

Overview of the Energy Storage Possibilities to Support the Electrical Power System

Research Paper to assist the ERRA
Licensing and Competition Committee

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Overview of the Energy Storage Possibilities to Support the Electrical Power System

Electrical power grids/systems will basically change in the near future (or in some places, this transformation has already begun): the increasing penetration of renewable energy sources causing high percentage of intermittent and decentralized generation. This procedure will lead to problems which are unknown for a conventionally planned and operated grid. Bidirectional power flows, unbalances, power quality issues and voltage sags (dips) can occur. Energy Storage Systems are able to play a key role in the solutions.

The scope of this research paper to provide an up-to-date and detailed summarization about:

- the technical background of the different technology possibilities, identify the main parameters of a storage system (for classification and comparison);
- the electric power grid/system supporting applications;
- regulatory aspects of the deployment.

The information gathered from the accessible literature (listed in the reference with download links) gave Regulators a chance to understand the main concepts of these solutions and keep the pace with a rapidly growing part of the energy industry. If Regulators know when and how to utilize these possibilities correctly (introducing support mechanisms), these problems with the power grid could be avoided.

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List of Abbreviations

T&D - Transmission and distribution networks

ESS - Energy Storage Systems

PHS – Pumped Hydro Storage

CAES – Compressed Air Energy Storage

EPRI – Electric Power Research Institute

BESS – Battery Energy Storage System

DLC – Double Layer Capacitor

SMES – Superconducting Magnetic Energy Storage

TOU – Time of Use

TSO – Transmission System Operator

DSO – Distribution System Operator

VG - Variable Generation

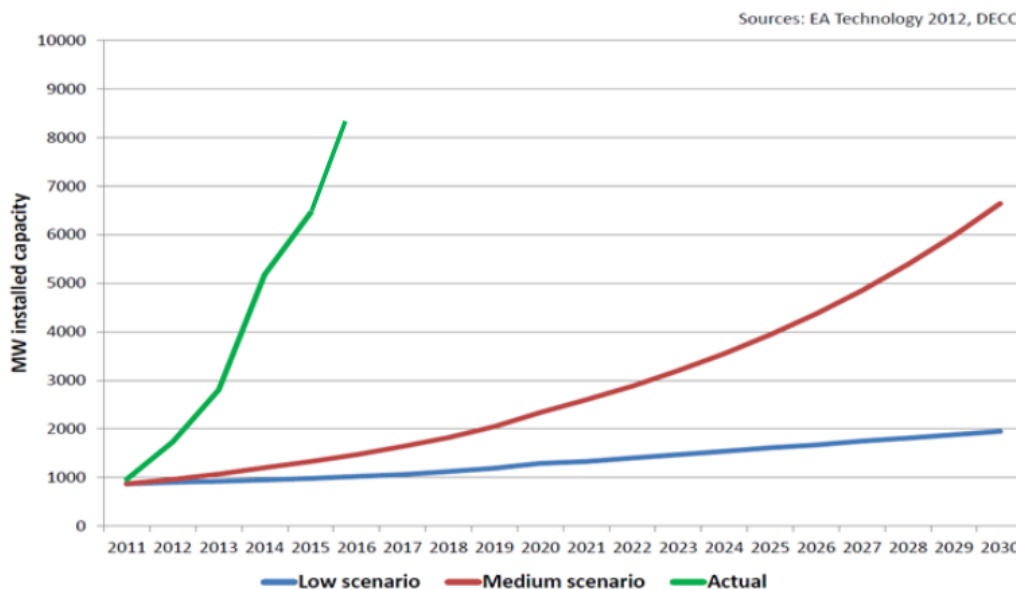
LCOE - Levelized Cost of Electricity

LCOS - Levelized Cost of Storage

Energy Storage: Holy Grail for Grid Support?

