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DECENTRALISED STORAGE: IMPACT ON FUTURE DISTRIBUTION GRIDS

A EURELECTRIC report, June 2012

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Decentralised storage: impact on future distribution grids

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Executive Summary

Europe’s electricity system is undergoing profound changes. The EU is planning a decarbonisation path that will see the EU and other industrialised countries reduce their emissions by up to 95% by 2050. To reach this ambition of a carbon-neutral power supply, the electricity sector will see an increase of variable renewable energy sources (RES) like wind and solar power in the energy generation portfolio.

As a consequence, the electricity system will not only continue to face varying electricity demand throughout the day, but increasingly experience generation-driven fluctuations. This will lead to challenges in ensuring the stability of electricity supply. Electricity storage is one of the flexible solutions to reduce temporary mismatches between supply and demand. Conventional and pumped hydropower already support the integration of increasing amounts of RES by providing the necessary flexibility and storage capacity to balance fluctuations.

However, peak production of intermittent renewable sources that feed into the medium and low voltage grid will require additional small-scale, grid-connected electricity storage solutions. This ‘decentralised’ storage can support the development of distributed generation. It can also provide a range of applications and services to the distribution system operators (DSOs) facing challenges such as increasing peak loads and stricter power quality requirements.

It is therefore high time to outline the role of decentralised electricity storage in the electricity grid, focusing on the impact of those technologies on the distribution grid and their implications for the DSO business. Decentralised storage systems could affect the management of the distribution grid in a number of functional areas, including **energy management**, **system services** and **the internal business of the DSO**:

- *Energy management* refers to energy arbitrage by decoupling electricity generation from its instantaneous consumption, as delivered by electricity storage facilities.
- *System services* cover the support storage could offer to quality of service and security of supply in the electric power system.
- Finally, for some special and well defined applications which cannot be provided by the market, storage devices could be installed as a grid asset to primarily support the *core operational tasks* of the grid operator.

Situated within the low- and medium voltage grid or on the customer side of the network, the present small-scale storage technologies could provide a large spectrum of performances and capacities to support and optimise the operation of the distribution system. However today there are very few indications and rules as to how to integrate decentralised storage into the distribution grid. This creates uncertainty among DSOs and storage providers regarding the necessary agreements between actors as well as storage connection and access rights.

In this paper EURELECTRIC therefore addresses the industry needs related to storage by presenting its view on the necessary division of responsibilities for each of the three areas mentioned above. Decentralised storage is not a natural monopoly. As a general rule, it should therefore be owned and operated by market actors. Depending on the storage technology and on commercial and regulatory incentives, these actors would use their storage facilities for market-driven energy management purposes and to provide system services to the distribution grid.

However, for very specific applications which cannot be provided by the market and which are exclusively used to ensure system stability, thereby optimising DSOs' internal business operations, storage could be seen as part of the grid operator's assets. These applications should of course not interfere with market arrangements.
It is against this background of storage's potential contribution to security of energy supply and CO_2 emissions reductions that policymakers should assess the requirements for future decentralised storage, thereby clarifying roles and responsibilities of the actors involved.

Key issues for policymakers: what do we need for decentralised storage to take off?

1. **Decentralised storage should be seen as a part of the development of a smarter electricity system.**

2. **Decentralised storage could serve the business of market agents as well as of DSOs. Therefore market models, roles and responsibilities of the actors involved need to be clearly designed.**

3. **Decentralised storage is not the silver bullet for a more efficient and stable grid, but should be assessed and compared to other flexibility options such as demand-side participation or back-up generation.**

4. **European research funding on storage should focus on key technologies that encourage the integration of decentralised storage systems into the electricity grid.**

5. **A holistic approach considering all costs and benefits is needed in order to achieve the EU's energy targets and smoothly integrate distributed generation technologies into the smart electricity system.**

6. **The system of grid tariffs should be reconsidered within the smart grid context.**

1. Introduction

In the last decade, European energy and climate policies have led to an accelerated increase in the application of renewable energy sources (RES) such as wind and solar. As society looks to move away from fossil fuels, these RES are attractive energy generating options: they are inexhaustible, have a low carbon footprint and can operate on a small scale.

However, unlike the dispatchable sources used for the majority of electricity generation, many RES are variable, producing alternating and partly unpredictable amounts of electricity over time. The wind does not always blow and the sun does not always shine – and neither follows peak demand. The increasing role of such RES within the electricity network has therefore raised concerns about grid reliability and security of supply.

Since the European electricity grid requires electricity generation to match consumption on a second-by-second basis, the future electricity system will have difficulties in meeting this fundamental stability requirement. Renewables will challenge the traditional way of continuously matching supply and demand. Several options exist to manage the variability of intermittent RES, integrate them into the electric grid and maximise their value: dispatchable flexible and back-up generation, demand-side participation, interconnections, market tools (e.g. market coupling) and **electricity storage**. This paper aims to develop an understanding of the last point.

Electricity storage offers the potential of storing electrical energy once generated and to subsequently match supply and demand as required. Storage technologies could therefore relax the grid's matching constraint by decoupling energy production and consumption. Indeed, it could play a variety of roles in firming up RES in different timeframes, i.e. from moment to moment, daily and even seasonally. Such storage options are not only essential to expand renewable energy sources, but also to ensure continuity of supply, increase energy autonomy and mediate against intermittent power production.

Large-scale storage, like water reservoirs and pumped storage plants, are uniquely situated to help integrate intermittent renewables. Small-scale, grid-connected electricity storage, on the other hand, will open new markets, offer new opportunities and also pose new challenges to the business of distribution grid operators.

1.1 Renewable energy sources and electricity storage: a perfect match?

With the introduction of large amounts of RES into the generation mix, electricity storage should play two important roles: it will be a source of efficiency, as it allows renewable energy sources to be captured and stored for later use, thus not wasting resources which cannot otherwise be used; and it can also be a valuable instrument to provide the needed flexibility.

We can roughly distinguish between two groups of RES: big, high power plants which are frequently situated in remote areas as well as small, low power plants which are located close to or in dense consumption areas. As a consequence two ‘bridges’ have to be built: a ‘time bridge’ between the time of generation and the time of consumption, as well as a ‘connection bridge’ between the physical generation and the consumption site.

The first bridge should be constructed by a smart market (time based generation-load balance) and the second one by the smart grid (transportation of electricity). Electricity storage systems could contribute to the generation-load balance and thus are mainly seen as an element of the smart market. However, as we will see throughout this paper, storage systems and above all small scale storage might also have a positive impact on grid investments. Buffering of high generation surplus and high generation lack might reduce requested grid capacities.

Naturally, the increase in storage capacity will both depend on and affect the existing and prospective generation mix. Therefore, in the presence of increasing levels of RES penetration, and given its intermittency, storage could be a valuable instrument that has to be taken into account by all agents within the electric sector value chain.

From a conceptual point of view of the electricity system, consider the phasing in of variable renewable energy sources (wind and sun) with the following three levels of RES in the generation mix:

A. Phasing in of RES (up to some 25% of the total power generation capacity)

The volatile electricity generation of the RES portfolio can be completely absorbed by consumers at any time. Complementary power plants are necessary to cope with periods of low RES generation. Electricity storage systems are not absolutely required in this situation.

B. Establishment of RES (up to some 45% of the total power generation capacity)

The installed capacity of RES is higher than the consumption needed. Complementary power plants are still needed to cover low annual generation times of RES. Simultaneously substantial controllable loads are also necessary in order to make use of the generated energy in times of surplus generation. In this situation, electricity storage systems can prove their value by acting as generator as well as load.

C. Dominance of RES (above some 45% of the total power generation capacity)

The installed capacity of RES is much higher than the consumption power. In this case storage systems - absorbing and feeding back energy – can become indispensable. Storage could actually 'consume' electricity at negative prices[1], thus saving the electricity until its value has increased. Additional loads and some complementary power plants are still needed; however, the capacity of the necessary power plants might be reduced.

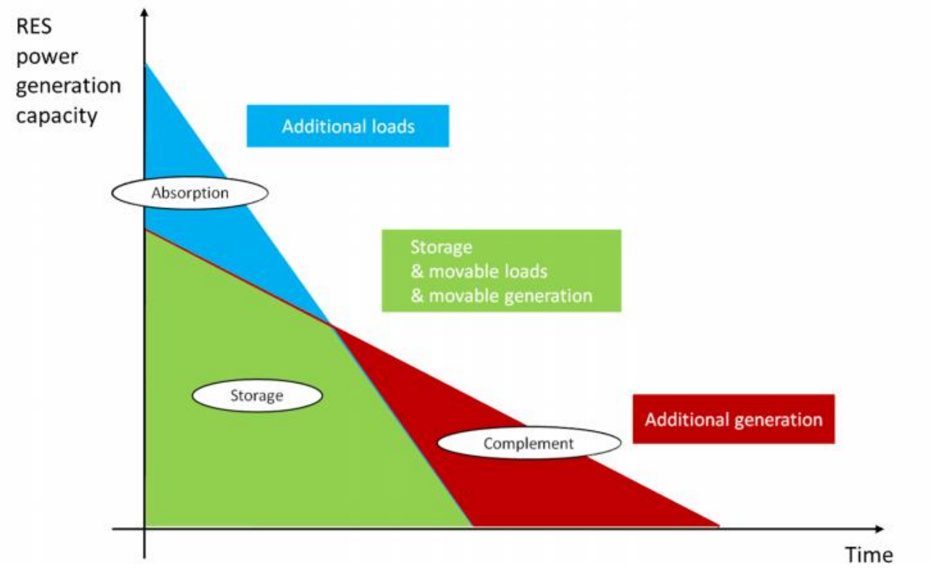

Figure 1 – The value of storage at different levels of RES in the generation portfolio

1.2 Bringing decentralised storage to the grid: the vision

Where we are today: "centralised" bulk power storage

Electricity storage systems play an important role in the electricity supply. In a relatively strongly integrated grid like Europe's, the technology for this is provided by large water reservoirs and pumped hydropower plants ranging from several MW up to more than a thousand MW. For commercial, environmental and system stability reasons, these plants are spread all over Europe, wherever the landscape permits more than 100m difference in altitude and available water resources[2]. Pumping water from lower elevation to a higher elevation is still the most practical and affordable way to store large amounts of electricity that can then be released during periods of high prices. Like other large power plants, such hydropower plants are dispatched and controlled according to price signals on the electricity wholesale and ancillary services markets or based on reserve contracts with transmission system operators (TSOs).

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[1] With high levels of RES, we may observe an increase in the frequency of situations where there is more supply than demand, even at a price of zero. To solve this issue, some power exchanges have already introduced negative price boundaries.

[2] Representing about 190 GW of installed capacity in EURELECTRIC Europe, hydropower represents about 70% of the total renewable electricity generation today. *EURELECTRIC, Hydro in Europe: Powering Renewables, September 2011.*

Along with market-driven energy management, pumped storage systems help control electrical network frequency and provide reserve generation. Unlike thermal plants, pumped storage plants can start, stop, load and unload within mere minutes. The basic business case of storage today is therefore a combination of peak shaving at the wholesale markets, asset backing, internal energy optimisation, balance control and system service for grid stability. This is all business of "central storage" application feeding into the high voltage grid. While such capacities are rather cheap compared to other technological options (especially concerning operational expenditure), they are limited to some extent, e.g. by geographical conditions and public acceptance.

Decentralised storage connected to the smart grid

Although much of the present-day grid operates effectively without storage, cost-effective ways of storing electrical energy can help make the grid more efficient and reliable. Peak production of intermittent renewable sources feeding into the medium- and low-voltage grid could foster the need for additional storage at this level. Distribution system operators (DSOs) will continue to face challenges such as increasing peak loads, more severe power quality requirements and the continuous development of distributed generation. Today's most economical method to "solve" the problem usually consists of building additional lines. Tomorrow, new additional solutions may be considered, based on active network management in which smart and small-scale storage facilities will be a resource.

