energy management system.

Top-down approach: view of the aggregator on energy & flexibility management

The coordinating Energy Management System (coordinating EMS) has the primary function to control the network of energy-intensive devices, energy production and other devices providing flexibility to optimize the use cases. The coordinating EMS usually optimizes the energy management from an economic perspective or for self-consumption, but the optimization parameter can also be chosen. In Figure 4 the energy trading markets use cases are mentioned to show the interaction of an aggregator with the energy market. An EMS is responsible for a single location, might not interact with any energy market at all, and optimize by using other use cases. A coordinating EMS can control multiple appliances, including energy storage systems. It runs algorithms to optimize the business case for the (local) ecosystem that is connected to the coordinating EMS. A coordinating EMS can be connected to a higher-level coordinating EMS.

Bottom-up approach: view of the energy storage system developer

The physical energy storage system is controlled by a battery management system (BMS) and a storage energy management system (storage EMS). The primary goal of the ESS control is to guarantee safe, reliable and efficient operation, so it is optimizing the physical components. The BMS is responsible for the safety of the batteries. It can control multiple storage units (like lithium-ion batteries) that are combined into a single storage system. The storage EMS is responsible for energy efficient operation of the energy storage system and executes control strategies requested by the flex provider. The storage EMS can execute (near) real-time functionality (e.g. grid power control).

Interface

The interface between the storage EMS and the coordinating EMS should be as simple as possible and only exchange relevant information. Therefore, only information that is actionable should be communicated between the energy storage system and the use case. E.g. an energy storage system cannot in explicitly relate to the market price of the energy it stores; that information is only actionable on the use case side. The use case should translate such information in terms of power (e.g. kWh to be stored), which the energy storage can relate to. The energy storage will further translate it into its own specific terms which are not actionable to the use case (e.g. state of charge, temperature).

We see it as essential that the interface between the two only contains elements that both can relate to and perform actions on. That is what we mean by actionable. Please note that some ESS providers add the function of economic optimization to their ESS so both functionalities are inside the boundaries of the energy storage unit, so it can function as a ‘standalone’ system. This only means that a relatively simple coordinating EMS is incorporated in the system that can execute certain use cases which aren’t dependent on external signals (from an external organization).

The interaction between the storage energy management system and the coordinating EMS can be summarized as follows:

- A control signal from the coordinating EMS to the storage EMS, where the required use case is indicated with required energy use (requested power and time duration). The required power might also be negative, be within a band width or over a range over time.
- Feedback signal from the storage energy management system to the coordinating EMS, where the actual and expected conditions of the energy storage system are translated into relevant parameters for the flex provider.

3.2 Energy storage system use cases

3.2.1 Electricity market scenarios

The energy market is changing and has to deal with conflicting issues: the electricity delivery must remain stable while more and more (fluctuating) renewables like wind and solar PV are introduced. With fluctuating renewables, it is a problem to deliver electricity at the exact time and in the same place the energy is needed. With the introduction of energy storage, the playing field is changing. Not only because the storage can shift the energy in time (delivery earlier produced energy), but it can also help with other electricity-related issues.

The following paragraphs describe possible scenarios where controlling an energy storage system helps solve (one of the) issues. Each paragraph starts with the description of use case. A use case is a description of an application of the storage in the energy ecosystem. The control strategy is determined based on the use case. A control strategy is the way the use case needs to control the energy storage system to achieve his goal. There are only a limited set of control strategies compared to the number of use cases. The control strategies are so that almost every use case can be mapped on the existing control strategies.

Please note that in the control of an energy storage system, there is a major difference between real-time and non-real-time behavior. With the design where the coordinating EMS, storage EMS and the BMS fulfill the required function, we must be aware of the physical location of the three subsystems. The storage EMS and the BMS are located close to each other, which makes real-time communication possible. The coordinating EMS is usually located on a different location, resulting in a longer communication time and lower reliability of the connection.

To define a realistic control strategy, we define the timing as follows:

- real-time: times < 1 sec (generally < 100 ms).
- non-real-time: times longer than 10 seconds, where we assume 10 seconds is the worst-case response time (in 99% of the cases the delay time is less than 10 seconds). As a guideline we say that information is exchanged every 10 seconds.

In general, when non-real-time control strategies are used, the functionality of the use case is running on the coordinating EMS. Functionality that needs real-time control strategies are usually split into two: the real-time part on the storage EMS and the overall (non-real-time) parts on the coordinating EMS.

The reason to use a storage system in an (electrical) energy network differs. There are many use cases possible. The most common use cases are described in the next paragraphs.

3.2.1.1 Frequency containment reserves (FCR)

Frequency containment reserves (FCR) in the European Union Internal Electricity Balancing Market means that operating reserves are necessary to stabilize frequency deviations (fluctuations) from the nominal value of 50 Hz in order to constantly maintain the power balance in the whole synchronously interconnected system.

Activation of these reserves results in a restored power balance at a frequency deviating from nominal value. The FCR category typically includes operating reserves with an activation time up to 30 seconds, they are activated automatically and locally.

Because the response time must be at least 4 second, the control strategy must be real time. The algorithm will run on the storage EMS where the coordinating EMS will set the properties of the control. The used control strategy is “grid frequency control”.

3.2.1.2 Frequency Restoration Reserve (FRR)

Frequency restoration reserve or ‘FRR’ means the active power reserves available to restore system frequency to the nominal frequency and, for a synchronous area consisting of more than one LFC (load frequency control) area, to restore power balance to the scheduled value.

In the EU Internal Electricity Balancing Market, FRR includes operating reserves with an activation time typically between 30 seconds up to 15 minutes (depending on the specific requirements of the synchronous area).

The used (non-real-time) control strategy is “energy time shifting”; energy that is stored for later usage.

3.2.1.3 Day-ahead and Intraday

The day-ahead market is a place where trading takes place one day before the delivery of electricity. Intraday and day-ahead markets are system services for balance responsible parties.
Market members submit their orders electronically, after which supply and demand are compared and the market price is calculated for each hour of the following day. Hourly contracts as well as flexible block contracts can be traded. During the day, the intraday market (based on the day-ahead calculation of the previous day) will be active. During the day the balance is made up every 15 minutes and when there is an imbalance, the market is requested to push/pull energy to/from the grid to compensate the imbalance.

Note that not all the storage systems are suitable for this use case. The storage must be efficient for long-term storage of energy.

The used control strategy for both intraday and day-ahead is “energy time shifting”, where the day-ahead differs in the storage time.

3.2.1.4 Congestion management on primary assets DSO/TSOs

The electricity network is increasingly loaded. The decentral production, the renewables; they all increase the load of the network. The load calculations are more complex compared to the central production network. Beside this, the electrification of the energy consumption (EV, cooking, …) increases the possibility of congestions on the electricity grid.

With the increased renewable and decentral production, congestion management will become more and more important to avoid overload of primary assets like cables and transformers. One of the possibilities is to connect decentral storage distributed across the grid. The storage will store energy when the local production is too high and discharge the storage when the local consumption is too high. The coordinating EMS needs to predict the necessary energy that should be stored to prepare for congestion.

The used control strategy is “energy time shifting”: energy is stored for later usage. Congestions are almost never acute. The primary assets can be overloaded for a short period of time (e.g. 10 minutes). This makes it possible to use slow switching storage like flow batteries.

3.2.1.5 Congestion management - cable/station failure

Congestion management on a network failure is similar to congestion management on primary assets, with the difference being that the response time must be much shorter. When the failure appears, the storage unit must switch to local autonomic operation (see next chapter).

Note: this use case describes the situation where a part of the grid is disconnected. It is also possible that the grid is still connected, but the capacity of the rerouting is too less. This is a special situation of the previous use case.

In case a part of the grid fails and the power reroute capacity is too small, the control strategy “grid max. power control” is used. In that case the maximum power over the reroute network is monitored and limited.
In case the entire grid disconnects the control strategy “local rotating power driver” is used.

When an asset fails and a part of the energy distribution network is disconnected from the rest of the network, the storage can temporarily take over the energy distribution. It must be a well-coordinated process between the grid and the storage. During the time that the storage has taken over, the storage system needs to be grid forming (e.g. determines the voltage and the frequency). It is not possible to put two frequencies on the same grid, so storage control (storage EMS) must be sure the grid is disconnected. When the grid is restored, the storage must take care of the procedure to switch back. It must be sure that the frequency is synchronized, and the voltage is leveled. This is a real-time function handled in the storage EMS.

3.2.1.6 Autonomous operation (microgrid)

A microgrid is a grid independent electricity network. An electricity network needs a stable rotating driver that generates a stable 50 Hz. This rotating device can be both mechanical as well as electric. A battery energy storage system into the microgrid can provide the functionality of a rotating driver. A combination of multiple storages (e.g. short term and long term) is also possible.