Motivations in the background

Current trends in energy supply and use are patently unsustainable – economically, environmentally and socially. Renewable energy sources, such as wind and solar, have vast potential to reduce dependence on fossil fuels and greenhouse gas emissions in the electric sector. Climate change concerns, initiatives such as Emission Trading Systems in the European Union and the United States', renewable portfolio standards, and consumer efforts are resulting in increased deployments of both technologies. Both solar photovoltaic (PV) and wind energy have variable and uncertain output, which are unlike the dispatchable sources used for the majority of electricity generation. However, the variability of these sources has led to concerns regarding the reliability of an electrical power grid/system. There has been an increased call for different solutions, including the deployment of energy storage as an essential component of energy systems that use large amount of variable renewable resources. [1]



1. Figure: Expansion of the renewable energy technologies [13]

1. Figure (showing the UK projected scenarios and the reality) represents the speed of the changes in renewable generation clearly. The renewable energy sources are spreading, and that will result strategic and behavioral change of system and market participants.

But what is energy storage exactly? It mediates between variable sources and variable loads. Power grids/systems are designed without (large amount of) storage capacity, so in this conventional way, the energy generation must be equal with the energy consumption. With the increasing variability, the controlling methods must be changed to provide reliability. These systems can support energy security and climate change goals by providing valuable services in developed and developing energy systems. A system approach in the designing will lead to more integrated and optimized energy systems. Energy storage technologies can help to better integrate our electricity and heat systems and can play a crucial role in the decarbonization process by:

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- improving the efficiency of using the resources
- helping to integrate high penetration of renewable energy sources
- supporting greater production of energy where it is consumed (decentralization)
- increasing energy access
- helping to defer capital intensive transmission and distribution system developments
- improving electricity grid stability, flexibility, reliability and resilience

The smart grid related network developments cause more complex measuring and controlling methods which will need flexible, decentralized energy storage to provide the benefits listed above. Furthermore the growing market of the electric vehicles could play a key role in storage technologies: the battery manufacturing industry is growing and the charging of those vehicles could be used as a storage capacity of the electricity systems.

Beside the electrical energy storage there are other options: hydro pumped storage, petroleum reserves, natural gas storage reservoirs and pipelines and thermal energy (ice, melted salt). [2] [3] [4]

Definitions and parameters

Energy storage technologies absorb energy, store it for a period of time before releasing it to supply energy or power services. Electrical energy storage systems convert electricity into other forms of energy (e.g. potential, thermal, chemical or magnetic) and then reverse this process to release electricity. Just as transmission and distribution (T&D) networks can move electricity over distances to the end users, energy storage systems can move electricity through time, providing it when and where it is needed. By setting aside the power system it can decouple supply from demand, and also increasing the system flexibility and reliability, as well as the utilization. [12] [4] [6]

A widely-used approach for classifying energy storage technologies is the determination according to the form of energy used. Different applications with different requirements demand different features from the storage systems. The comprehensive comparison and assessment of all storage technologies is rather ambitious, but it is necessary to create “storage characteristic” for any further examination:

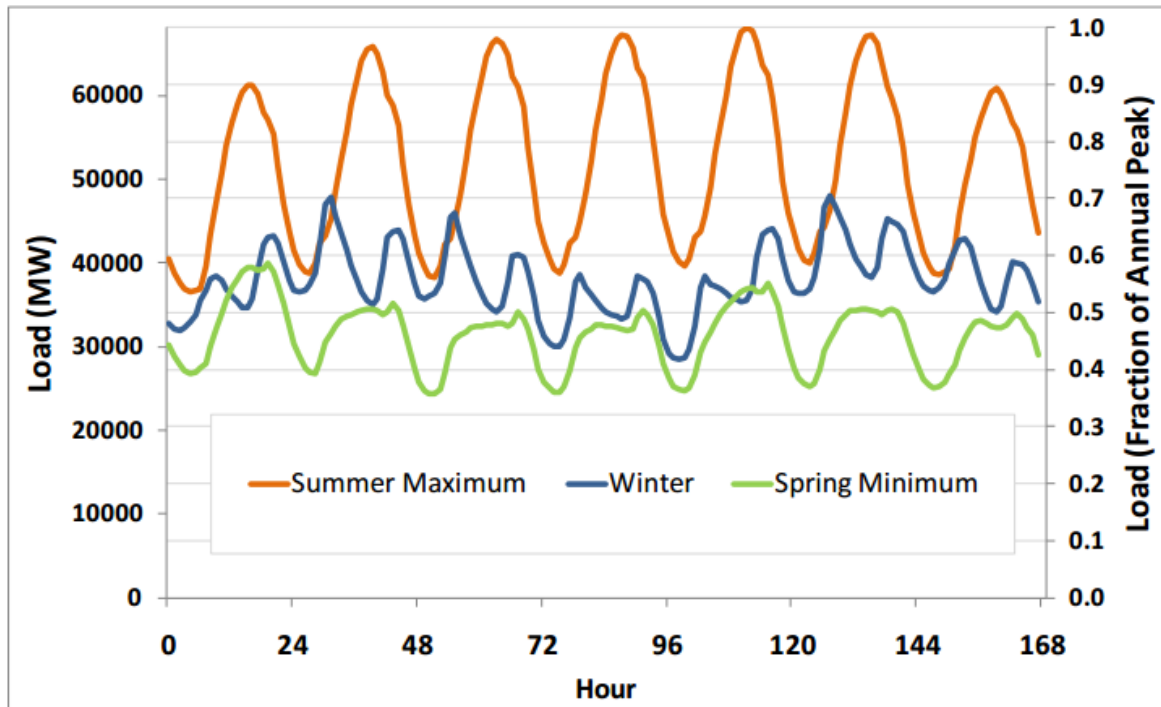
Energy storage system parameters could be the following:

- Nominal Power: $[P]=W$;
- Capacity: $[E]=Wh (J)$;
- Lifetime: $[T]=\text{years}$;
- Efficiency: $[\eta]=\%$;
- Discharge time: $[T_d]=\text{hours}$;
- Response time: $[T_r]=\text{seconds}$;
- Cycle lifetime: $[c]=\text{number}$;
- Physical Size: $[\rho] [m^3]$ (Could be measured as energy density, power density or actual size)

Changes in the electrical power grid/system

The operation of electric power systems involves a complex process of forecasting the demand for electricity, and scheduling and operating a large number of power plants to meet that varying demand. The instantaneous supply of electricity must always meet the constantly changing demand.

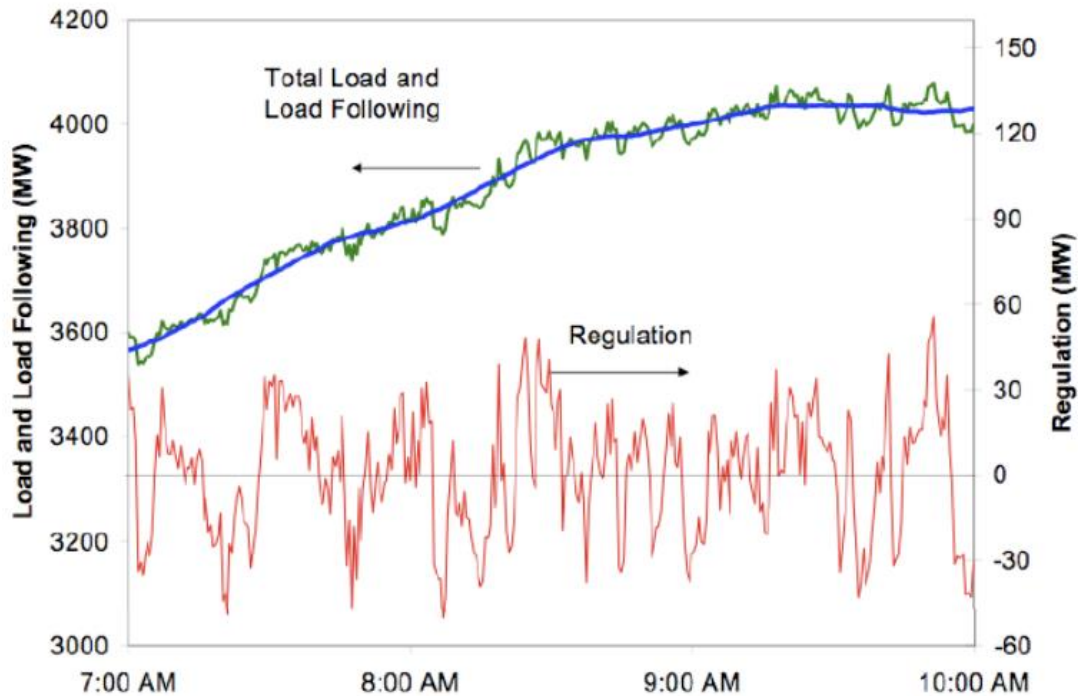
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2. Figure: Hourly loads [Electric Reliability Council of Texas] [1]