Storage capacity provided by 'classical' hydropower plants connected to the high-voltage grid could in future be complemented by smaller-scale storage at transmission or distribution level:

- Adiabatic compressed air energy storage (CAES) technology is well understood but has not yet been demonstrated due to financial and technological risks.
- The world-wide development of e-mobility is linked to a new market of batteries, improving technology, market volume and price.
- Several other technologies like flywheels, super-capacitors and superconducting magnetic energy storage (SMES) may find suitable niche application for short-term storage needs.
- The huge storage capacity of the natural gas grid could be used by producing hydrogen during periods of high renewable electricity production, transforming it into methane and injecting it into the natural gas grid.

The new storage technologies, especially the batteries, range from a few kW up to some MW. They will be connected to the distribution grid. Decentralised storage could therefore play an important role in the smart grid concept of the future electrical system. In a bi-directional and less predictable system that nevertheless needs balancing, electrical storage devices in the DSO grid could deliver a "smoothing out" when supply and demand are not in balance. Moreover DSOs could take advantage of such new technical options to support conventional solutions for distribution systems.

In the long term, decentralised storage will be one of the solutions of a decarbonised power system.[3] So far however, grid-connected electricity storage technologies are seldom economically efficient. Deployment of electricity storage will depend on the economic merits of storage technologies compared to other flexibility alternatives. Initial R&D support is needed to bring technology costs down and stimulate high-value market niches. However, the potential high value of the system services market in a RES-dominated Europe, and the advantages electricity storage brings in providing these services, will ensure that decentralised storage technologies become a competitive solution.

“Centralised” versus “Decentralised”

The term “decentralised” is used as a distinction from large “centralised” energy storage technologies such as large centralised hydropower plants. Decentralised or distributed energy storage refers to such systems connected to the low or medium voltage grid. They are installed close to load centres, renewable generation sources, on distribution feeder circuits or at consumer premises behind the meter.

When referring to decentralised storage, this paper only takes into consideration technologies that transform electricity into another form of energy and then back to electricity. Systems that store electricity in the form of natural gas, hydrogen, fuelcells or heat are beyond the scope of this paper, although the authors recognise their importance.

1.3 The objective of the report

In this report, we explore the role of decentralised electricity storage in the electricity grid, focusing on the impact of decentralised storage technologies on the distribution grid and its implications for the business of distribution system operators.

Some questions need to be answered: for which purposes will DSOs be able to use storage technologies in the future? What will be the role of storage technologies among other types of flexibility solutions (such as demand response/demand side management)[4]? How will the roles and responsibilities with regard to ownership and operation of storage facilities be divided between grid operators and market actors in a smart, unbundled electricity system?

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[3] With its "Roadmap for moving to a competitive low-carbon economy in 2050" the European Commission is looking beyond its 2020 objectives and setting out a plan to meet the long-term target of reducing domestic emissions by 80 to 95% by mid-century as agreed by European heads of state and government.

[4] More information on the definition of both concepts can be found in EURELECTRIC views on Demand-Side Participation: Involving Customers, Improving Markets, Enhancing Network Operation. August, 2011.

The remainder of the report is divided into three major sections:

1. The first gives an overview of decentralised storage technologies, their characteristics and physical location within the grid. (Chapter 2)
2. The following section provides an overview of their applications in a liberalised power system, with a focus on DSOs. For each of those applications we identify stakeholder roles and responsibilities with respect to the ownership and operation of storage assets. (Chapter 3)
3. Regulatory issues and potential barriers are addressed in the final recommendations. (Chapter 4)
4. The annex showcases some national examples of small-scale grid connected storage projects.

What about Power to Gas?

In the reshaping of the European energy system, gas (and also heat) networks may emerge as a critical new infrastructure requirement. One promising approach to longer term storage of large quantities of renewables electricity is to use the natural gas grid. Power-to-Gas (P2G) is a recently developed technology that produces natural gas using electricity.

The process involves the use of excess power to produce hydrogen by electrolysing water and, if required, the conversion of hydrogen into synthetic methane by reaction with carbon dioxide (CO2) [www.powertogas.info].

The resulting renewable gas can be stored and transported in the gas network and its distributed gas tanks. This can be done by feeding the gas into the natural gas grid. Alternatively, it can be burnt on demand in gas-fired power plants and generate electricity when needed.*

The innovative idea is to use the technology, which is known from the chemical industry, for energy management. Economies of scale and technical conditions mean that such applications will fall in the range of several MW. It is bound to gas storage or gas pipelines and thus not available for most distribution grid regions. It is therefore at the borderline between large-scale and decentralised storage applications and will not be discussed within this report.

* The efficiency of P2G is 60% and 35-40% for converting power to gas to power (P2G2P).

1.4 Implications of decentralised storage for the smart grid

Much of the smart grid development is driven by a desire to improve capacity factors[5] of RES installations by shifting the demand curve through either incentives or controls. Energy storage offers one way to help balance the system as a means to adapt production to demand while improving capacity factors.

In other words, a future smart grid without decentralised electricity storage could be like a computer without a hard drive: seriously limited. Energy stored throughout the grid can provide dispatchable power to address peak power needs, making the price less volatile. Looking to the high-level services for smart grids,[6] decentralised storage may contribute to:

1. *Enabling the network to integrate users with new requirements;*
   Decentralised storage can help to mitigate congestion in the capacity of power supply and allows greater use of intermittent renewable generation technologies. At the same time, decentralised energy storage can respond promptly to imbalances that generate unacceptable voltages or currents in the low and medium voltage grid, caused by such non-dispatchable resources.

2. *Enhancing efficiency in day-to-day grid operation;*
   Instead of reducing RES generation due to distribution system congestion, decentralised storage can help to save the energy and shift it to time periods with available grid transfer capacities. Excess energy can be stored and then delivered when the distribution system is not congested.

3. *Ensuring network security, system control and quality of supply;*
   In the case of regional lack of quality of supply decentralised storage devices may support load curve smoothing and voltage control. The vast majority of grid-related power quality events are voltage sags and interruptions of less than two seconds – instances where distributed energy storage solutions can be valuable.

4. *Enabling better planning of future network investment;*
   Independent of DSO needs and of smart grids, decentralised storage will grow as the energy system becomes more decentralised. Decentralised storage can offer valuable services to the smart grid which should help to optimise operation of and investment in grids. A decentralised storage system can shave the peaks off the distribution transport capacity demand, which leads to a possible postponement of investments in grid capacity and to its more efficient use.

5. *Improving market functioning and customer service;*
   The overall service to the end-user can be significantly improved with decentralised storage applications distributed throughout the local grid. For instance, batteries in a smart grid can provide limited local (back-up) energy. Energy service providers could use on-site decentralised energy storage to provide premium reliability and power quality services to

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[5] The capacity factor of a power plant is “the ratio of the actual electricity produced in a given period to the hypothetical maximum possible, i.e. if the plant had operated at full nameplate capacity around the clock, throughout the whole year.” Definition in EURELECTRIC Power Statistics.

[6] As defined by the European Commission Task Force on Smart Grids (2010) Expert Group 1: Functionalities of smart grid and smart meters.

(large) customers, for a price. Simultaneously, suppliers or energy service providers will have the opportunity to develop and sell new products and services.

6. *Enabling and encouraging stronger and more direct involvement of consumers in their energy usage and management;*
   A smart grid will provide consumers with safe, reliable electricity on demand. The implementation of demand side management and demand response tools should be considered as another way to optimise the use of grid assets and stimulate consumer interaction. By installing storage devices at the end of the grid, close to electricity consumers, decentralised storage systems will empower those consumers. In the end the consumer will benefit without being involved in power management. Decentralised energy storage, being bidirectional, will thus increase the grid's ability to absorb increasing demand response resources and can at the same time be used as a demand response tool.

Compared with long-term future services of the smart grid, most important short-term benefits of decentralised electricity storage for distribution system operators involve "buying time"[7]:

- Deferring system (and grid asset) upgrade costs and replacements by reducing load peaks;
- Improving service reliability and stability support where conventional solutions (newly built power lines or substations) might not be readily available or would take several years to implement;
- Allowing more recovery time for the power system during scheduled or accidental power interruptions, while providing interim power to customers;
- Providing short-term flexibility to strategically develop and implement less costly, more efficient responses to changing business conditions and system operations.

Whereas the long-term benefits of decentralised storage are the motivation behind the development of the future smart grid, it is actually the short-term benefits that help devise a starting strategy for achieving that goal. In integrating the concept of supply of services from decentralised storage into their investment decisions, DSO executives will be encouraged to assess alternative grid asset and system investments more fully. At a time when investment in smarter grids is urgently needed to achieve agreed political targets, this will create an incentive to consider new ways of doing electricity distribution business and the inclusion of emerging technologies.

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[7] NOURAI A., Installation of the First Distributed Energy Storage System (DESS) at American Electric Power (AEP) – A Study for the DOE Energy Storage Program, Sandia National Laboratories, SAND2007-3580, 2007.

2. Decentralised storage technologies in the electricity value chain

The storage of electricity does not usually involve the storage of the electric energy itself. Rather, electricity is taken from the electric network and transformed into a storable form of energy with a certain efficiency factor, allowing it to be preserved for some time. When needed, the stored energy is then rapidly converted to electric energy (with certain losses).

Common storable forms of energy include chemical, magnetic or mechanical energy. Some electric storage technologies are more appropriate for providing short bursts of electricity for certain power quality applications, such as smoothing the output of variable renewable technologies from hour to hour. Other technologies are useful for storing and releasing large amounts of electricity over longer time periods.

Recent interest in developing and testing storage technologies throughout the electricity value chain have been motivated by at least four factors:

- Advancements in new decentralised storage technologies;
- The development of deregulated energy markets including markets for high-value ancillary services;
- Challenging future adjustments to transmission and distribution facilities;
- The perceived need for storage and the opportunities it can bring in a RES-dominated Europe.

Electric energy storage could be of utmost importance in **two broad functional areas**:

1. **Energy management**

Electric energy management can be defined as the practice of arbitrage in the energy market by decoupling the generation of electricity from its instantaneous consumption. From this side the possible energy efficiency gains should be capable of providing the economic resources for sustaining the profitability of the activity.

In this context energy management is thus intended to provide the service of supplying energy by using generation, transmission, distribution and, eventually, consumption assets in the most efficient way.

- **On the production (generation) side:** Storage delivers energy capacity opportunities to the wholesale market and for energy arbitrage. In the transition from subsidising fixed tariff systems for RES to a system of market-driven products, storage is needed to compensate intermittency and to enhance the availability of RES production, especially concerning non-manageable renewable energy generation.
- **On the network (transmission and distribution) side:** Storage facilities could contribute to an increase of the utilisation factor of the network and investment deferral.

- **On the load (consumption) side:** Storage facilities may help to shift demand for electricity from peak times to off-peak times, levelling the asset load, improving the utilisation and serving the consumer.

2. System services

A **system service**, in this paper, is defined as any service that can be provided by distributed energy resources (DER), e.g. demand side management[8], distributed generation, electric vehicles or decentralised storage, in order to improve and support the quality of service and the security of supply in the electric power system.

Electricity storage could be useful to guarantee the power quality of supply for consumers. New electric storage facilities could cost-effectively reduce the variations in power flow that RES generation could introduce – mainly voltage sags and swells and voltage fluctuations, although not necessarily flicker[9].

Energy Management	**System Services**
Decoupling the generation of electricity from its instantaneous consumption.	Any service that is able to improve and support the quality of service and the security of supply in the electric power system

Stakeholder groups for electricity storage systems include generators, transmission and distribution system operators, traders, retail service providers, suppliers, customers, regulators and policymakers.

For both functional areas a set of applications provided by electricity storage systems can be identified along the electricity value chain, from generation support over transmission and distribution support to end-consumer uses. Figure 2 illustrates the variety of applications by size of application (in MW – X-axis) and operational timescale (seconds to months – Y-axis).

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[8] EURELECTRIC views on demand-side participation, Task force on storage, flexible loads and smart grids. August 2011.