The used control strategy depends on the function. A storage that is also the rotating driver must have a real-time local algorithm and local sensors to control the 50 Hz. The buffer that drives the rotating power must be regulated so that the driver function is always available. The coordinating EMS can shift energy from a long-term storage to the short-term storage with rotating power function. In that case, there are two control strategies active:
-1- a “local rotating power driver“ control strategy;
-2- an “energy time shifting” control strategy.

Typically, the coordinating EMS has a view on the complete (local) grid, controlling all the available storages and appliances in the local grid. The grid frequency is controlled by a storage EMS.

3.2.1.7 Self-consumption

There are many situations where local energy sources are available, but not reliable or predictable enough to fully rely on as is done in the previously described micro-grid situation. In such cases there may be incentives to ensure that locally produced energy is consumed locally. These incentives range from idealistic (ensure minimal carbon footprint, attain higher local autonomy) to economic (lower connection capacity required, prevent purchasing at higher cost than sales prices of locally generated energy, ...).

In these cases, the coordinating EMS will be tasked with the forecasting local energy production, optimizing timeshiftable planning of loads as possible and directing the storage EMS to ensure ample storage capacity or energy supply as needed. The control strategy used is “energy time shifting”.

3.2.1.8 Power quality (PQ)

Storage can be used to control the power quality of a (local) grid. Because controlling the power quality is always real time, the algorithm must run locally on the storage EMS. Power quality algorithms are:

- Voltage control (when the voltage is too low, power is injected and when too high the storage is charged).
- Reactive power compensation (phase of the current is compensated by injecting/rejecting power).

Note that there are more PQ values that could be adjusted (frequency, THD, transients, …), but those are not naturally compensated by a grid-connected storage unit.

The used control strategy is “grid PQ control”, where the type of control depends on the setting.

3.2.1.9 Capacity limitation

In some cases, a grid connection is limited. This can be due to the limited capacity, or because of contract limitations. The difference is that limited capacity peaks are not allowed, while contract limited grid connections to high current peaks are allowed as long as the average current in the contractual time is limited to the contract current.

In case of limited capacity, a storage can be used to shift energy peaks over the limit in time. Because of the (near) real-time aspect, the coordinating EMS will run the algorithm to limit the grid energy as well as a second algorithm to keep the energy level into the buffer approx. 50% (to be able to limit both consumption and production). The used control strategy is “grid max power control”.

In case the limitation is contractual, the energy is mostly calculated over a longer period, e.g. 10 minutes. This means that there is no real-time regulation needed and a standard “energy time shifting” control strategy is sufficient.

3.2.2 Control strategies

The use cases described above use a limited set of control strategies:

- energy time shifting;
- grid frequency control;
- grid max. power control;
- local rotating power driver;
- grid PQ control.

Only the control strategy “energy time shifting” is a non-real-time strategy. This runs on the coordinating EMS. The other control strategies are running on the storage EMS and are commands given from the coordinating EMS to the storage EMS to perform a function.

3.2.2.1 Energy time shifting

Time shifting is used to move (peak) power over time. For example: power used in the building normally comes from the grid. In case of energy shift, the storage injects the power into the building for a specific amount of time resulting into higher autarky from the grid. At a later time, the power can be taken from the grid to reload the storage again. The other way around is also possible: injected power from the building (e.g. PV) is stored in the storage and injected into the grid at a later time. Equal to that, this can be done on a larger scale, like district level.

The use cases using this control strategy are relatively slow processes with a response time longer than 10 seconds (non-real-time). This means that the control loop may be spread over multiple geographical spread systems. The control algorithm will run on a coordinating EMS, sending the settings to the storage EMS.

3.2.2.2 Grid frequency control

Controlling the grid frequency is a near real-time algorithm. A storage must, if the grid frequency exceeds the set boundaries, start within 4 seconds. These 4 seconds encompass detection of a deviation, initialization of the storage system and ramping it up or down to the (generally maximum) power. Given this short time frame the algorithm to control the storage must run locally, typically on the storage EMS.

The algorithm will control as follows: when the grid frequency is too high, there is too much power injected into the grid compared to the consumption. The storage will start charging. When the frequency is too low, there is more consumption than production connected to the grid. The storage will start discharging. A second, much slower, algorithm must fill the storage to predefined level (e.g. to 50% to have both upward and downward flexibility).

3.2.2.3 Grid max. power control

Controlling the grid power is a real-time algorithm. A storage must, if the grid power exceeds the set boundaries, change its setpoint immediately. The algorithm that controls the storage must run locally on the storage EMS.

The algorithm will control as follows: when the power requested by the devices from the grid is too high, the storage starts compensating the power by discharging until the power from the grid is compensated (power is below the max. power coming from the grid boundary). When the power to the grid is too high caused by overproduction, the storage starts compensating the power by charging until the power to the grid is compensated (power is below the max. power going to the grid boundary). A second, much slower, algorithm must fill the storage to a preset intermediate stationary level, so both situations can be compensated.

3.2.2.4 Local rotating power driver

A (local) grid always needs a “low impedance” power driver. This driver makes sure that when power is suddenly taken from (or injected to) the grid, the voltage and frequency stays within the (PQ) boundaries. In large grids, the (synchronized) power plants take on this job. Because the electrical power is three-phased, these power plants are also called rotating power drivers.
In case of a local grid, there must be a “power plant”-like system in the grid. Typically, this is a (fast switching) storage system. The storage must continually measure the voltage and frequency and inject or subtract power to/from the local grid to keep the frequency and voltage between the (PQ) boundaries.

Controlling the local grid frequency is a real-time process, always running on the storage EMS. Sensors to monitor the grid condition are directly connected to the storage EMS.

When there is a coordinating EMS in the local grid, the coordinating EMS orders the storage EMS to start controlling the grid frequency/voltage. The coordinating EMS will control the appliances to avoid surplus or deficit on the grid. As in the previous control strategies a second, slow algorithm is in place to direct the system to a stationary level with both up and downward flexibility.

3.2.2.5 Grid PQ control

The PQ components that can be compensated by storage units are voltage compensation and reactive power compensation. Other PQ components, like waveform compensation are more effectively compensated with other technics. Each PQ value compensation needs a separately controlled algorithm.
The PQ control algorithms are (near) real-time. Because of this, the algorithm to control the storage must run locally on the storage EMS.

3.3 Energy storage system

3.3.1 Energy storage system components

Energy storage systems cover a whole range of different technologies with different characteristics (power, energy capacity and response time). The most important, which are currently relevant for the Dutch market are lithium-ion (Li-ion) batteries, flow batteries and flywheels. Lead-acid battery storage systems are still widely used for UPS (uninterrupted power supply) functionalities, but in general not considered suitable for flexibility solutions by the market, therefore lead-acid is not discussed in this report. All energy storage systems consist of the same components but have different safety and performance aspects to take into account when operating. The general components are described below, as well as specific relevant details from these storage devices.

In Figure 5, the various components and flow of data and power for an ESS are schematically depicted. Although minor changes exist between the various storage technologies, the block diagram can be used to map every ESS.

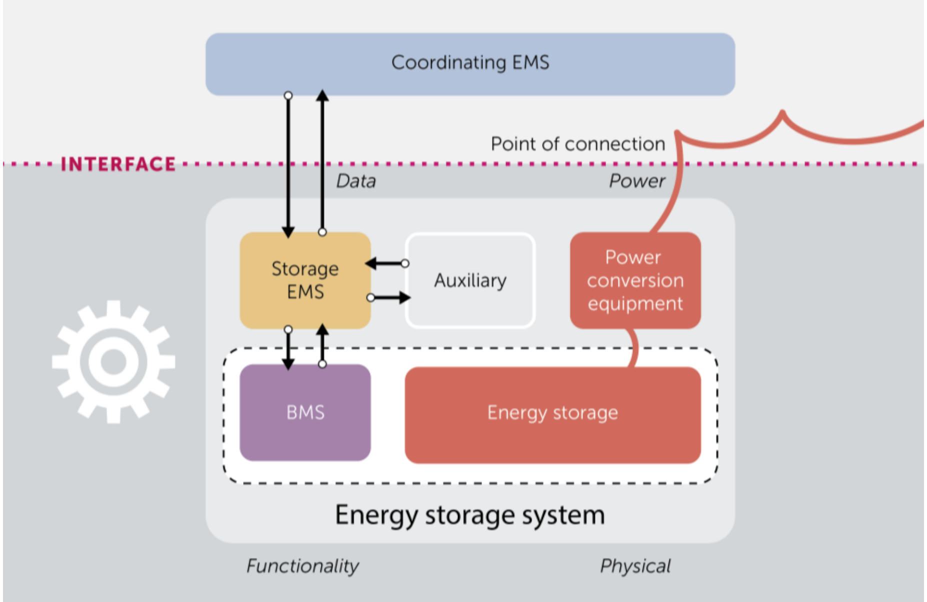


Figure 5. Schematic drawing of an energy storage system.