2. Figure shows the electricity demand patterns for three weeks during 2005 in Texas. The seasonal and daily patterns are driven by factors such as the need for heating, cooling, lighting, etc. While this demand pattern is area specific (Texas), many of the general trends shown in these are common throughout the United States, and also some other countries, where the air-conditioning is widely used in the summer period. To meet this demand, utilities build and operate a variety of power plant types. Base load plants are used to meet the large permanent demand for electricity. These are often nuclear and coal-fired plants, and operators try to run these plants at full output as much as possible. While these plants can vary output, their high capital costs, and low variable costs (largely the fuel), encourage continuous operation. Furthermore, technical constraints restrict rapid change in output needed to follow load. Variation in load is typically met with load-following or “cycling” plants. These units are typically hydroelectric generators or plants fueled with natural gas or oil. These are “load-following” units, which are used to meet most of the day-to-day variable demand; and peaking units, which meet the peak demand and often run less than a few hundred hours per year. [1]

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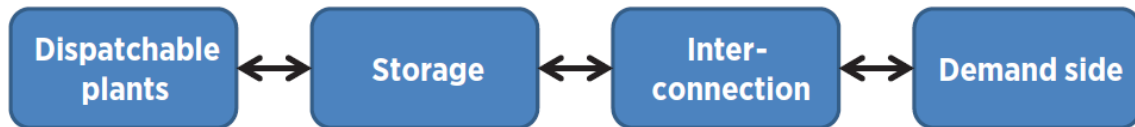


3. Figure: System load following and regulation [1]

In addition to meeting the predictable daily, weekly, and seasonal variation in demand, system operators must keep additional plants available to meet unforeseen increases in demand, losses of conventional plants and transmission lines, and other contingencies. This class of responsive reserves is often referred to as operating reserves and includes meeting frequency regulation (the ability to respond to small, random fluctuations around normal load), load-forecasting errors (the ability to respond to a greater or less than predicted change in demand), and contingencies (the ability to respond to a major contingency such as an unscheduled power plant or transmission line outage). Both frequency regulation and contingency reserves are among a larger class of services often referred to as ancillary services¹, which require units that can rapidly change output. 3. Figure illustrates the need for rapidly responding frequency regulation (red) in addition to the longer term ramping requirements (blue). In this utility system, the morning load increases smoothly by about 400 megawatts (MW) in two hours. During this period, however, there are rapid short-term ramps (green) of +/- 50 (MW) within a few minutes. [1]

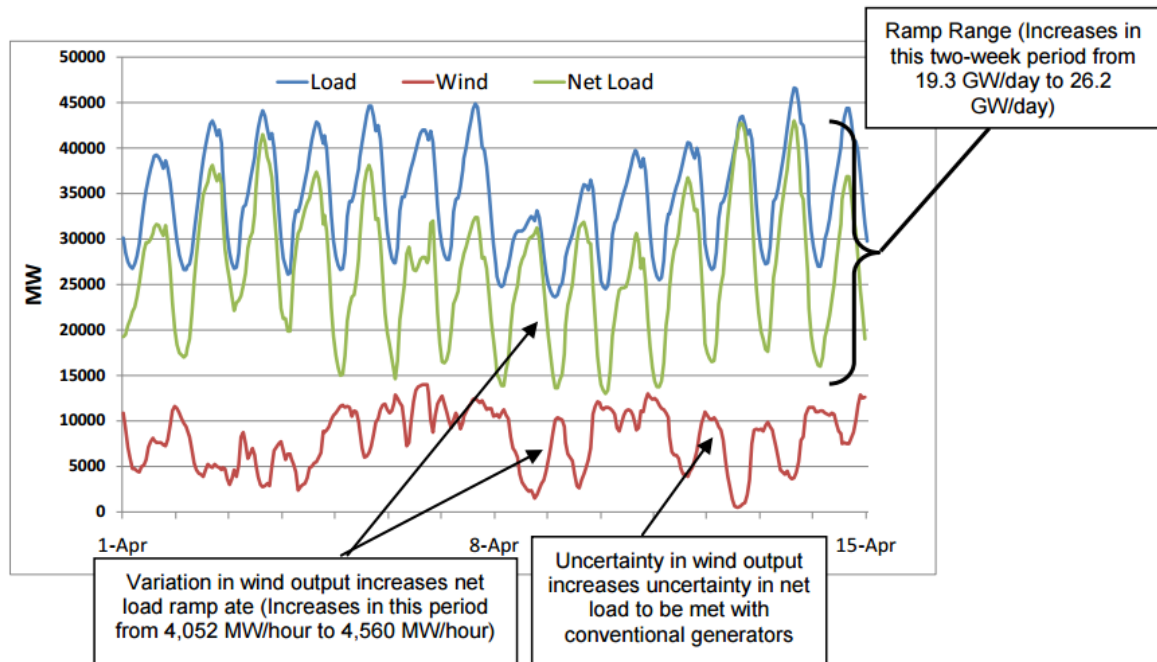
It is important to understand that the generation mix changes cause problems that cannot be solved with the conventional operation. The controlling methods will change to follow the needs. The need for operating reserves and the large variation in demand restricts the contribution from low-cost base load units and increases the need for units that can vary output to provide both load-following and ancillary services, and this could result a market in which energy storage solutions could be competitive.