[9] Flicker refers to the varying luminance of light sources under conditions of varying supply voltage levels. Causes include arc furnaces, motor starts and cycling on/off of large loads.

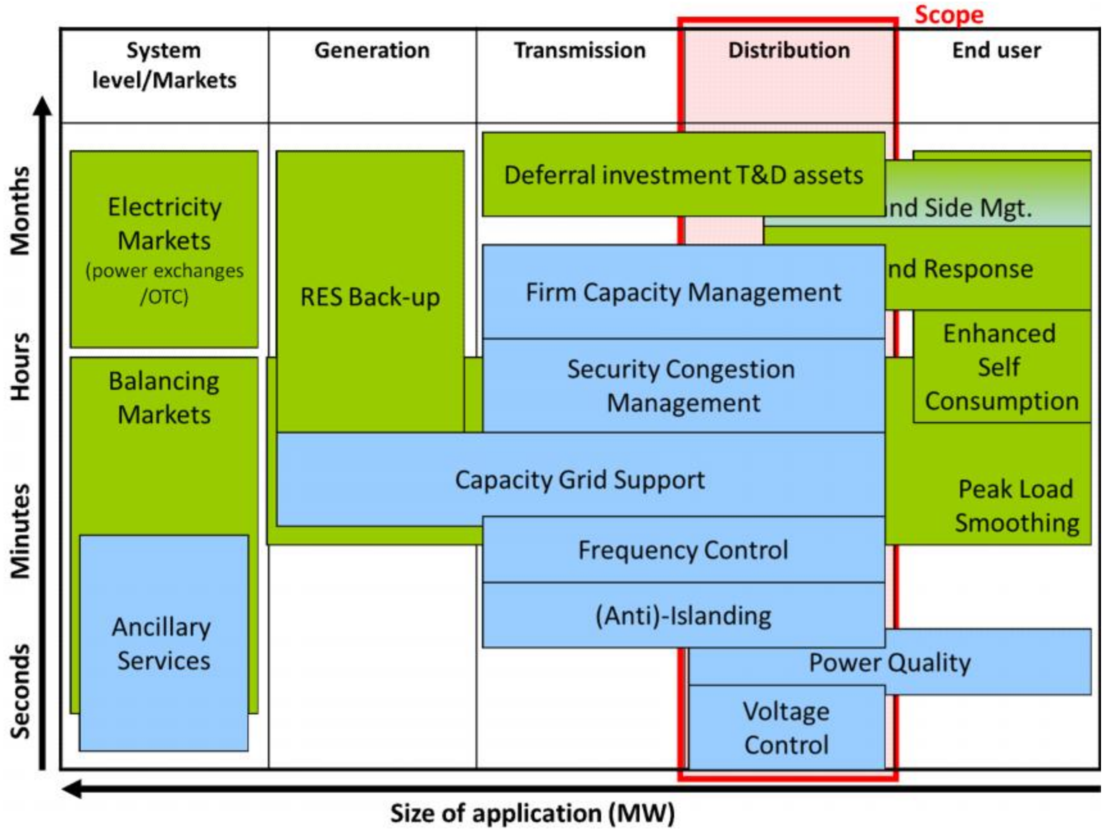

Figure 2 – Storage applications throughout the electricity value chain

Electricity storage in Energy Management applications:

- **Electricity markets (power exchanges/OTC)**: Hydroelectricity is traded in Europe on power exchanges as well as in form of bilateral over-the-counter (OTC) contracts on electronic platforms.
- **Balancing markets**: Balancing energy flows via electricity storage can improve the capacity factors of power plants, hence optimising and matching the energy flows between demand and supply and the power generation economics. To provide the necessary flexibility, operators maintain sufficient reserves, both negative balancing energy (to mitigate a sudden surplus) and positive balancing energy (to respond to a sudden deficit). The high prices paid today for these reserves, which can be called on at short notice, already indicate an economic potential for storage systems.
- **RES back-up**: Electricity storage will firm up intermittent RES by reducing the requirement for conventional generation to provide 'back-up'. Storage helps to compensate the intermittency of RES. The value of storage back-up is related to the market price in the energy and regulation power market. It is an enabling technology to enhance the integration of RES in the grid.
- **Deferred investment in T&D assets**: Transmission and distribution assets are sized to meet peak demand, but are seldom used at those levels. Decentralised storage systems can be deployed to defer the considerable cost associated with upgrading T&D capacity. Rather than upgrading the T&D assets (in large blocks) to support a projected increase in electricity demand years ahead of time, decentralised storage offers a solution that can coincide with the incremental increase in demand.
- **Peak load smoothing**: Transmission network operators have to hold sufficient reserve capacity to meet any peaks in demand. During peak times, each kW of energy supplied through decentralised storage represents one kW less required to be supplied from other sources. Energy storage can therefore shave peaks and compensate with fast-responding conventional fossil fuelled peaking plants.

  Demand side management: Demand side management refers to implementing measures on the demand side to increase the efficiency of the energy system. It is a task for power companies to reduce or remove peak load, hence deferring the installation of new capacities and distribution facilities. In this view, decentralised storage should be seen as provider of peak-load shaving or load-shifting functionalities or as an operational tool to facilitate efficient usage of electricity.

- **Demand response**: Demand response aims to reduce electricity consumption in times of high energy cost or network constraints by allowing customers to respond to price or quantity signals. Decentralised storage systems can incentivise end users to engage in demand response by optimising their power consumption as a response to market-reflective end-user prices.
- **Enhanced own consumption**: Decentralised storage offers customers who own distributed generation (like solar panels) the possibility to maximise the share of the electricity they generate for personal use. The local storage device will load energy in case of high production and discharge when consumption is required.

Electricity storage in System Services applications:

- **Ancillary Services**: The key parameters that need to be controlled to ensure a stable electricity flow are frequency, voltage and reactive power, as well as inertia or spinning reserve of the system. These are the major factors enabling the right balance between variable and dispatchable generation. Hydroelectricity can help by delivering a range of system services including back-up, reserve, black start capability, quick-start capability, regulation and frequency response, voltage support and spinning reserve.

- **Demand side management**: The most typical example of DSM is the use of load shedding in case of an alert or emergency state of the system. In such cases, decentralised storage devices can help to avoid a supply interruption for consumers by synchronising the system operator's signal of supply curtailment with the operation of the device that delivers stored energy.

Other System Service applications provided by decentralised storage are dealt with in chapter 3.2.

The rest of the paper will focus on the potential of decentralised storage systems that can support and optimise the operation of the distribution system or, in other words, the DSO business. These are energy storage systems located within distribution grids (MV/LV) or on the customer side of the network.

Before understanding the different storage technologies and their contribution at different voltage levels in distribution grids, Table 1 summarises the characteristics of different distribution voltage levels, also in comparison to the transmission level.

Types of Grid		Structure (Topology)	Operation Type	Clients (Nº)	Assets (Nº)	Operation Flexibility	Monitoring Level
Transmission (Security of supply) - (400, 220 kV)		Mesh	Mesh	Very few	Not many	High	High
Distribution (Quality of Service)	**HV/MV**[10] (132, 110, 66, 45, 36 kV)	Mesh / Radial	Mesh / Radial	Few	Quite a lot	Medium	High
	MV (20, 13.5, 15, 11 kV)	Mesh/ Radial	Mesh/ Radial	Several	Many	Low	Medium
	LV (400, 380 V)	Mesh / Radial	Radial	Many	Many	Very Low	Very low

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[10] In some European countries HV/MV voltage levels are being managed by the TSO and in some others by the DSO's.

Table 1 – Characteristics of transmission and distribution networks[11]

2.1 Storage technologies and characteristics

As stated in the introduction, the electricity industry uses many types of energy storage technologies. Together, they provide a large spectrum of performances and capacities for different application environments and electricity storage scales.

Hydroelectricity's primary function is to store energy in the range of hours up to days. It mainly supports the electricity markets. Spinning reserve is the mechanical stored energy of large-scale power plants which stabilises frequency and power flow in the high voltage grid. Where this is missing, e.g. on islands, they can be substituted by lead, nickel, lithium and sodium based stand-by batteries. These technologies feed into the high voltage grid, which falls under the responsibility of the transmission system operator.

New emerging technologies can contribute to the increasing requirement for storage capacity and counter the decreasing capacity of spinning reserve. Many physical effects are still the focus of feasibility studies, and there are only a few technologies which will be able to make a relevant contribution in the near future. Developing from an emerging to a mature technology is not only a technological problem; it is also a question of costs in CAPEX and OPEX. Moreover, a critical factor for the building of additional storage capacity is its economic performance compared to other alternatives. Until now, decentralised storage assets have been rather small due to missing economies of scale.

Costs versus benefits?

This paper does not conduct a cost-benefit analysis of the different storage technologies. Various studies available provide different cost and benefit figures for the same technology, caused by the use of different market indicators, operational and grid conditions, valuation methodologies, price estimations, etc. A technology comparison should be based on some specific applications even if the economic viability of a technology would make it suitable for a large range of applications.

Given the objective of this report, the authors find it more important to include a soft description of the most relevant technologies without making hard statements regarding costs or real technical possibilities. Therefore, we do not show an economic preference for any of the considered technologies, but rather refer to the available technical papers* on storage technologies.

The most recent contribution regarding power storage technologies, their costs and development stage, elaborated by the European Commission Joint Research Centre, is attached in Annex II.

* - EPRI-DOE Handbook of Energy Storage for Transmission and Distribution Applications, EPRIPalo Alto, CA, and the US Department of Energy, Washington, DC: 2003. 1001834

- J. Eyer, J. Iannucci, G. Corey, "Energy Storage Benefits and Market Analysis Handbook – A Study for the DOE Energy Storage Program", Sandia National Laboratories, Tech. Rep. SAND2004-6177, Dec. 2004.

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[11] The voltage levels and topology presented in Table 1 are only indicative and are not the same for all European countries.

For comparative purposes, Figure 3 organises the technology options by the duration of the discharge time and the rated power for the distribution and transmission system environment. In the DSO field the most promising technologies include batteries, vehicle-to-grid, superconducting magnetic energy storage and flywheels, which may have the potential of near future deployment.

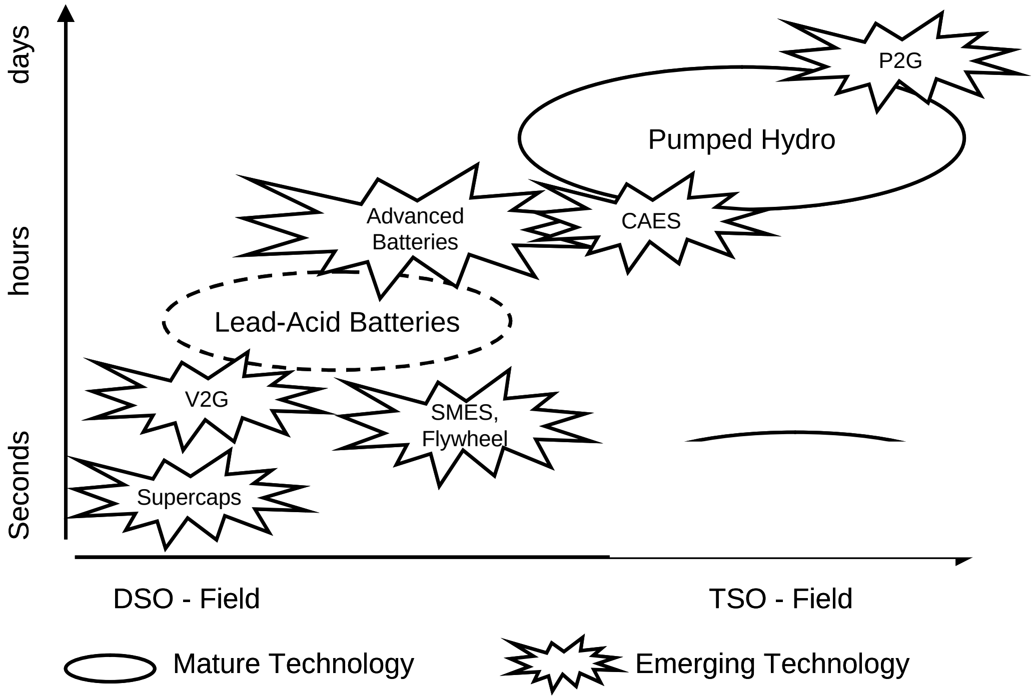

Figure 3 – Relevant storage technologies in the DSO and TSO field

2.1.1. Overview of general storage characteristics

As different technologies have different characteristics, not all of them are equally suited for the different identified applications. The various decentralised storage systems can differ in physical layout, energy density or chemical composition. Their voltage and current output characteristics may differ, as might other operational features such as efficiency and size.