3.3.1.1 Energy storage

The energy storage refers to the physical medium that stores the energy. This is the location where the electrochemical or physical process of energy storage occur, such as batteries (electrochemical), flywheels (mechanical), hydrogen (chemical), etc. In case of lithium-ion battery technologies, the entire ESS can be subdivided into racks which comprise of individual battery modules and each of the batteries are composed of individual battery cells.

3.3.1.2 Power conversion equipment

Power conversion equipment converts the stored energy into electricity, using converters and transformers. The converter can be a single power converter or a distributed conversion system depending on the power rating and use case of the storage system. In case of an ESS with multiple converters a transformer is used. The transformer converts the electricity to the grid voltage. The point of connection indicates the connection to the electricity grid.

3.3.1.3 Peripheries/auxiliaries

The peripheral and auxiliary systems refer to other equipment and components that are required to run the ESS depending on the type of ESS used. In general, these can refer to the following:

- Cooling/air conditioning systems (generally for all storage technologies);
- pumps for liquid electrolytes (flow batteries);
- vacuum pumps (flywheel);
- monitoring system, monitoring of general parameters such as system temperature;
- data recording and acquisition systems.

Hence, there is a data flow and environmental conditioning flow between the physical energy storage, BMS, peripheral/auxiliary systems and the storage EMS.

3.3.1.4 Battery management system

The state of the physical energy storage is monitored and controlled by the system's low-level controls, which, in case of batteries (cell-based and redox flow), is referred to as battery management system. The BMS safeguards the storage system. The BMS reads and monitors all relevant data from the physical ESS, such as voltages and temperatures, to ensure that the system is operating within the specified safety limits. Furthermore, it checks whether the electric power requested is within the operating range of the current system status. The BMS needs to balance the system and can put the system on standby or (partly) switch off in case the system is no longer within its operating window. In the case that the communication between storage EMS and BMS is lost, the BMS system needs to switch off for safety reasons to prevent, for example, overheating of batteries (e.g. a malfunctioning HVAC system). There can be multiple levels of battery management systems e.g. cell, module, pack and system.

3.3.1.5 Storage Energy Management System (storage EMS)

The high-level storage EMS controls the ESS which determine its functionality such as charging of the storage system, temperature control in the battery container, measuring the grid frequency and respond to the fire alarm. Depending on the functionality of the system, this can occur locally with minimal response times (milliseconds or less) based on locally measured data and algorithms (e.g. current, voltage, power, frequency), or within an external energy management system, connected via a digital protocol (DNP3, modbus, etc.), which results in slower response times (seconds). This system is sometimes called SCADA. A good practice (in case the communication between storage EMS and external EMS, the coordinating EMS, is lost) is to switch off the storage EMS after a set period of time (e.g. 5 minutes) as the economic optimization function of the coordinating EMS is no longer reliable.

The BMS works on a near real-time resolution basis which means that the unit communicates every 50-100 ms with the battery pack or system parameters. Storage EMS can always communicate to the BMS to read and relay the key battery parameters. The storage EMS works on a similar near real-time resolution basis as the BMS, because it is all connected via wires in the energy storage container or box. The coordinating EMS works on a second to minute time resolution basis with the storage EMS and the other generators, loads and other EMS units.

3.3.2 Energy storage technologies

Each energy storage technology behaves differently and operates most efficiently in a different regime. In order to guarantee safe and efficient performance, it is relevant to understand the safety and performance functionality of the storage technology. Safety aspects are, for example, temperature control or safeguarding the maximum rotation speed for a flywheel. Performance parameters support the most efficient use of the energy storage system. Not only the storage system itself is relevant, but also how to operate the auxiliaries, such as the temperature control, and the power conversion equipment. A converter/transformer is most efficient in a specific power range and the ESS can significantly loose efficiency if the temperature control is inefficient.

The typical energy capacity of a battery energy storage system varies for different applications. Typical powers for example 5-10 kWh for home storage, 50-100 kWh for EV and 0.5-2 MWh for large grid connected storage systems.

3.3.2.1 *Lithium-ion technology*

A lithium-ion battery is the umbrella term referring to any electrochemical energy storage system that uses lithium ions as the charge carrier between the cathode & anode during charging and discharging cycles. There are many types of lithium-ion batteries, usually differentiated by the chemical structure of the cathode material. The anode material is generally graphite, however, there are some alternatives such as LTO (lithium titanate) or graphite with silicon additives. Changes in the chemistry of the cathode and anode gives rise to huge variations in properties such as specific energy, specific power, cycle lifetime, cost, safety & thermal stability.

A battery energy storage system has a modular structure. It consists of several racks (or strings) connected in parallel to deliver the required power. The voltage of each rack is the same and equal to the battery system voltage. Each rack is an aggregation of modules connected in series and it may contain a superior BMS that controls the interactions of the modules inside. The rack-BMS provides information on the state of the rack to a superior control system. The modules inside the rack are cells connected in series and/or parallel. Cells are the smallest subpart of the battery system. The electrical energy is stored in the cells as chemical energy. Modules may contain a basic BMS (module-BMS) that checks voltages, currents and temperature, and balances the state of charge (SoC) of the aggregated cells. The module-BMS provides information on internal states to a superior BMS (and may receive control signals). The module is normally the smallest interchangeable part of the battery system and may also be referred to as a pack or tray.

Safety functionality

It is essential for the BMS to monitor the following key parameters to safeguard the battery energy storage system:

- Operating temperature: a cell is designed to operate under a predefined temperature range. Once the battery starts exceeding the designed operating temperature, thermal instability sets in which can lead to thermal runaway and other dangerous reactions. Thermal runaway can happen when chemical reactions are triggered that are exothermic, i.e. creating heat. Because the reaction speed of chemical reactions increases with temperature, self-heating is accelerated further. In a reactive environment like a lithium-ion cell, the exothermic reaction can trigger other reactions that can also be exothermic, thereby further aggravating the self-heating process. This will eventually lead to a cell fire, that may propagate to the next cell or other battery components.
- Cell voltage: the cell voltage in ESS is generally indicated by the state of charge, the SoC level, of the battery. 0% SoC is defined by a specific lower boundary value of cell voltage and 100% SoC is defined by a specific upper boundary value of cell voltage.

Performance functionality

In regard to optimum performance of the energy storage system, the following parameters are important: temperature, (dis)charge rate, average state of charge, SoC window [1].

The capacity of the battery gradually decreases during its lifetime (Figure 6). The lifetime of a battery can be divided into three parts which are mentioned below:

- Phase 1: in early life, the battery functions at a capacity ≥ 100% but then rapidly drops slightly in capacity before entering phase 2. Generally, the remaining capacity at the start of phase 2 is defined as the initial capacity or nameplate capacity (i.e. capacity = 100%).
- Phase 2: linear degradation caused by normal use.

- Phase 3: the battery rapidly degrades after reaching the knee of the curve as shown in the figure below. The rapid degradation of the battery commonly starts after 50-70% of the initial capacity is reached. 50-70% is a typical capacity limit used in cycling studies for NMC batteries. The energy density is an important parameter for mobile applications, the capacity limit for mobile storage systems is therefore often higher, around 80%.

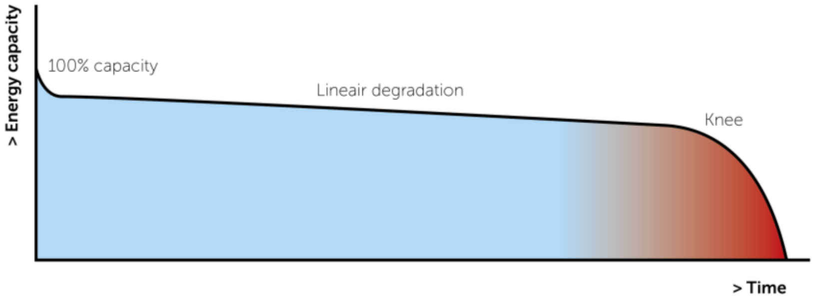


Figure 6. Illustration of typical lithium-ion battery lifetime energy capacity.