¹ https://www.swissgrid.ch/dam/swissgrid/experts/ancillary_services/Dokumente/D100412_AS-concept_V1R0_en.pdf



4. Figure: Flexibility resources in the power system [10]

The introduction of variable renewables is now one of the primary drivers behind renewed interest in energy storage. The common claim is that wind and solar energy are intermittent and unreliable therefore they require backup and firming. This is generally qualitative in nature and provide little insight into the actual role of renewable energy storage. The conventional generators meeting the variability of the demand now, as discussed before. The huge variation in daily demand is met by the constant up-down cycling of generators. In addition to this cycling, the frequency regulation and contingency reserves are provided by the “flexible generators” (and partially demand side responses). Most of these units are hydro generators, combustion turbines, some combined-cycle power plants, large thermal generators or existing storage capacity (mostly pumped hydro). The variable generation will basically change that, because the output is unlike the conventional dispatchable generators. The easiest way to understand the impact of the intermittent sources is to consider them as a source of demand reduction with unique temporal characteristics. So instead of a source of a generation, wind and solar could be considered as a reduction in load, and the conventional generation has to meet that “residual load” of the normal demand minus the electricity produced by these generators. 5. Figure illustrates this framework. [1]



5. Figure: Impact of net load from increased use of renewable energy [1]

In the 5. Figure, the renewable energy generation is subtracted from the normal load, showing the residual (net) load that would need to be met with conventional generation. There are also four significant impacts in the system operation:

- there is an increased need for frequency regulation (especially because wind can increase the short-term variability of the net load)

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- the system needs load-following generators with higher ramp rate (capability of increasing and decreasing output fast)
- there is uncertainty in the wind resource and that affects the net load calculation
- the overall ramping range is increasing: the difference between the minimum and maximum demand and the associated reduction in minimum load, which can force baseload generators to reduce output (or in extreme cases force the units to cycle off during periods of high wind output).

Together, the increased variability of the net load requires greater amount of flexibility and operating reserves in the system. The use of these variable and uncertain resources will require changes in the operation of the remaining system, and this will incur additional costs, typically referred to as integration costs. The growing need for flexibility has been brought possible solutions into the spotlight, including energy storage.

Facilitating the spreading, projections for the future

While some energy storage technologies are mature or near of maturity, most are still in the early stages of development and currently struggle to compete with other non-storage technologies due to high costs. They will require additional attention before their potential can be fully realized. Regulators can help the system operators ensuring greater amount of flexibility and as one solution accelerate the development and deployment of energy storage technologies by supporting targeted demonstration projects for promising storage technologies and by eliminating price distortions that prevent storage technologies from being compensated for the suit of services they provide. [4]