The main characteristics include:

- **Storage power rating**

When characterising the rating of a storage system, the key criteria to address are power and energy.

- *Power* indicates the amount of energy per time unit that a storage technology is charging or discharging at any given instant (expressed in kW).
- *Energy* relates to the amount of energy that can be delivered to loads within a time interval (typically hours). So the capacity of for example batteries is expressed as the amount of usable energy stored in the range between empty and full state of charge considering all losses of a charging cycle.

- **Lifetime**

Most energy storage media degrade with use (i.e. during each charge discharge cycle). The rate of degradation depends on the type of storage technology, operating conditions, and other variables. This is especially important for electrochemical batteries.

- **Energy Efficiency**

Storage system round-trip efficiency (efficiency) reflects the amount of energy that comes out of storage relative to the amount put into the storage.

- **Response time**

In practical terms, the amount of energy stored determines the amount of time that the system can discharge at its rated power (output), hence the term *discharge duration*. At one extreme, under almost all conditions, storage has to respond quite rapidly if used to provide capacity under distribution capacity conditions. That is because the output from distribution equipment (i.e. grid wires and transformers) changes nearly instantaneously in response to demand. In contrast, storage used in lieu of generation capacity does not need to respond as quickly because generation tends to respond relatively slowly to demand changes.

2.1.2. Overview of decentralised electricity storage types

Many storage technology and system descriptions are covered in detail by other studies and reports. This section provides a brief description of some storage types that could be of value for the distribution grid operations.

A. Lead acid batteries

Lead acid batteries have a quite long history of use for grid-connected stationary applications. They provide power at distribution substations for switching components and for substation communication and control equipment when the grid is not energised. Their main advantages are their low cost, relatively good efficiency and very high availability in various application-specific products. However, they have quite low specific energy, a moderate lifetime, include toxic materials, are temperature-sensitive and are globally outperformed by newer techniques.[12]

B. Stand-by advanced industrial batteries and Vehicle-to-Grid (V2G)

There are many different electrochemical industrial batteries under development to support specific grid functions. They differ in the chemistry and thus in their specific performance. Most famous are advanced lithium, nickel, lead, sodium and ZnBr batteries. Present technologies are also emerging on the electric vehicle market. Electrochemical batteries are characterised by high power and energy densities as well as higher efficiency and a longer lifetime. Due to the lack of mass application, complex production and precious materials they still remain very expensive.

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[12] G. Delille, B. François, “A Review of Some Technical and Economic Features of Energy Storage Technologies for Distribution System Integration”, in *Proc. International Conference on Electrical Machines and Power Systems (ELMA’08)*, Sofia, Bulgaria, vol. 1, pp. 67-72, Oct. 2008.

Advanced batteries can be of varying size, from some kWh for private installations up to some MWh in grid back-up or island back-up application, typically in mobile containers. Beside this stationary application, the dual use of batteries of electric vehicles is also being tested. An intelligent management of charging and discharging can guarantee users a certain level of availability and mobility. However, further field testing is still needed to understand the possibilities of electric vehicle batteries to support industrial batteries, which are specifically designed for that.

Vehicle-to-grid (V2G) storage could allow the smart grid to use electric vehicles as batteries connected to the grid to store power (at off-peak times). Control of the bidirectional electric flow could include payments to owners for use of their automobile batteries for load levelling or regulation and for spinning reserve. Present battery vehicles have a power capacity of about 10kW. Considerable work and testing still needs to be done to develop the market protocols, information exchange standards, and possibly the electronic interfaces that will govern V2G integration and interaction.

C. Flywheels and SMES

Flywheel electric energy storage systems (flywheel storage or flywheels) store mechanical energy in a spinning shaft which is connected to a motor or generator. In revolving, the mass builds up inertial energy. This kinetic energy is then released when the rotor is switched off. The storage medium in a superconducting magnetic energy storage (SMES) system consists of a coil of superconducting material. Energy is stored in the magnetic field created by the flow of direct current in the coil.

Both technologies can deliver high power at a rather small capacity. Their main application lies in the time range of a few seconds up to a minute. In contrast to spinning reserve both technologies waste energy either in rotating the well or in cooling the coil, both in reserve state and in active state.

D. Supercapacitors

A third relevant – non-chemical storage system – comprises supercapacitors. Supercaps are true capacitors in that energy is stored via charge separation at the electrode-electrolyte interface. They can withstand hundreds of thousands of charge/discharge cycles without degrading.

2.2 Location of the decentralised storage device in the distribution grid

Decentralised storage systems can be connected to the distribution grid (MV/LV) at different locations. Figure 4 and the related table below give a non-exhaustive overview of the main locations.

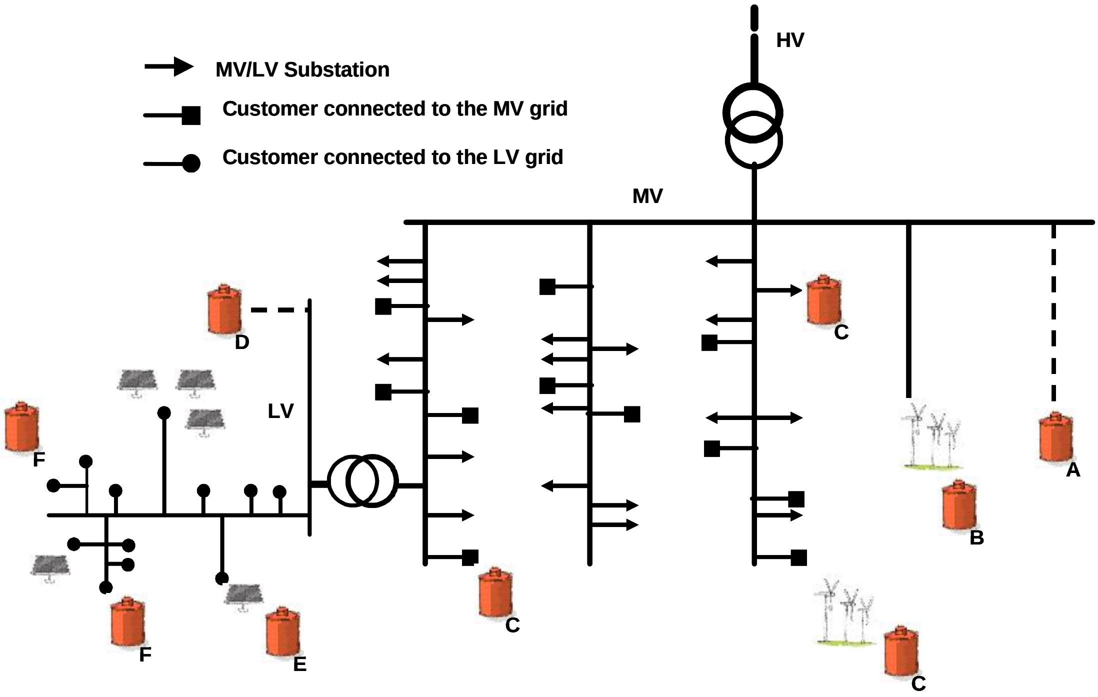

Figure 4 - Possible location of the decentralised storage systems in the distribution grid

A.	At an HV/MV substation
B.	At a feeder of RES in the MV grid
C.	At any point of an existing MV grid
D.	At an MV/LV substation
E	At a ‘prosumer’ facility connected to an LV grid
F.	At any point of an existing LV grid

A) Connection at the HV/MV substation

At HV/MV stations there is often room to install additional assets of some 100 m². In case DSOs own the station and its site, they could offer the possibility to install the device with a minimum of expenditure. Technically this location is both near the HV grid and the distributed generation in the MV grid. This implies that it offers the best conditions for all the applications listed in chapter 3. Currently some niche applications and demonstration projects of battery storage systems in the range of several MW are installed at such sites.

B) Connection to a feeder of RES in the MV grid

Renewable energy sources of high power, which are connected to the MV grid via their own cable, are typically a few windmills or larger photovoltaic farms. Such plants are located in rural regions, where enough space is available to position storage assets.. If the connecting cable is intended to support the RES, the capacity may reach its limits. In that case the storage device can be used to postpone investment in enhanced cable capacity. However, in case the storage asset owner has installed the device for other functional purposes, the DSO should be aware that both RES feed and storage feed may work in parallel and, combined, could increase the load on the cable.

C) Connection at any point of the MV grid

Within the MV grid decentralised storage devices can be installed via a new connection, using the connection of an end user or using the connection of a RES device. At each of these connections, storage devices will have an impact on voltage and power in the direct neighbourhood as well as on the stations towards the high and low voltage grid.

It is important for these connections that the application of the storage system is compatible with the grid situation and does not disturb the quality of supply. Vice versa storage devices at such locations may help to solve congestion and restrictions, especially at critical parts of the grid.

D) Connection at the MV/LV substation

At MV/LV stations there is often space to install additional assets. The capacity of those stations limits the power of the storage device to some 10-100 kWh. As owners of the station and its site, DSOs could install storage devices with a minimum of expenditure. Storage technologies which can be placed in containers and which are independent of rough weather situations may be especially suitable for those locations.

E) Connection at the ‘prosumer’ facility connected to an LV grid

More and more domestic applications like solar panels are installed on customer premises, changing the role of a customer from a consumer to a ‘prosumer’. Small battery systems combined with the power converter of those photovoltaic systems can be placed in adjusted heated cellars of private houses. In this way, prosumers become energy managers who use their own generation.

F) Connection at any point of the LV grid

Location characteristics for decentralised storage systems connected to the LV grid are similar to those indicated for the MV grid.

Summarising this chapter, the following table presents the technologies discussed above. It shows the technology types, their rated power, voltage level connection and the functional areas to which they are suited.

Storage technologies	Technology types	Rated power	Voltage level connection				Energy Management	System services
			Transmission	Distribution				
				HV/MV	MV	LV		
Electro-chemical batteries	PbA	5-10kW				X	X	
	NiCd					X	X	
	NiMh					X	X	
	NiZn					X		X
	Li		X	X	X	X	X	X
	NAS	>1MW	X	X	X		X	X
	ZEBRA			X	X		X	X
Flow batteries	PSB				X	X		X
	VRB	5kW – 10MW		X	X	X	X	X
	ZnBr	25kW – 1MW		X	X	X	X	X
Mechanical	CAES	10MW – 3GW	X	X	X		X	X
	Hydro-Electric	10MW – 3GW	X	X	X		X	X
	Flywheel	<20MW	X	X	X	X		X
Electro-Magnetic	SMES	<10MW	X	X	X	X		X
Electrostatic	SuperCap	<20MW	X	X	X	X		X

Table 2 – Electricity storage technologies

3. Impact of decentralised storage on the distribution grid

Decentralised storage devices can fall under different functional areas that impact the management of the distribution grid. In reference to the applications defined in chapter 2, we see decentralised storage delivering benefits to DSO operations in the following ways:

1. **Energy Management**

Decentralised storage is used for arbitrage in the energy market by decoupling the timing of electricity supply and demand. In this case, the deployment of a decentralised storage device is intended for market purposes only.