Operational window

The operational window of a lithium-ion storage system refers to the range of parameters such as voltage, current, temperature and capacity in terms of Ah to ensure that the battery pack or system can function without failure as intended by the manufacturer. Example parameters are minimum/maximum cut-off voltage, minimum/maximum (dis)charging current, operating temperature range, and usable capacity. The range or the absolute values of these parameters should be in line with datasheets provided by the manufacturer.

It is important to distinguish the safety window and the economic window (Figure 7):

- The safety window refers to the maximum tolerable range of parameters such as voltage, temperature, and current to ensure that the battery pack or system can function without failure. The safety window consists of hard limits which are set by the BMS.
- Economic window refers to the range of parameters to ensure that the battery pack or system can function to attain the desired economic performance in line with the business case of the application or to extend the lifetime of the battery pack or system. Example parameters are economic operating temperature range, economic operating voltage range, and economic operating range (dis)charge rate. The economic window consists of soft limits which are set by the storage EMS. The economic window is indicated in Figure 7a in light blue.

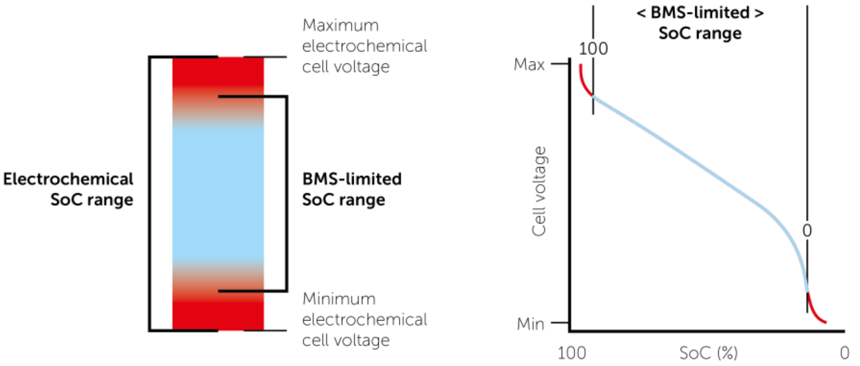


Figure 7. a) The operational window of a lithium ion storage system. The safety window is hard limited by the BMS, optimal (economic) performance, indicated in light blue, is EMS responsibility. The economic window is always smaller than the safety window. b) The relation between the cell voltage and the SoC. The safety window is limited by the cell voltage of a lithium ion storage system.

3.3.2.2 Flywheel

A flywheel is an example of kinetic energy storage system, energy is hence stored by the rotational kinetic energy of a spinning mass that is the rotor. In charging mode, the rotor is accelerated by an electric machine (here the electric machine acts as a motor). During discharging mode, this electric machine is used to decelerate the rotor hence acting as a generator. The spinning mass like the rotor is placed in a vacuum chamber to reduce friction losses and magnetic bearings are used to keep the rotor in position.

The amount of energy that can be stored in a flywheel is proportional to the following parameters:

- Mass of the spinning rotor.
- Square of the rotational speed of spinning rotor.
- Square of the radius of the rotor.

Safety functionality

Important safety aspects safeguarded by the storage systems are torque vibrations, mechanical failure of the flywheel or its components, malfunction of the bearing system, vacuum system, and malfunction of the cooling system. The BMS ensures the rotating speed stays within the safety limits. To mollify the failure modes, flywheel systems incorporate a containment to detect when parts of the flywheel can trigger an unsafe situation.

Performance functionality

In regard to optimum performance of the energy storage system, the following parameters are important: speed of the flywheel, the upper and lower limit of the speed of the flywheel and vacuum of the system.

A flywheel is expected to experience limited degradation, but replacement of pumps and bearings is expected after an amount of years. Depending on the material used for the flywheel: fatigue of material is expected after 15-25 years.

3.3.2.3 Flow battery

Redox flow batteries use two electrolytes to store energy: one in high oxidation state and one in low oxidation state. Redox flow batteries exist in a variety of combinations of electrolytes, mostly used are the zinc-bromide flow battery and the vanadium redox flow battery technology. The electrolytes are divided by a separator, such as an ion-selective membrane, which, in charging and discharging conditions, allows selected ions to pass and complete chemical reactions at the cell level. A flow battery uses an ion-exchange membrane (through which the electrolyte is fed), a liquid circulation pump for the electrolytes and a controlling BMS system. The total available energy capacity depends on the amount of active chemicals that is stored in two separate tanks and the total available power depends on the active electrode area within the cell stacks. Flow batteries can easily be scaled due to their independence in terms of energy and power rating from the battery system.

Safety functionality

The BMS system needs to make sure the (corrosive) electrolyte is in good condition. Monitoring operating temperatures and electrolyte spillage is therefore essential.

Performance functionality

Redox flow batteries use a controlled pump to induce flow and improve the performance and efficiency of the battery. Degradation of the membrane causes efficiency losses.

3.3.3 Storage Energy Management System vs Battery Management System

There is a clear separation of tasks between the storage EMS and BMS. The battery management system ensures safe operation. The storage energy management system optimizes battery efficiency and lifetime, or in other words: the storage EMS determines when, and at what rate which part of the energy storage system shall be charged, idle or discharged.

The BMS ensures that the storage system is operated in recommended safe conditions. Each BMS is designed specifically for a particular chemistry type and cannot be used for other batteries. In general, lithium-ion based battery systems needs a relatively advanced BMS for safety and lifetime reasons.

The lithium-ion battery management system measures and monitors the battery critical parameters; at least voltage and temperature, but more advanced BMSs also measure the current and leakage currents to detect possible faults. Note that for lithium-ion batteries, there are a wide range of chemical materials utilized which can affect both current and voltage ranges.

The control safety functionality of the BMS provides cell balancing and ensures that the batteries are operated in the recommended safety operation range. The BMS processes information from low-level measurement systems, such as cell battery management systems and module battery management systems, depending on how the storage system is structured (Figure 8). Examples of control to stay within safety limits are over-current protection, under/over-voltage protection, over-(dis)charge protection, low/high temperature limits, and low/high voltage limits. The values of safe operation are unique to each battery equipment and its chemistry, so there are no uniform temperature and voltage limits across the market. Advanced diagnostic, such as cell pressure, electrolyte conductivity, flow rates, density of electrolyte, etc. are implemented in specific cases.

Most communication of the BMS occurs within the storage system: cell balancing to the module/cell BMS, temperature settings to the temperature management system, and to protective devices (isolators) or protective electronic circuits. Availability and maintenance are communicated externally. A good BMS design provides fail-safe protections to ensure safe operation of the energy storage system.

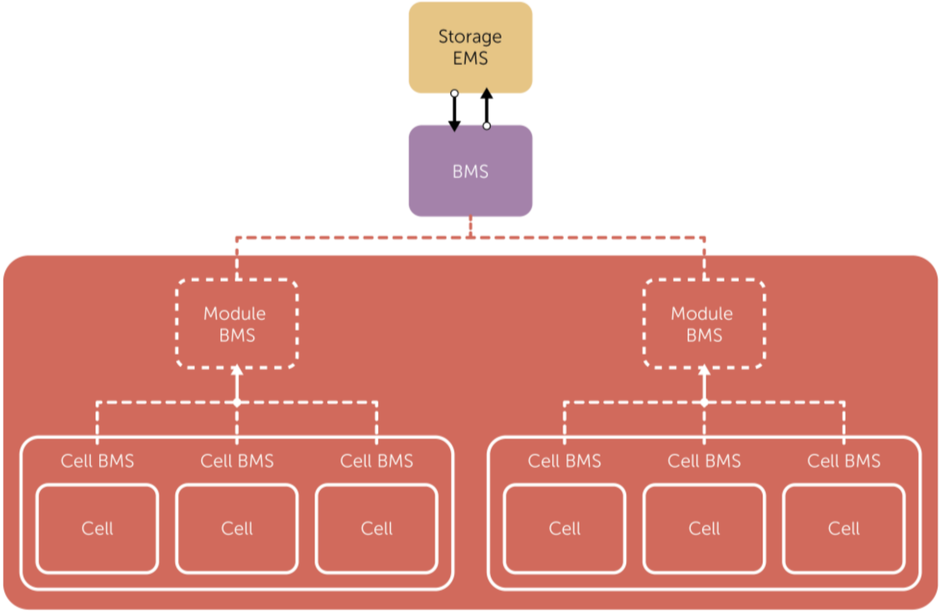


Figure 8. Schematic overview of the BMS information with the cell battery management system (cell BMS), module battery management system (module BMS) and battery management system (BMS).