2. **System Services**

Decentralised storage is installed to support quality of service and ensure the security of supply in the electric power system. These applications can be provided as a system service by third parties (via markets, bilateral agreements or mandatory via grid codes).

3. **Internal DSO business**

Decentralised storage is used to ensure grid stability and support the management of the distribution grid, but serves only special niche applications which cannot be provided by the market and contribute to internal DSO operations.

The following paragraphs describe the most relevant applications in each of the functional areas in more detail.

3.1 Energy Management

Energy Management

- Demand side management
- Demand response
- Deferral of investment in distribution assets
- Peak load smoothing

➢ **Decentralised storage as a demand side management (DSM) mechanism:**

Demand side management is a concept that falls under both energy management and system services area. As an energy management application, demand side management can be defined as a tool to reduce electricity load and to improve overall electricity usage efficiency through the implementation of policies and methods that control electricity demand[13].

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[13] EURELECTRIC views on Demand-Side Participation: Involving Customers, Improving Markets, Enhancing Network Operation. August, 2011.

DSM is usually a task for power companies to reduce or remove peak load, hence **deferring the installation of new capacities and distribution facilities**. In this view, decentralised storage could be seen as provider of peak-load shaving or load shifting functionalities or as an operational tool to facilitate efficient usage of electricity. Decentralised storage facilities could be used to capture the cheaper, more-efficient off-peak generated electricity and effectively shift portions of peak load to off-peak hours. Moreover reshaping the load curve by decreasing peak load and increasing base load improves an electricity generator's capacity factor. In this perspective it will be the task of distribution system operators to deploy the infrastructure that will enable decentralised storage providers (like suppliers, aggregators or consumers) to meet on an open market place for flexible loads. Therefore, storage should be seen as a tool for DSM in which all costs (generation, consumption, grid) should be taken into account for viable business models.

- **Decentralised storage as a demand response mechanism:**

Demand response describes shifts in electricity use by end-use customers from their normal patterns in response to changes in the price of electricity. It includes all modifications to customers' electricity consumption patterns that are intended to alter the timing and level of instantaneous demand or total electricity consumption.[14]

Placing energy storage devices at the local distribution grid could empower customers to become more active in steering their electricity consumption. Suppliers or electric resources aggregators will get the opportunity to manage electricity costs by time-shifting low-priced electricity and by using storage devices to arbitrage in the wholesale market and possibly provide cheaper electricity as a “service” when needed. Therefore, decentralised storage could be a possible tool for them to use when creating new flexible demand response products and services for customers.

- **Decentralised storage as a mechanism to defer investment in distribution assets:**

Using services spurring from decentralised storage systems downstream could defer the need for to upgrade distribution equipment. Notably, the highest loads occur on just a few days per year, for just a few hours per year.

The key idea here is that, in some very specific situations, just a small amount of storage can be used to provide enough incremental capacity to defer (or avoid) the need for a large ‘lump’ investment in distribution equipment. When a storage solution proves to be competitive against the cost of expanding network capacity, it should be preferred, as it reduces the overall cost for ratepayers (consumers), improves the utilisation of distribution assets and, in the end, offers DSOs a better use of capital for other projects. The anticipated reduction of storage costs should give more room for storage solutions.

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[14] ibid.

- **Decentralised storage as a (peak) load smoothing, levelling and buffering mechanism:**

As described above, load shifting is achieved by using decentralised storage to store energy during periods of low demand and releasing the stored energy during periods of high demand. Load shifting comes in several different forms, of which peak shaving is the most common. Peak shaving describes the use of energy storage to reduce peak demand in a certain distribution area and allows the DSO concerned to defer the investment required to upgrade the network capacity.

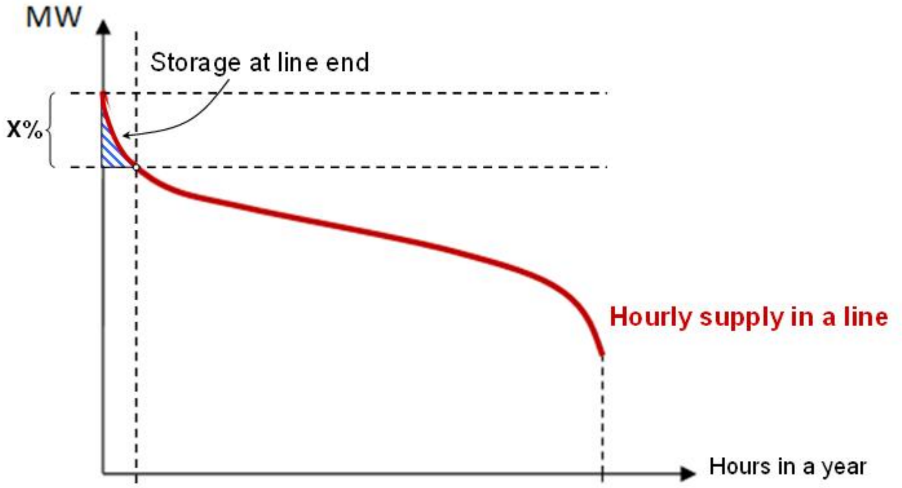

Figure 5 - Decentralised storage as a peak shaving mechanism

Another functionality provided by decentralised storage systems is load buffering, which occurs when decentralised storage is installed as a facility to a RES generator connected to the MV/LV grid. RES generator-owned storage can be used to better manage electricity production by time-shifting high energy production and selling it when market price signals are more convenient. The advantages for RES generators are two-fold: they can offer services to the market, but also to grid operators by means of energy management – provided the DSO is able to send the right signal to the generator.

In other words, load buffering as enabled by such storage systems makes RES a more "manageable" energy source and optimises production by reducing spillages. It facilitates the increase of RES connected to the grid and contributes to fulfilling the 2020 targets.

3.2 System Services

The current "**business as usual**" (BAU) approach is built on the "grid and generation follow demand" paradigm. Due to a higher penetration of distributed energy resources (DER), this approach will bring higher network costs, particularly for very large DER penetration levels[15].

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[15] R. Cossent, T. G6mez, L. Olmos, C. Mateo, and P. Frias, "Assessing the impact of distributed generation on distribution network costs," in Proc. 6th International Conference on the European Energy Market, Leuven, Belgium, 2009, pp. 586-593.

By contrast, smart grids actively integrate generators and consumers in order to supply electricity more efficiently in a sustainable, economic and secure manner. In this perspective, the implementation of new system services, enabling DSOs to take an active network management role, may contribute to mitigating[16] the increasing costs of large amounts of DER.

Decentralised storage is expected to deliver new system services for DSOs. A **system service**, in this paper, is defined as every service that can be provided by all DER, e.g. demand side management, distributed generation, electric vehicles and decentralised storage, in order to improve and support the quality of service and the security of supply in the electric power system. [17]

System Services

- Anti-islanding Operation
- Islanding Operation
- Frequency Control
- Security Congestion Management
- Firm Capacity Management
- Power Quality Management
- Demand side management

Upcoming decentralised storage technologies will be able to deliver **energy and power services**). An **energy service** is the contribution of decentralised storage to the quality of service and the security of supply in the electric power system, thanks to the energy it generates. This energy injection into the grid is not related to the wholesale market, but merely intended to support the quality and security of supply.

A **power service** is the contribution of decentralised storage to the quality of service and the security of supply in the electric power system, thanks to the decentralised storage power generation.

Some of these new system services will be power services like voltage control, anti-islanding and power quality. Others will be energy services. Finally, there will be combined power-energy services like firm capacity management, frequency control and islanding operation.

The most important system services expected from decentralised storage could include:

- **Anti-islanding Operation**: Distribution networks have a radial or weak mesh structure. Therefore when distribution assets trip or fail, some unbalance islands may occur, causing quality problems in terms of voltage or frequency. Anti-islanding

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[16] R. Cossent, L. Olmos, T. Gómez, C. Mateo, P. Frías, "Mitigating the impact of distributed generation on distribution network costs through advanced response options", 7th Conference on the European Energy Market - EEM10. Madrid, España, 23-25 Junio 2010

[17] EURELECTRIC views on Demand-Side Participation: Involving Customers, Improving Markets, Enhancing Network Operation. August, 2011.

decentralised storage devices will be needed where local balancing is not technically possible.

- **Islanding Operation/Frequency control:** In future, the presence of DER will make local balancing in distribution networks possible. Decentralised storage could play a key role to balance power when islands are disconnected from the main grid. In DSO networks that are connected to TSO networks, the TSO will be responsible for managing the frequency control and the DSO will contribute thanks to DER. However, when DSO networks are disconnected from the transmission level, DSOs will be responsible for the frequency control[18] and DER will contribute to active network management.

- **Security Congestion Management**: DSOs should facilitate grid access and well-functioning wholesale and retail markets. Nevertheless there are some situations where commercial arrangements are not compatible with the security standards of distribution networks. In these situations, decentralised storage (and DER in general) can contribute to providing congestion management services.

- **Firm Capacity Management**: As stated in Article 25.7 of Directive 2009/72/CE, DSOs, when planning, will have to take into account DER and conventional assets. The key question is how DER will provide firm capacity and which methods or mechanisms will be the most suitable to manage this new situation.

- **Power Quality Management**: Power or voltage quality is related to the voltage magnitude, the frequency, the voltage wave form and the three phase balance delivered by a DSO to final customers. Decentralised storage and DER are expected to provide new system services that help DSOs improve voltage quality.

- **Demand side management**: The most typical example of DSM is the use of load shedding in case of an alert or emergency state of the system. In such cases, decentralised storage devices could help to avoid a supply interruption for consumers by synchronising the system operator's signal of supply curtailment with the operation of the device that delivers stored energy. In this perspective, DSOs could procure services from decentralised storage systems as an efficient tool to cope with forecasted future demand and the connection requirements of new distributed generation. As such decentralised storage could foster demand flexibility and spur the development of demand side management.

For each of the identified system services, agreements between decentralised storage providers and DSOs have to be set (except in the specific cases outlined in chapter 3.3). The table below presents some generic examples of possible arrangements.

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[18] Especially ensuring a sufficient level of short circuit power and the persisting functionality of the protective system is relevant for this kind of operation.

An example of agreements between DSOs and decentralised storage (DS) providers				
Object of agreement	**Purpose**	**Responsible Actor**	**Service / product provider**	**DS (power-energy)**
Anti - islanding operation	Avoid unsafe, unbalanced and poor quality distribution electric islands	DSO	DS	Power
Islanding operation	Improve continuity of supply when higher voltage source is unavailable	DSO	DS, DSM, DG's	Power / Energy
Frequency control	Frequency and international programs control	TSO	DSO's, Conventional generation, DSM, DG's, CS, and DS	Power / Energy
Security congestion management (short-term)	Operate the grid within the security standards	DSO	DS, DSM, DG's	Power
Firm capacity management (long-term)	DSO's planning purpose; efficiency in assets utilization	DSO	DS, DSM, DG's	Power / Energy
Power Quality control	Maintain high voltage quality in transient timescales	DSO	DS	Power
Demand side management	Make new market products compatible with grid security standards	DSO	DS	Power

Table 3 – DS system services for DSOs

Decentralised storage is expected to bring DSOs new system services for planning (long term) and operation (short term). In terms of **planning**, DSOs have to decide on the most efficient investments in order to cope with the forecasted future demand and the connection requirements of DER. Decentralised storage is expected to be a technology that can be scheduled and managed. Its contribution to firm capacity could thus be extremely important for system efficiency. Due to this firmness of decentralised storage, the smart grids approach will bring long-term firm capacity, given new agreements between DSOs and decentralised storage providers[19].

The types of new agreements set out in Table 3 will allow DSOs to optimise their investments in distribution assets. In fact, in areas where grid improvements are not economically feasible or efficient, a combination of mandatory/voluntary firmness from decentralised storage could be arranged and performed through the supply of new system services.

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[19] D. Trebolle, T. Gómez, R. Cossent, P. Frías, "Distribution planning with reliability options for distributed generation", Electric Power Systems Research. vol. 80, no. 2, pp. 222-229, Enero 2010

At **operation** timescales DSOs will act as market facilitators by enabling suppliers to offer market products and at the same time ensuring security, integrity and quality of supply. When market products are not compatible with distribution grid security standards, new decentralised storage system services will be required. Therefore, new agreements between DSOs and decentralised storage providers will allow DSOs to solve grid constraints.

3.3 Internal DSO business

As shown in the previous chapters, storage devices have a role to play in delivering services for the energy market and for the operation of the transmission and distribution grid. As decentralised storage will be integrated into the distribution grid, DSOs will help to support these different applications in different modes of operation.

However, in a very few niche applications which cannot be provided by the market, DSOs could imagine installing storage devices exclusively for their own internal business of operating the grid. In general DSOs can collaborate with a third party owning a storage device, and to some technically driven extent DSOs should be able to ask for mandatory services of storage devices installed in their distribution grids.

Examples of techniques which can be used for **internal DSO business operations** include:

- **Load curve smoothing**

One of the most important operational tasks for DSOs is to avoid at all times a fatal overload in power of grid devices such as transformers, switch bars and cables. Simultaneously, DSOs face the continuous challenge of avoiding unnecessary grid investments. *Load curve smoothing* is a response to both these issues. Storage can help to fulfil this function: firstly, by acting as a local generator and feeding in if the load current exceeds the thermal limits of the grid assets, and secondly by storing energy if generation current in the grid area in the other direction exceeds the thermal limits of the grid assets.

Technical requirement	Assessment
This application requires a feedback loop to the critical asset temperatures, a proper automatic control system and permanent supervision by the operator, who has to intervene to prevent failures in the system. This is a DSO task. The operator of the storage device should ensure that the storage is able to charge or discharge over the whole time period of critical overload. There should be an option in addition to control generation or load in case the storage reaches its capacity limit, both in full or empty state of charge.	Because this service can extend over hours the energy capacity of the storage must be rather high, which makes this solution potentially expensive. It should therefore be seen as a niche application which can be used temporarily to cover the period of grid enhancement.

- **Voltage control using active power**

Voltage control is an important internal DSO business operation. This application can be executed by using *active power*. A storage device is used to keep the voltage of a specified grid segment within a defined range, with the aim of guaranteeing the standard of supply. To achieve this, storage has to feed in when voltage is low and store energy when voltage is too high. The power, the reaction time and the maximal period of time for this service should be adapted to the local situation. For slow voltage control the reaction time can be in the range of minutes, but for decreasing flicker and sacs the reaction time should be mere milliseconds.

Technical requirement	Assessment
The timescale is rather fast, ranging from minutes to several hundreds of milliseconds. For that reason control and supervision should be realised by automated C&I schemes with a high degree of availability and additional supervision by the operation centre to fulfil test cycles. The operator of the storage device should ensure that the storage is prepared to charge or discharge over the whole time period. After a control action the storage should be recharged or discharged to be ready for the next critical situation. In addition, there should be an option to control generation or load in case the storage reaches its capacity limit, both in full or empty state of charge.	If used for slow voltage control, this service can extend over hours. The energy capacity of the storage must thus be rather high, making this solution potentially expensive. It should therefore be seen as a niche application which can be used temporarily to cover the period of grid enhancement. By contrast, fast voltage control like flicker and sacs normally requires less energy content, making the use of storage more accessible. On-going and future demonstration projects should verify and assess this application based on practical experiences from the real environment and technical storage capabilities.

- **Voltage control using reactive power**

Another application of storage uses the ability of the DC/AC converter of storage devices to control its *reactive power* input. In case of voltage increase due to high reactive power load this can be used to reduce the deviation of voltage in a smaller range than using active power. However, it is independent of the state of charge of the storage device and can be coupled to other services provided by the storage system. This kind of voltage control is only suitable for slow voltage control.

Technical requirement	Assessment
A minimal service can be realised within the asset which stabilises the voltage via the characteristic of reactive power and voltage. It takes an internal voltage measure as reference quantity for the control loop. More sophisticated concepts take an external measurement and/or control device to stabilise the voltage and require a dedicated communication line between the control device, the measurement module and the storage capacity.	Especially the local option can be realised in a very easy and cost-effective way. Again, future demonstration projects should verify and assess this application based on practical experiences from real technical storage capabilities.

3.4 View on regulation and responsibilities

Decentralised storage would represent a new class of electric infrastructure assets that would require the adaptation of the existing tools, protocols, and regulatory paradigms for connecting, planning, developing and operating these assets. Storage could bring flexibility into the electric system and would be most valued when the right new methods and understandings are in place.

Today there are very few indications on how to integrate distributed energy storage.[20] The lack of clear integration rules confronts DSOs and decentralised storage providers with uncertainty regarding whether energy storage technologies will affect a particular electric system. However, one must bear in mind that decentralised storage facilities simultaneously represent both distributed generation and load. Any necessary rules should therefore be an evolution of rules that currently exist or are being developed, in particular, for distributed generation.

This situation leaves unanswered some questions regarding the necessary agreements between actors as well as regarding storage connection and access rights. EURELECTRIC recognises this potential degree of policy and regulatory risk for the security and quality of supply. This subchapter addresses the industry's needs by presenting its view on dividing the responsibilities of each agent for the different functional areas.

A. Energy Management

Energy management touches upon the market opportunities arising from decentralised storage. DSOs are not responsible for the implementation of such opportunities, but only facilitate energy management services by connecting decentralised storage systems to the medium and low voltage grid. This should be a generalisation of the procedures for dealing with decentralised generation and load.

Nevertheless, there is a need to identify and categorise the benefits springing from the storage activity, its recipient agents and the agents that are in charge of laying down the resources for the development of the markets. Those markets should thrive and must be responsible for correctly remunerating the investments.

The new paradigm should therefore take into consideration the following aspects:

1. Assure quality of supply through the provision of a market-driven incentive scheme for a given consumer when the electricity grid is not able to provide all the demanded peak energy by means of some agreements between the decentralised storage provider (supplier or aggregator) and the consumer for making that energy

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[20] One example of the few references to storage is Article 16 of Directive 2009/28/EC on the promotion of the use of RES: "Member States shall take the appropriate steps to develop transmission and distribution grid infrastructure, intelligent networks, **storage facilities** and the electricity system, in order to allow the secure operation of the electricity system as it accommodates the further development of electricity production from renewable energy sources [...]"

available. The DSO would play the role of neutral market facilitator by integrating the storage requirements into its network management.

2. Make the integration of RES generation more manageable with a decentralised storage facility by modulating the electricity delivery in accordance with the capability network state, as the other generators do.

In all these cases there is a clear need for coordination among all agents regarding the planning process, the different responsibilities and the different timings for developing the decentralised storage systems.

B. System Services

System services as defined in this report would be provided by market actors. DSOs can either procure the services via the electricity markets – on the same basis as balancing services that are provided by generators to TSOs – or they can be reflected in new grid codes. Therefore a network code or similar should define the technical requirements any system service has to comply with. The DSOs, as actors responsible for the quality of service, would have to take an active part in the definition of system services provided by decentralised storage. It is important to remember that storage is not a system service in itself, but a possible provider of services. Distributed generation or demand response would be other potential providers of these services.

In addition, the network code should also define whether some system services have to be mandatory, as is already the case in some member states, for example, concerning primary reserve for generators. Regarding possible mandatory services the network code must clarify whether it is the delivery of the service which is mandatory or only the ability to deliver it. DSOs would support the authorities in selecting system services which need to be mandatory, amongst other services that would be driven by market decisions.

As a final point the regulation has to specify for each service the mechanism for pricing the service and remunerating the service providers. This should be a market-based principle. In any case, regulation should stipulate, for instance, whether service providers should be paid for their capacity to deliver the service, how the service would be charged to the network users, the possible penalties for failing to deliver and when they would effectively deliver the service.

C. Internal DSO business

As stated in the previous chapter, for specific applications which cannot be provided by the market, DSOs could imagine installing storage devices exclusively for their own internal business of operating the grid.

Decentralised storage for internal DSO business is currently only a niche application. The technology is in the state of demonstration and deployment, and the competing solution of grid enhancement is less costly and more readily available. But with a growing share of RES more applications will be needed and more such niches will have to be applied. Even though it would be a minimal subset of applications, regulation should accept the costs of decentralised storage if it is necessary for an optimal grid design.

1. If decentralised storage systems exclusively for DSO operational purposes are implemented by independent third parties or by customers in the distribution grid, DSOs should have the right to control the storage device due to operational needs. Network codes should define rules for measuring, supervision and control of the decentralised storage system by the DSO. Such rules pertaining to the reliability, maintenance and standard of storage systems should be binding for decentralised storage owners to ensure that the DSO has the services of an asset of the quality demanded internally for any DSO operational asset.

2. Decentralised storage enables additional installation of RES and helps to develop the sustainability and security of energy supply. DSOs will support the installation of decentralised storage by any party as is the case in all network connections. Proper rules should ensure that costs of installation at the grid side will be covered by appropriate parties based on ownership and beneficiaries. Since in these cases it concerns installation and ownership borne by the DSO, this should be through the appropriate regulated financing schemes, when technically and economically justified.

4. Conclusions and recommendations

Electricity storage has gained political attention in light of the development of renewables and distributed generation, as a way to reduce carbon emissions, to improve grid stability and to control the fluctuations of variable resources.[21] It has been identified as a critical technological priority in the development of the European low-carbon power system, in line with the EU's 2020 and 2050 energy policies.

Against the background of storage's potential contribution to energy security and greenhouse gas emissions reductions, this paper has analysed the future role of electricity storage, the impact of decentralised storage technologies on the distribution grid and the implications for the DSO business. As a conclusion, EURELECTRIC puts forward the following recommendations regarding the development of decentralised storage systems:

1. **Decentralised storage should be seen as part of the development of a smarter electricity system.**

Grids must be ready to integrate decentralised storage and other new technologies so they can deliver at their best. While the one-way grid is the optimal solution for large centralised production, decentralised solutions will require the two-way smart grid for optimum operation. Thus decentralised storage is an emerging set of energy management and system service technologies that will allow a better integration of RES and distributed generation into the grid. The role of the DSO is to ensure that the smart grid will integrate and profit from their capabilities.

Smoothly connecting storage to the smart grid will require putting the right information and communication technologies in place. DSOs will have to invest in these new communication and metering technologies. The regulatory framework therefore needs to incentivise DSOs to innovate and invest in smart grids.

2. **Decentralised storage could serve the business of market agents as well as DSOs – market models, roles and responsibilities of the actors need to be designed.**

Decentralised storage systems can bring a range of benefits across the energy market – to generators, TSOs, DSOs, suppliers, wholesalers and traders – which ultimately benefits end-consumers. Optimising the commercial returns on storage system investment potentially requires agreements with all the above actors, introducing a series of possible constraints and risks in maximising the achievable value. So far no overall strategy or policy has set out how decentralised storage technologies can be incorporated into existing components of the electricity industry and what role the different agents should play.

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[21] - European Commission, 2009. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009. Promotion of the use of energy from renewable sources. Amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.
- European Commission, 2010. Energy infrastructure priorities for 2020 and beyond - A Blueprint for an integrated European energy network, COM(2010) 677 final.

Decentralised storage is not a natural monopoly. It should therefore be owned and operated by market actors (generators, suppliers, end consumers, aggregators, etc.). Depending on the storage technology and on commercial and regulatory incentives, these actors will use their storage facilities for market-driven energy management purposes and for the provision of system services to the distribution grid. The latter should be procured by DSOs either via organised markets (similar to balancing markets on the transmission level, where TSOs procure reserve capacity for frequency response via auctions/tenders), or be based on bilateral contracts. The provision of such system services will be voluntary. Alternatively, where market-based provision is not possible, the provision of system services by storage could be made mandatory via grid codes.