The storage EMS optimizes the storage systems efficiency and lifetime. It uses the measurements from the BMS to estimates its state. Variables such as state of charge (SoC) and state of health (SoH) are monitored with respect to manufacturer recommended values. Optimization of the operation of the storage system can be realized through cell balancing, optimal operation of the thermal management system and load management. The storage EMS determines when and at what rate the energy storage equipment shall be charged, idle or discharged and coordinates the operation of the battery equipment through the power converters applicable to the relevant operating schedule e.g. to provide frequency response services. This can occur locally with minimal response times (milliseconds or less) based on locally measured data (e.g. current, voltage, energy, power, frequency) or within an external energy management system, possibly with external signals, which leads to slower response times (seconds).

4 COORDINATING EMS - STORAGE EMS INTERFACE

Simple and effective interaction between the coordinating EMS and storage EMS are necessary in order to scale up energy storage technologies, and to allow effective collaboration between actors in the energy sector.

Through simple interaction, continuity of operation at controlled costs is guaranteed. The following aspects play a role in the simplicity of interaction:

- **Interoperability**: the extent to which different coordinating EMSs can be combined with different storage EMSs (different suppliers, product generations, storage technology; interchangeability with other energy-intensive devices in addition to a storage EMS).
- **Flexibility**: the extent to which adjustments to coordinating EMSs, storage EMSs and their interaction can be implemented at low costs, throughput times and risks.
- **Separation of concerns**: the extent to which responsibilities for subsystems (coordinating EMS, storage EMS) can be separated and in which achieved results and required activities can be assigned to different parties.

The following aspects play a role in the effectiveness of the interaction:

- **Bandwidth**: the extent to which a coordinating EMS can use the freedom of an energy storage system via a storage EMS to optimize a use case.
- **Responsiveness**: the extent to which an energy storage system is able to respond quickly to control signals from a coordinating EMS and provide accurate feedback.
- **Safety**: the extent to which safety and security of the physical battery system and integrity of the (local) energy system remain intact, despite internal and external disruptions.

4.1 Ecosystem ‘flavors’

Figure 4 (in chapter 3) shows the complete overview of the interactions between coordinating EMS and storage EMS. In general, we can distinguish three categories: simple ecosystem system, the single location ecosystem and the aggregator ecosystem.

4.1.1 Simple ecosystem

The coordinating EMS functionality can be built into and be part of the (battery) energy storage system (Figure 9). The storage system is the only device providing flexibility and does not need to interact with other systems in order to optimize the energy management. The separation of tasks is still relevant; therefore the interface lies within the (battery) energy storage system.

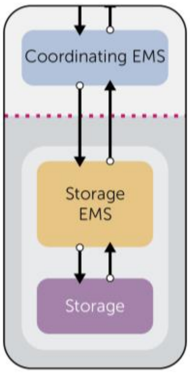


Figure 9. The interface between the coordinating EMS and the storage EMS is located within the storage system.

4.1.2 Single location ecosystem

The coordinating EMS of a building, flat or other location, consider different flexibility solutions and optimize for economic, self-consumption, or sustainable use.

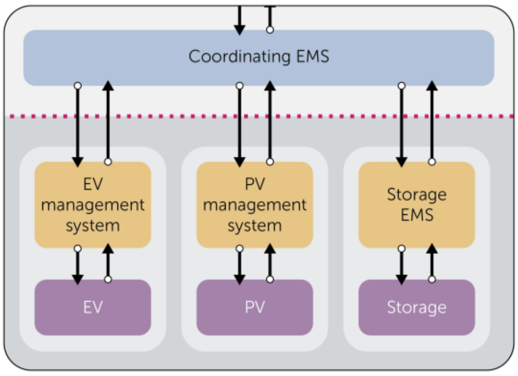


Figure 10. Local optimization by the coordinating EMS in a building or industrial area, considering and using different flexibility devices for the (multiple) EMS use case(s).

4.1.3 Aggregator ecosystem

The coordinating EMS that has direct access to the markets and uses flexibility devices to optimize its portfolio with trading on the different energy markets.

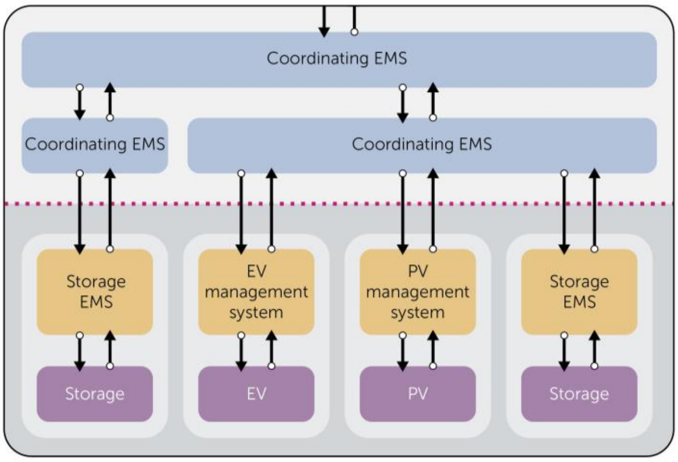
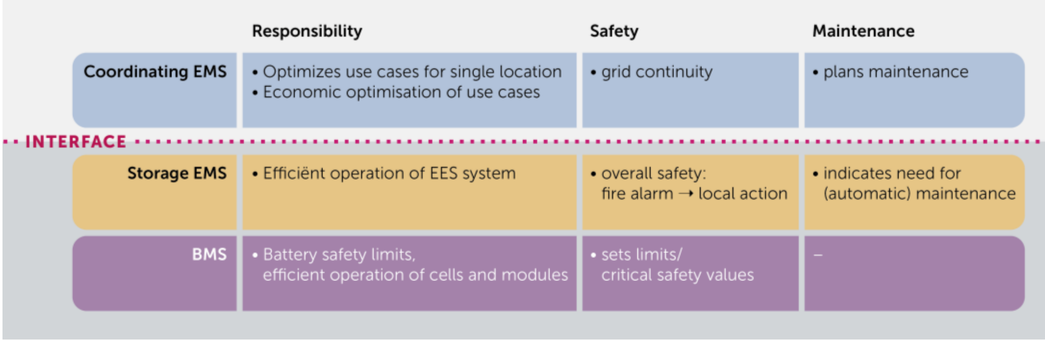


Figure 11. The coordinating EMS that has direct access to the markets and optimize for economic use of the different flexibility devices for its portfolio.

4.2 Summary responsibilities

The previous chapters describe the top-down and bottom-up approach regarding the tasks and responsibilities of an energy storage system and energy management on both sides of the interface. This is summarized in the table below.



	Responsibility	Safety	Maintenance
Coordinating EMS	• Optimizes use cases for single location • Economic optimisation of use cases	• grid continuity	• plans maintenance
INTERFACE			
Storage EMS	• Efficiënt operation of EES system	• overall safety: fire alarm → local action	• indicates need for (automatic) maintenance
BMS	• Battery safety limits, efficient operation of cells and modules	• sets limits/ critical safety values	–

Table 1. Overview of the responsibilities, safety and maintenance of the coordinating EMS, storage EMS and BMS.

In the previous chapter, both the needs for the storage EMS/BMS and the coordinating EMS are described. This chapter will describe the relation between the two. This means that the result of the storage EMS/BMS, the KPIs, which are linked to the result of the use cases in the coordinating EMS, and the control strategies are linked to each other.

Typically, the coordinating EMS sends control messages to the storage EMS. Sometimes, the storage EMS needs freedom to act, e.g. when a complete charge/discharge cycle must be performed for maintenance of the storage system. Even then, the storage EMS puts in a request with the coordinating EMS and starts after an acknowledgement from the coordinating EMS. In case of an acute problem, the storage EMS can reject the command of the coordinating EMS and change its state of health.

Note that the properties that are communicated over the interface, should be directly usable values. E.g. that when a SoC (state of charge) is communicated, not the percentage of SoC is communicated but the amount of energy that can be charged and the amount of energy that can be discharged. In that case, the values can be directly used by the coordinating EMS. Relations to the max. storage power, temperature of the storage, etc. are made by the storage EMS and aren’t relevant for the coordinating EMS.

In short, the communication between the coordinating EMS and the storage EMS should only contain the information that is actionable to the other system, in terms (generally energy and power) that both systems can relate to. In the following figure, examples of common information to be exchanged between the coordinating EMS and the storage EMS is shown for both non-real time and real time use cases.