In practice some exceptions to this general rule may be required for very specific applications of small-scale storage which cannot be provided by the market and which are exclusively used to ensure system stability, thereby optimising DSOs' internal business operations. In such cases, DSOs could be allowed to own and operate storage facilities and should be able to recover the cost as far as economically and technically justified. These cases must be clearly defined in order to avoid the competitive distortions arising from any commercialisation of such DSO-owned and operated storage facilities. EURELECTRIC acknowledges that further work with respect to the market design is needed and therefore encourages policymakers to assess the regulatory requirements for future decentralised storage, and to clarify the roles and responsibilities of the involved actors.

3. Decentralised storage is not the silver bullet for a more efficient and stable grid.

Most decentralised storage technologies are not yet mature and still under development. It is therefore still too early to predict their potential contribution to integrating RES and ensuring grid stability. While some emerging technologies appear promising, decentralised storage cannot yet be considered the silver bullet to meet all future challenges.

The development of decentralised storage still faces uncertainties surrounding the evolution of the power sector, including the future share of RES, the carbon price, and the share of demand side programmes. Therefore it should neither be privileged nor be put at disadvantage compared to other flexibility options such as demand response, flexible generation or, in limited cases, the curtailment of RES feed-in. Accordingly, newly designed markets for system services to the distribution grid must create a level playing field on which decentralised storage can fairly compete with other solutions.

Simultaneously, the design of the European low-carbon system will depend on estimating the decentralised storage potential. Although the RES 2020 targets can be met without decentralised storage, the development of cost-effective flexible energy storage systems is likely to deliver the RES targets at a reduced overall cost and with enhanced network flexibility. EURELECTRIC encourages the European Commission to further address existing uncertainties surrounding electricity storage and the composition of the future electricity technology mix.

4. **European research funding should focus on key technologies that encourage the integration of decentralised storage systems into the electricity grid.**

Some decentralised storage systems are beginning to reach the market, as can be seen from the examples in Annex I. EU policymakers can facilitate the expansion of activities that test applications at small and large scales by creating new financing options. Advanced storage technologies and materials as well as demonstration projects at the distribution business level require RD&D incentives. They are necessary to gain field experience and to build industrial confidence.

EURELECTRIC therefore strongly supports existing R&D initiatives, including the SET Plan, the European Electricity Grid Initiative (EEGI) and the European Energy Research Alliance (EERA), believing that a deeper understanding of storage technologies, applications and capabilities to respond to market and grid needs is necessary for economic and technical purposes.

5. **A holistic approach considering all costs and benefits is needed in order to achieve energy targets and smoothly integrate distributed generation technologies into the smart electricity system.**

Once decentralised storage systems are connected to the grid, DSOs will be able to neutrally facilitate energy management services for market players. At the same time, they will be able to provide high-value system services to secure network reliability and control. Decentralised storage thus provides multiple applications to the power system, making its economics difficult to assess.

Not only DSOs, but all actors in the electricity value chain could potentially benefit from decentralised storage systems. Establishing a market framework to assess the value streams of decentralised storage for all actors -what technologies will bring what kind of benefit by when for whom - would enable public authorities to support its development and industry to make investment decisions accordingly. In particular, it should focus on the contributions of decentralised storage to renewable integration and DSO grid planning. EURELECTRIC is in favour of contributing to the establishment of such a framework, as already advocated by the SET Plan’s Information System (SETIS).

6. **The system of grid tariffs should be reconsidered within the smart grid context.**

Today’s grid tariff structure is commonly defined on the basis of consumed energy. This does not reflect the cost structure of the grid.

The future electricity system will be more dynamic. As a consequence, the role of power in the grid tariff system should be reconsidered in light of the costs to the grid or the benefits for the grid’s capacity. In the context of increased distributed generation, it will probably have to evolve towards grid tariffs with a higher charge for peak load and lower for energy. The structure should also be amended in the context of remuneration for system and energy management services at the distribution level. All generation and storage plants offering such services should act on the same level playing field.

ANNEX I – Country examples: decentralised storage projects

5.1 Smart Storage (Netherlands)

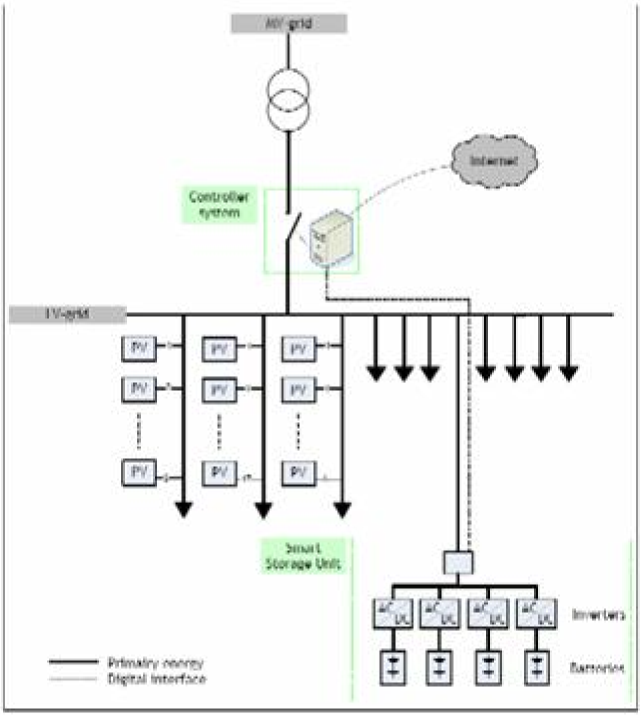
The Smart Storage project is initiated and managed by Enexis (DSO) in cooperation with Alliander and ECN. The aim of the project is to demonstrate that decentralised generated energy can be stored locally in practice and thereby realise 3 objectives simultaneously:

1. Optimal local network utilization
    - Reduce utilization of MV network and MV/LV transformer (peak shaving)
    - Charge/discharge of battery system based on network utilization

2. Optimise the integration of embedded generation (PV)
    - Charge/discharge of battery system based on local production vs. demand in order to balance the supply vs. demand.

3. Improve reliability of electricity distribution by possibility to operate in island mode (microgrid)
    - Stand-alone operation of battery system in case of MV outages in order to reduce the impact of these outages

In order to demonstrate that decentralised storage of renewable energy can be performed in practice, a so-called Smart Storage Unit (SSU) will be connected to the LV-grid of Enexis in Etten-Leur (Netherlands). The SSU will be connected to the LV-side of a local 400 kVA transformer station. To this same station, approximately 240 public housings are connected from which 40 houses have locally installed PV (in total 186 kW Peak). Peak load of this transformer is measured at 386 kW.

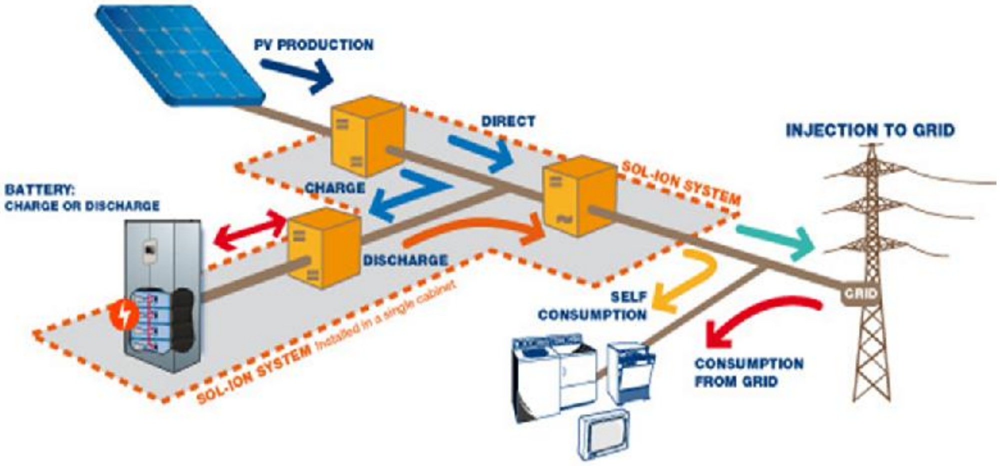


This SSU is a physical station consisting of a battery system and AC/DC inverters. The battery system has a total capacity of 230 kWh, consisting of 4 separate 58 kWh battery strings, each separately connected to a 100kVA inverter.

The controller system consists of a MV/LV coupling switch, measurement devices and a server. This coupling switch is connected to a server, which enables the system to operate in island mode or charge/discharge the battery conform pre-specified objectives and conditions.

5.2 Project Sol-Ion (France-Germany)

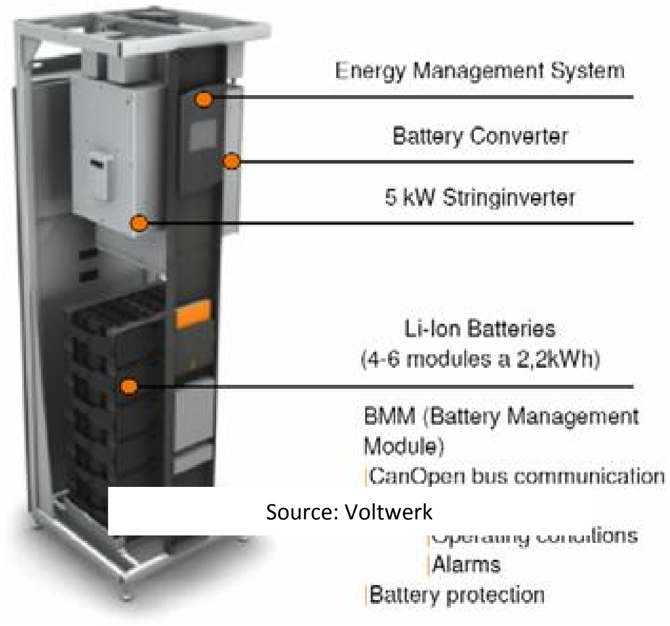
The contractors SAFT, Voltwerk, TENESOL, CEA and E.ON cooperate in the Sol-Ion project concerning the study and the development of a new concept of energy conversion and storage system applied to renewable energy systems, mainly photovoltaic. It is supported by INES, ISEA, IES and ZSW concerning scientific issues.



Source: SAFT

Main activities developed in the framework of the project are:

- System modelling and simulation of operations in order to determine and select the optimised strategies for the management of the energy and the best impact on the grid,
- System definition and development with the target to integrate in a single and modular unit both energy storage (battery), energy conversion (inverter), control and monitoring equipment (system management),
- Field experimentation on 75 sites deployed in France and Germany,
- Economic assessment of such a concept, added value of the storage function and impact on the distribution grid.



Source: Voltwerk

A string inverter is responsible to provide a mixture of PV power and battery power to the grid. This inverter is also able to provide a stable island grid, in order to allow off-grid or backup-applications. The battery converter is responsible for charging und discharging the battery and has also the capability to stabilize the inverter operation. The overall operational strategies are managed by the energy management system.

The unit can be configured to operate in different configurations, such as “back-up for grid failure”, optimisation of self-consummation and/or support of grid stability.

The final goal of the SOLION project is to develop and test flexible and multifunctional systems which allow: smooth power dispatching to respond to peak power demand, improvement of grid stability, islanding in case of emergency situation (network failure) and globally which offer energy services and not only kWh production. Installed at private customer sites it will prove the acceptance of the technology and the impact on the distribution grid.

5.3 STORE project (Spain)

The STORE (**S**tore **T**echnologies **O**f **R**eliable **E**nergy) project is lead, initiated and managed by Endesa Generación (Spain) in cooperation with some industrial partners (Telvent, Acciona, Isotrol and Ingeteam) and some other research centres (Universidad Politécnica, AICIA, IIT U.Comillas, Mondragón Universitatea and CIEMAT-MITyC). The project is developing in three different locations trying to demonstrate:

- What the best technologies are for the energy management, regarding the network in order to provide a more flexible and secure operation,
- Testing the possible solutions in real exploitation conditions,
- Providing new valuable information for the next future facilities,
- Engaging the regulators aiming to stimulate a new regulatory framework that considers these investments in the new storage facilities, its maintenance and operation.