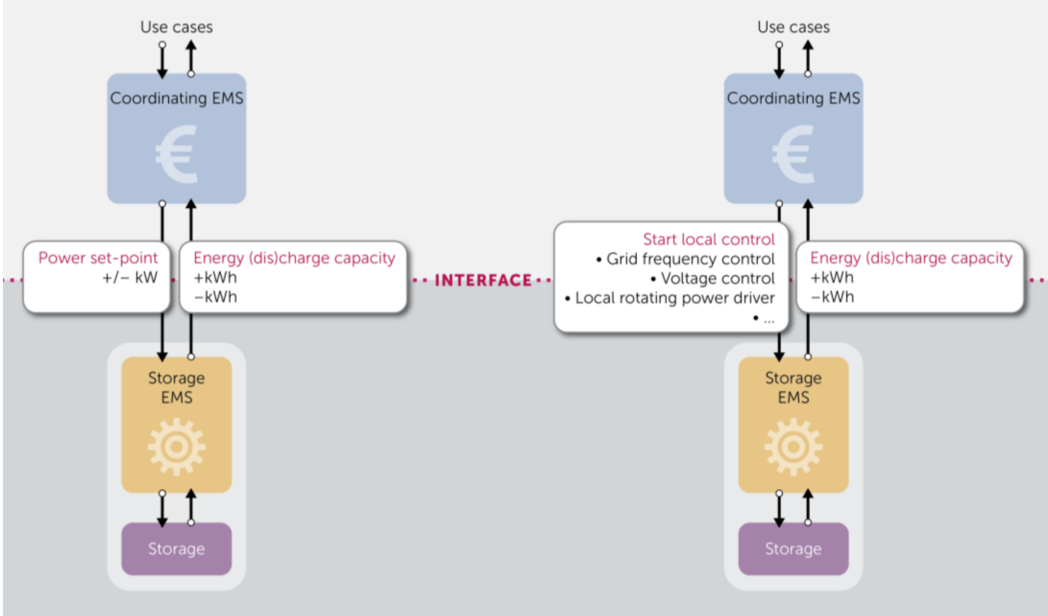


Figure 12. Non-real-time (left) vs real-time (right) communication between the coordinating EMS and the storage EMS.

4.3 Other general interface aspects

4.3.1 Cybersecurity

The interface is part of a critical infrastructure. Cybersecurity is an important issue that should be noticed from the design phase on, as many current reports from different industries underscore[1].

When large storage units can be controlled by hackers, it becomes possible to influence the power grid in such a way that it could shut down. Large storage units can be both a single large storage unit as well as a cluster of small storage units that can be controlled remotely from a single location (e.g. the manufacture maintenance department).

To avoid misusage of the storages, some good practices should be taken:

- Make it impossible for hackers to remotely update the firmware. The easiest way is to forbid remote firmware updates. This is a particularly good solution for large storage units. When remote updates are the only practical solution, the updates must be signed and only be installed when checked for authenticity.
- The network between the storage EMS and BMS should be physical separated from the network of the storage EMS of the other world. The storage EMS must be properly secured. The BMS, from where the true control is executed, should not be directly accessible from the outside world.

4.3.2 Safety

Responsibilities of safety must be well defined. In general, safety should be as local as possible. This means: the BMS is responsible for the physical safety: fire, overcharging, etc. It may not be possible to (physically) damage the storage through the interface. Both the technical as well as the legal safety limits are the responsibility of the BMS, in both situations whether the manufacturer designed it himself or integrated standard components from the market. The storage EMS can/will take extra measures in case the BMS fails such as: controlling fire reduction measures or physical

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[1] E.g. see reference [7] for an interesting and relevant example.

warning signs. The coordinating EMS is not responsible for the safety of the storage. The interface will never be suitable for dealing with safety issues.

4.3.3 Reliability of SoC

The storage EMS, with the BMS information, will determine the SoC. This SoC will be used to communicate the amount of energy that can be stored or discharged. For several types of storage systems, the SoC becomes less reliable after a period of time. Sometime a full charge-discharge cycle is needed to make the SoC reliable again. For the coordinating EMS it is important to know the (derived) values of the SoC with some form of certainty. It is the responsibility of the storage EMS (through the BMS) to determine the reliability of the values and to communicate them to the storage EMS.

For some situations, it is good practice to distinguish between the type of usage: average use, high power use, minimal use, etc. The values can differ per type of use.

5 GOOD PRACTICES

This chapter describes good practices to consider *for the developers* and *system integrators* of energy storage systems and for service providers who work in the field of energy storage (hardware/software) when developing an energy storage system.

5.1 Ecosystem

5.1.1 Be aware that you are part of a big ecosystem

An energy storage system never functions on its own. It is always part of a bigger system. The ecosystem around the energy storage system (appliances, other storage systems, renewables, applications, etc) will change continuously. It is therefore important to consider potential future changes and include flexibility in order to adapt and so storage systems can be used by different ecosystems with their use cases.

5.1.2 Keep functions separate

Do not put everything in one system. The world is connected and you, as a company, cannot provide connections to everything. To do this, clear definitions of components with well-defined functions are necessary. The interfaces between the modules must be simple and clear. When interfaces become complex, reconsider the definition of the component.

5.1.3 Critical infrastructure

The energy infrastructure is a critical infrastructure for a country. This infrastructure is interesting to, not only regular hackers, but also foreign countries as they would like to control this infrastructure. Knowing that, e.g. in Europe, all the countries are connected, makes this an even more vulnerable position. This means that designing parts for the grid must be with (cyber)security in mind (security by design). Also, small storage units can become critical when there are (too) many systems installed and there is only a single maintenance link between the head office and the storage units.

Cybersecurity is not only a communication issue. It is a way of thinking that reflects on software, hardware and communication. When designing an EMS of BMS, be aware of the risks and take measures to prevent risks that are not acceptable (but do not take measures for acceptable risks). For more info, see reference [8] for a general guide of good practices.

The reason that a coordinating EMS should be made resilient to cyber security and other integrity compromising events is that is almost by principle a focal point for risks. If its function is to keep a local grid stable, failure to do so (or even efforts to do the opposite) will put the local energy infrastructure at risk.

A corollary of this is that the coordinating EMS and storage EMS must be designed and dimensioned to overcome a situation where they may temporarily be out of communication with each other. First, they must be explicitly aware of the availability and health of the other system (using frequent communication as a heartbeat function). Secondly, they must have explicit instructions and freedom of movement if communications are down. Should the storage EMS the for instance shut down the activities of the BMS? Or should it remain executing the command it was already running? Does the coordination EMS have enough other resources to control if it is out of synch with a single storage EMS?

5.1.4 Focus on functionality instead of technology

It is easy to define a system based on what (you think) is state of the art technology at that time. Most of the requests are designed for a long lifetime, during which maintenance parts of systems will need to be changed. When you, during your request, focus on functionality and on well-defined open interfaces between the modules, the system can be maintained for a longer period. If part of the system needs to be exchanged, it is possible to upgrade that part (e.g. because of new security knowledge). One of the main issues is a well-defined (open) interface between the different components.

5.2 Interface between coordinating EMSs

5.2.1 Single interface

It is recommended to request a single interface between different coordinating EMSs, and between the storage EMS and coordinating EMS. This reduces the complexity and forces the designer to think about a truly functional interface. It could be allowed that the coordinating EMS – storage EMS interface is a subset of the coordinating EMS-coordinating EMS interface because of the required additional information.

As a note to aggregators (even though they are not the prime focus of this report:) aiming for a single interface makes stacking of coordinating EMSs easy. The coordinating EMS does not know if the underlying system is another coordinating EMS or a storage system. In terms of functionality, it is just the same.

5.3 Interface coordinating EMS – storage EMS

5.3.1 As simple as possible

Albert Einstein already knew: “Everything should be as simple as it can be, but not simpler”. A statement that is particularly applicable to interfaces. Sometimes we like to communicate values that are specific to a type of storage. If this is done for all the storage types, the interface will be too complex and set apart by the industry. Hence, the interface should be more generally applicable. This means that all the items that are communicated must be usable in general. Special values for e.g. only one specific storage should not be implemented in the interface. In that case, more functionality or calculations should be defined in the storage EMS/BMS to make the values more general.

In general, the communication between the coordinating EMS and the storage EMS only consists of the control strategy. The coordinating EMS translates the (global) grid functions to control strategies and the storage EMS translates the control strategies to physical controls. The interface definition must be as clean as possible. It only shares actionable information via the interface.

There is a difference between real-time and non-real-time control strategies. To keep the interface simple, the real-time control strategies have functionality on the storage EMS so only control parameters that are send via the interface. With non-real-time control strategies, the (often more complex) functions are running on the coordinating EMS and settings are communicated to the storage.

5.3.2 Stacking of coordinating EMS

The energy network is used by a lot of different users, all with their own concerns. Every user will have an EMS that controls their needs. The concerns can be local (e.g. a building) or but can also apply to a bigger geographical scope (e.g. a DSO or TSO). A regional oriented coordinating EMS may need to control multiple local EMSs. In that case, EMSs are stacked. To make sure this will work, all the EMSs must have a similar interface. So, for the EMS, it is equally simple to communicate with a coordinating EMS or a storage EMS.