The locations are the following ones:

1. **Gran Canaria: NaS battery.**
    - Location: La Aldea de San Nicolás, Gran Canaria.
    - Voltage: 20 kV
    - 1,05 MW/6,32 MWh
    - Cycles number: 2.500
    - Work temperature: 70 – 300 ºC
    - Efficiency rate: 86%
    - Effects' fulfilment: peak shaving, load levelling, voltage control, frequency control, etc.

2. **La Gomera: ZnBr battery**
    - Location: Playa Santiago, La Gomera.
    - Voltage: 20 kV
    - 0,5 MW/2,8 MWh
    - Cycles number: 13.000
    - Work temperature: ambience.
    - Efficiency rate: 70%
    - Effects' fulfilment: peak shaving, load levelling, voltage control, frequency control, etc.

3. La Palma. Ultra capacitors

- Location: Central Diesel Los Guinchos, La Palma.
- Voltage: 30 kV
- 4 MW/3-4 s
- Cycles number: 1.000.000
- Efficiency rate: 97%
- Work temperature: ambience
- Effects' fulfilment: fault ride through in the power plant.

5.4 Storage installation in HV/MV and MV/LV substation (Italy)

Storage installation in MV/LV substations

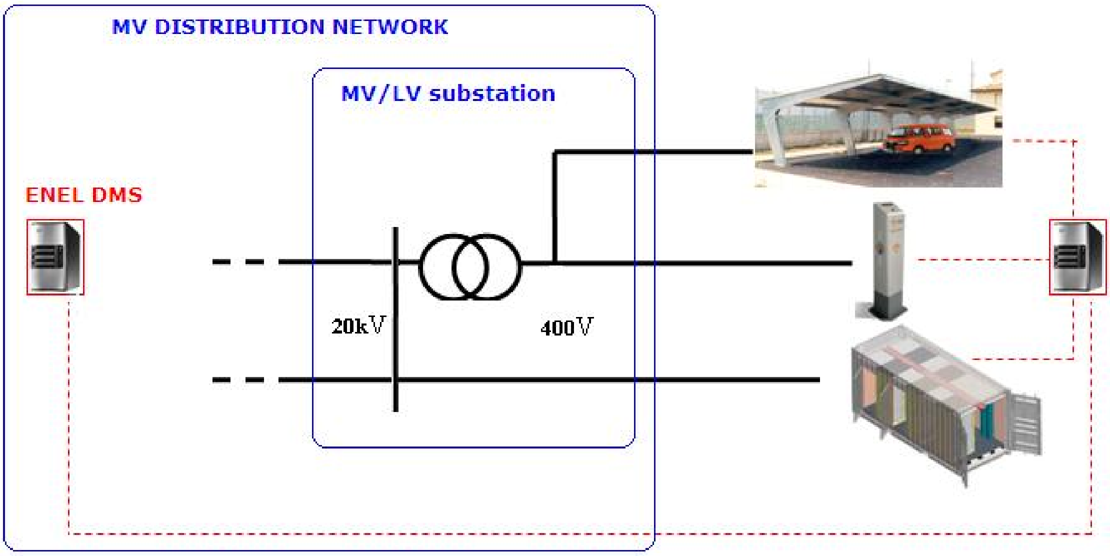
Two different projects are currently in progress:

- Isernia project (Storage in operation);
- Grid4EU European project (Storage under procurement).

A MV/LV substation of a MV feeder located in Isernia (Molise region in Italy) will be converted into a “complex” node with:

- Several EV charging stations connected to the LV busbar;
- Li-ion storage system (750 kVA – 500 kWh) connected to the MV busbar;
- PV power plant (50kW) connected to the LV busbar;
- A new local control system;
- Integration with the Enel’s Distribution Management System (Enel’s DMS).

The local control system will use the storage to optimise both the active and reactive power exchanges between the node and the feeder; alongside the mitigation of the PV emission and EV recharging impact on the network, a real optimisation of both local and global parameters will be taken into account by the integration with the Enel’s DMS.



The goal is to study new Enel Smart grids solution for:

- Voltage regulation;
- RES integration on MV network;
- Integration of EV charging stations on MV network;
- Black start;
- Network automation.

The installation of the storage system has been carried out.

The Italian Demo of the European project Grid4EU is located in Emilia Romagna (Italy). Enel, which is the demo leader, will install a storage system (1 MVA – 1 MWh) in a MV/LV substation that can be connected to several feeders.

The goal is to study a new centralized/decentralized solution for voltage regulation and increase of the hosting capacity.

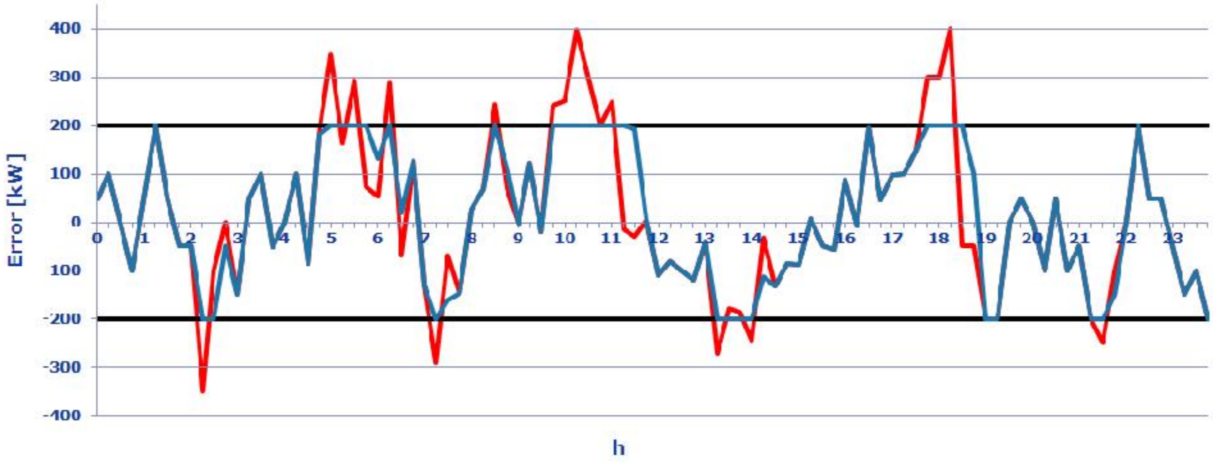
In particular, the secondary substation where the storage system will be installed provides with the possibility to switch the storage over several feeders depending on the results of an optimization procedure (able to determine the optimal storage location).
With reference to the storage technology, Enel will call for tenders and any technology complying with the technical specifications will be accepted.

Storage installation in HV/MV substations

In Southern Italy (namely in Puglia, Calabria and Sicilia regions) 3 storage systems will be installed to mitigate intermittency in renewable energy production. Fast storage systems (Li-ion technology 2 MVA – 1 MWh and 2 MVA – 2 MWh) will be used to reduce the variability of the power flow in the parts of the network with high penetration of RES, alleviating fast power flow variations in case of wind gusts or passage of clouds. In particular, the storage systems will be used to control energy exchange profiles between the HV/MV substations and the National Grid to make them more predictable (1h - 24h ahead).

The goal is to study a new possible dispatching service for distribution system operators:

- Energy exchange profiles with the National Grid (calculated by a forecast system) should be declared 1h/24h ahead by the DSO, in correspondence of each HV/MV substation;
- Storage systems (accepting a maximum error) should allow being compliant with the declared profile without any reduction of loads or modification of the status of the network connections.



ANNEX II

The figure below presents power storage technologies, as a function of their commercial maturity stage and the power investment costs.

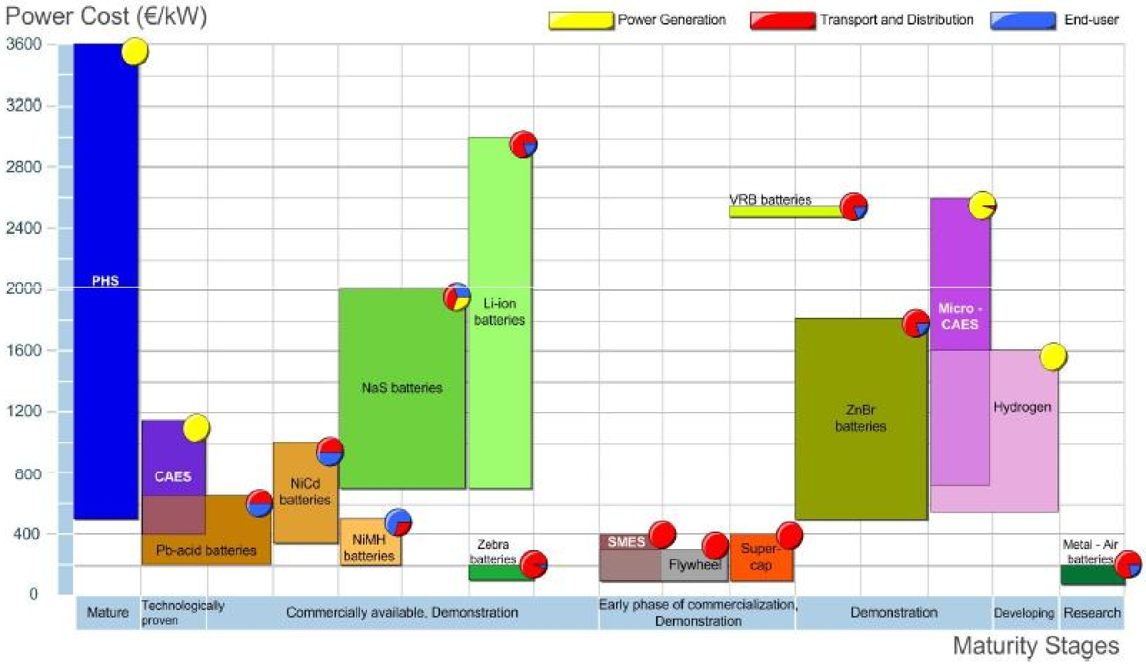


Figure 6: Power storage technologies as a function of their cost and development stage (EC, JRC-SETIS, Technology Map 2011)

ANNEX III

Expected benefits/services of smart grids

Smart grids will be a crucial part of tomorrow's low-carbon electricity system, bringing with them a number of key benefits:

1 - Smarter Network Management:

A first set of smart grids functionalities falls under the umbrella of "Smarter Network Management". Once implemented, functionalities in this group will deliver a more efficient management of distribution networks. Main functionalities include: conventional grid development, improvement and optimisation, grid automation, advanced network operation and control, and smart metering as an optimal grid operation tool. These functionalities were addressed in more detail in EURELECTRIC's paper on smarter network management, published in March 2011.

2 - Demand-side participation

The concept of demand-side participation covers both demand response and demand-side management. The EURELECTRIC paper, published in September 2011, aims to identify the main features of the future market platform for smart grids and flexible loads, so that the market design for demand response markets with smart meters is customer-centric, efficient and secure. Achieving this will require a clear definition of the competences of suppliers and distributors to ensure that customers benefit from proper market functioning, smooth processes, and security and reliability of supply.

3 - Decentralised Storage

Decentralised storage technologies such as batteries are part of the smart grids vision. Yet despite developing quickly, energy storage as a technique on the distribution side is currently less mature than other energy management tools. Questions that need to be addressed include: what agents are going to be entitled to build these facilities? Who will be the operator in charge of their management? For which applications will actors be able to use storage technologies in the future? How will the use of storage technologies complement other types of flexibility solutions such as demand response/demand side management? These questions are addressed in this paper.

4 - Aggregation and management of RES-DG

Integrating a large share of decentralised generation (DG) capacities in the distribution network is key for a low-carbon society and will be essential to deliver on the EU 20/20/20 objectives. This will however lead to increased challenges in balancing the power grid. Various technologies could help in this undertaking. Main functionalities include: distributed generation (and its aggregation) and balancing. A specific paper on this issue will be published by EURELECTRIC in summer of 2012.

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