5.3.3 Use standards/open interfaces

Proprietary interfaces hinder the growth potential of the system and limit the possibility to integrate components from other companies. Also, they require high maintenance in terms of bug fixing. An ecosystem will evolve, the market will change as well, and with that, the value of your part in the ecosystem.

It is preferred to use open standard interfaces. The interfaces are used for a longer period of time and problems are normally fixed. When in development, not only you are adding to a success, but also to other companies who adapt to that interface. When there is no standard interface, you can design and publish the interface. In that case other companies can add parts to the ecosystem to increase the value.

5.3.4 Information sharing/communication

The communication between the coordinating EMS and the storage EMS is a between a real-time and a non-real-time component. The result is that the communication is non-real-time (the slowest of the two). Also, this communication must be independent of the storage type due to the fact the coordinating EMS must be able to control different types of storages.

Knowing this, be aware of the following:

- Safety related values are not communicated over the interface. Safety is the responsibility of the local BMS/storage EMS.
- Storage dependent values are not communicated; only generic values that are actionable for both the coordinating EMS and the storage EMS.

5.3.5 Reliability of the values

Values that are used in functions/control algorithms are communicated over the interface. A clear definition of the parameters that are communicated is necessary. It is recommended to use the definition from standards. As a guideline the definitions from Appendix 2 can be used. Also, the uncertainty of these parameters should be considered to ensure that the storage system can always deliver the required energy/power over time. Periodically recalibration of the system, for example using a full charge-discharge cycle to determine the State of Charge or State of Energy is recommended.

It is good practice to send the uncertainty of values over the interface or overdimension the storage system, so that the delivery (discharging) or storage (charging) of energy (kWh) and the required power (kW) can be guaranteed.

5.4 BMSs and storage technologies

5.4.1 Cybersecurity considerations

Safety limits are the responsibility of the BMS. For cybersecurity reasons, it is recommended that it should not be possible to externally change the BMSs safety limits by, for example, hard coding in the circuit board. Another potential solution, which would allow for technical development, would be to only allow firmware updates to be installed locally. Depending on the acceptable safety level, a preferable cybersecurity solution should be chosen. Nevertheless, it should never be possible to overwrite BMS safety.

5.4.2 Battery system integrator needs to understand the ESS

A system integrator should understand the ESS technology in order to build the system architecture. A good system architecture clarifies responsibilities and has a clear structure on communication levels. The low-level BMS should be the master aspect in order to safeguard the system. When the technology and corresponding safety considerations are unknown, it is recommended to build the system from modules where BMS functionality is already incorporated.

5.4.3 Second life systems: information about cell history

System integrators/developers should be well aware of the history of second life battery cells/module/packs. Check whether systems have experienced heavy shocks/extreme environmental conditions. When this information is not available, make sure to legally and technically cover this in delivery contracts (for example by using performance guarantees). Priority number one should be the capability to connect the BMS system to guarantee working safely.

5.4.4 Usable energy capacity

The available capacity is monitored by coulomb counting or voltage measurements. Both methodologies are not very accurate and have an error bar. The responsibility for the best estimation of the available capacity should be with the storage EMS. The storage EMS sends regular status updates to the coordinating EMS to use for economic optimization. If possible, a good practice is to also communicate an uncertainty range and to consider potential differences in lower expected power as well as the implication thereof.

5.4.5 State of charge

In case the state of charge (SoC) is unknown or comes with a great deal of uncertainty, it is recommended to periodically measure the energy capacity (kWh) to calibrate the state of health and state of charge. Validation of the energy capacity can be part of the maintenance plan. Risking a large uncertainty is to either offer too much capacity or pay charges when more energy than the delivered capability is delivered to the grid or energy market, or lies in the fact of not using full capacity, which means that less flexibility than the capability of the ESS can be put on the market.

5.5 Coordinating EMSs & control strategies

From the use case and/or control strategies perspective, consider the following:

5.5.1 Responsibilities

The coordinating EMS is responsible for the economic part of the control, where the storage EMS is responsible for the more technical part. Do not mix up the different responsibilities. Keep the responsibilities in different parts of the system.

5.5.2 Predictive algorithms

For the coordinating EMS it is important to predict the behavior of the grid in order to be able to optimize. The characteristics of the storage EMS/BMS must be known to work with the coordinating EMS.

Monitor the appliances (does the storage do what is requested?) and send out a signal when it under-performs (coordinating EMS is responsible for energy). Monitoring storage is necessary from the functionality perspective. The technical monitoring is the responsibility of the storage EMS/BMS.

5.5.3 Losses

Each storage system has losses. Some losses of energy over time and some losses in charging direction. Especially since the function of the coordinating EMS is economic, it should know where the losses for this type of storage occur.

6 RECOMMENDATIONS

This chapter describes recommendations for policy makers to consider while making policy for (scaling up the) implementation of storage system in the energy system.

6.1 General

6.1.1 Safety regulations

Concerning safety regulations for energy storage systems reference should be made to global or European applicable safety standards (e.g. IEC or CENELEC) so that ESS developers and system integrators can use their products for the global or European market. Policy makers can make safety standards mandatory and create a level playing field.

Energy storage system safety should be the responsibility of the ESS product developer/system integrator. Safety measures should be implemented as local as possible to ensure proper integration and effectiveness. This means that the BMS is responsible for the technical (e.g. fire, overcharging, etc) as well as the legal safety limits. The storage EMS can/will take extra measures in case the BMS fails such as: HVAC control, controlling fire extinguishing measures, or physical warning signs. The coordinating EMS is not responsible for the safety of the storage. It is almost impossible to create a suitable interface that communicates all safety issues.

6.2 Interface between coordinating EMS and storage EMS

6.2.1 Cybersecurity

Systems without a properly designed cybersecurity are not acceptable anymore in these times where everything is connected. Although the initial price of systems without any cybersecurity measures are cheaper, the price will in the end be paid when the system fails due to external hackers. It is recommended to request cybersecurity that adapts to the needs. It is easy to define a set of rules for cybersecurity, but the past has shown that cybersecurity will then only last for a short period of time.

6.2.2 Open interfaces

There are many open interfaces. Some come and go, others stay for a longer period of time. Before adopting an interface, it is recommended to first research the available protocols (e.g. in a separate project). There are some European initiatives like CEN CENELEC that standardize interfaces in flexible devices. It is advisable to adopt a standardized interface, which could be based on the Energy Flexibility Interface (EFI) as it has several recommendations already in place.

6.2.3 Standardization

Standardization is the key to featuring extendibility and maintainability of the complete ecosystem. At first, proprietary system looks cheaper. During operation, the effect of a standardization is clearly visible. Examples are:

- ***Interconnectivity***: when parts of the system must be replaced during the operation, it is possible to take on a modern, perhaps even cheaper, module instead of the same “old” solution.
- ***Cybersecurity***: security requirements will change over time. By using standard components (hardware modules, software modules, …), it will be economically realistic to keep them up-to-date. Proprietary solution will be too costly to maintain.

- ***Maintenance interface***: system modules will be maintained. Normally, this will first be done by the manufacturer. When the system is somewhat older, it is good to consider if there are other, more general maintenance parties, who are more cost-effective. This is only possible with an open standardized interface.

APPENDIX 1 ABBREVIATIONS

BESS	Battery Energy Storage System
BMS	Battery Management System
BMU	Battery Management Unit
coordinating EMS	coordinating Energy Management System
EMS	Energy Management System
ESS	Energy Storage System
EV	Electric Vehicles
FCR	Frequency containment reserves
FRR	Frequency restauration reserve
HVAC	Heating, ventilation and air conditioning
KPI	Key performance indicator
NMC	Nickel Manganese Cobalt
PoC	Point of Connection
PV	Photovoltaics, solar panels
PQ	Power quality
storage EMS	storage Energy Management System
SoC	State of Charge
SoE	State of Energy
SoH	State of Health
THD	Total Harmonic Distortion
Use case	(in this document) a specific situation in which the energy storage system could potentially be used.

Relation between use cases, control strategies and coordinating EMS functionality

This report briefly describes the relation between these two terms and the functionality that is running into the coordinating EMS.

Use cases are abstract descriptions of what we want to achieve with the system; what benefits does the (complete) system has to offer. All the components in the system will contribute to the use case. The coordinating EMS will be responsible to initiate and control the needed functionality to achieve what is needed for this use case.

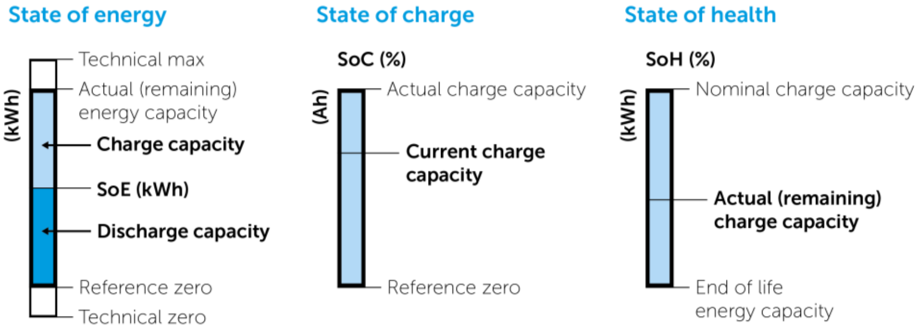
Functionality and/or algorithms are running on the coordinating EMS. These functionality/algorithms use information from the following items in order to run:

- (local) parameters to direct the needed functionality;
- requests/commands from higher coordinating EMS;
- capacity information from the storages of lower coordinating EMS;
- information from other lower appliances.

As a result of the functionality, the coordinating EMS controls the storage EMS via a control strategy. This means that the control strategies are the translation of the use case for the storage modules. If applicable, capacity information is sent to higher coordinating EMS.

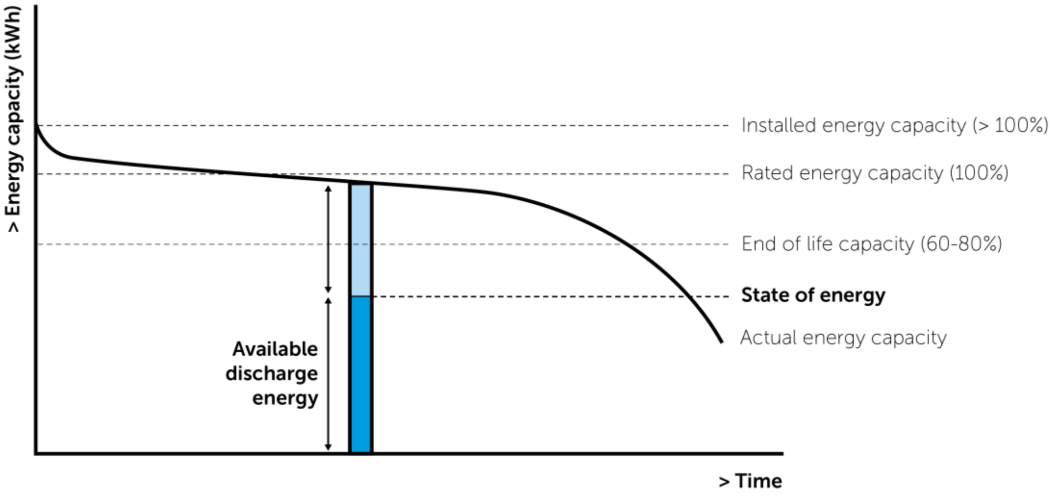
APPENDIX 2 DEFINITIONS

The key performance indicators and the definitions are summarized below.



State of health

The state of health is an indicator of degradation [2]. The narrowest definition of the SoH is the actual (energy) capacity relative to the initial rated (energy) capacity of the EES, given as a percentage. Additional indicators may be included in the SoH definition, i.e. maximum power relative to the initial rated power

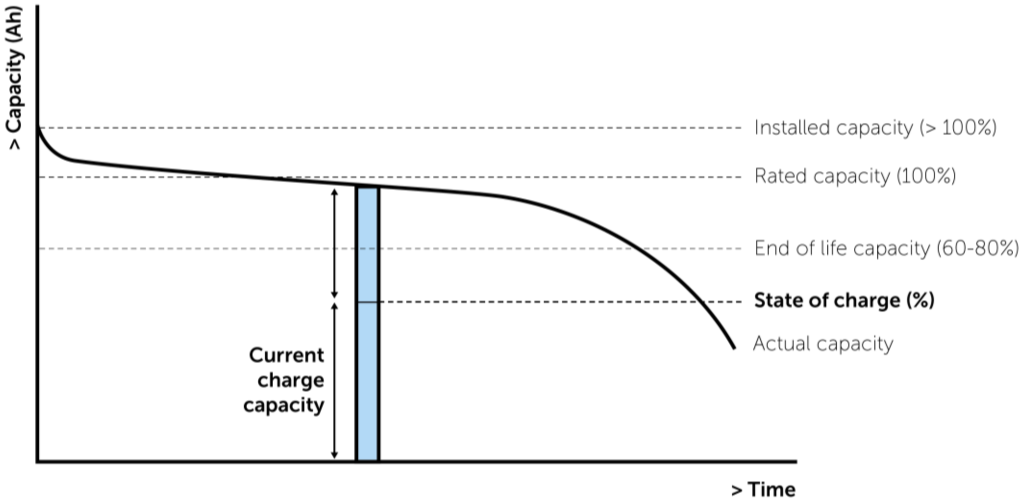


- **Actual energy capacity**
  The EES system energy capacity at any given time as a result of a degraded state of health and other factors.
- **Rated energy capacity**
  Designed value of the energy content for the EES system in continuous operating conditions, starting from a full state of charge and discharging continuously at rated active power during discharge, measured at the primary POC.**Fout! Verwijzingsbron niet gevonden.**
- **Nominal energy capacity**
  Initial value of the energy capacity of the EES as stated by the manufacturer and via which the EES is designated and identified.
- **Installed energy capacity**
  The energy capacity installed on commission of the BESS. Due to physical or chemical limitations for most storage technologies, the installed energy content is often higher than the generally usable energy content.

- **End of life**
  Moment in time after commissioning of the EES system when its performance, whether technical, financial or otherwise, has degraded to the point of no longer being usable in its current application. The end-of-life energy capacity is typically 60% for stationary applications, 80% for mobile applications.
- **Warranted energy capacity**
  The warranted energy capacity is the energy capacity that is guaranteed under the warranty of the supplier under specific conditions of use, such as number of cycles per time period and temperature range.
- **State of Energy (SoE)**
  The amount of energy stored in the EES system (indication how much can be (dis)charged.
- **Available (dis)charge energy capacity [kWh]**
  Maximum electrical energy that can be extracted from the ESS system from the current state of charge.
- **Actual energy capacity**
  The EES system energy capacity at any given time as a result of a degraded state of health and other factors.

State of charge [%]

The degree to which an electrochemical EES has been charged relative to a reference point (defined as SoC = 100%) indicating the total electrical charge that can be stored by the EES. The SoC reference point should be the actual charge capacity. [2]



- **Actual capacity**
  Actual value (i.e. present value) of the capacity of the EES.
- **Rated capacity**
  Capacity value of a battery determined under specified conditions and declared by the manufacturer.
- **Nominal capacity**
  Initial value of the capacity of the EES as stated by the manufacturer and by which the EES is designated and identified.
- **Available (dis)charge energy capacity [kWh]**
  Maximum electrical energy that can be extracted from the ESS system from the current state of charge.
- **Capacity**
  Electric charge which a cell or battery can deliver under specified discharge conditions.

APPENDIX 3 REFERENCES

[1] DNV GL, *2019 Battery performance scorecard*, November 2019, online available at https://www.dnvgl.com/publications/2019-battery-performance-scorecard-160620

[2] DNV GL, *GRIDSTOR recommended practice on safety operation and performance of grid-connected energy storage systems*, Sept 2017, online available at https://rules.dnvgl.com/docs/pdf/DNVGL/RP/2017-09/DNVGL-RP-0043.pdf ,

[3] IEC 62933-1:2018, *Electrical energy storage (EES) systems - Part 1: Vocabulary*

[4] IEC 62619:2017, *Secondary cells and batteries containing alkaline or other non-acid electrolytes – Safety requirements for secondary lithium cells and batteries, for use in industrial applications*

[5] IEV 482-03-15, *rated capacity*, http://www.electropedia.org/

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[7] Applied Risk, I Own Your Building (Management System), November 2019, online available at https://applied-risk.com/resources/i-own-your-building-management-system

[8] TKI Urban Energy, Cyber Security for smart energy, online available at https://www.topsectorenergie.nl/tki-urban-energy/kennisdossiers/cyber-security-voor-smart-energy

TKI URBAN ENERGY
Topsector Energie

Arthur van Schendelstraat 550
3511 MH Utrecht

Telefoonnummer: 030 747 00 27
Email: info@tki-urbanenergy.nl

volg ons!

@TKIUrbanEnergy