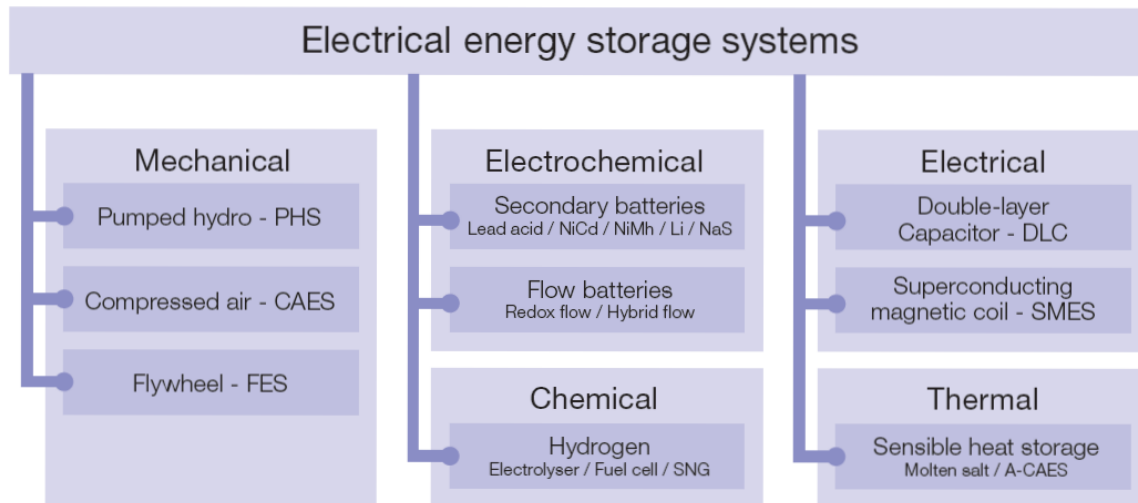
Current accessible survey results indicate that industry participants expect significant capital cost declines for some energy storage technologies over the next 5-10 years, driven primarily by increased manufacturing scale and improvement in engineering and design. The most likely drivers are:

- reductions in required high cost materials, sub-components and scale
- improved manufacturing and design
- integration time for manufacturing
- technical improvements: control and response time, battery chemistry
- improvement in operational sustainability
- increasing manufacturing scale and automation [14]

Energy Storage Technologies

The currently available and emerging energy storage technologies offer wide range of possibilities. It is important to know the main advantages and disadvantages of each system. The purpose of this section is to introduce the main particularities of each technology. This paper focuses on the electric power grid, in hence energy storage means that electrical power can be stored and discharged.

Classification



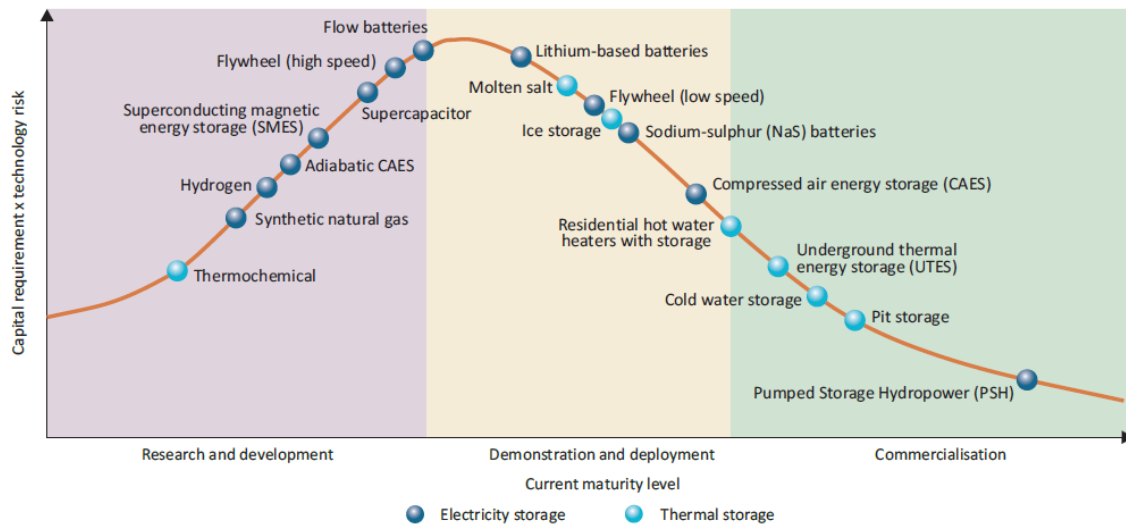
6. Figure: Classification of energy storage technologies [12]

The maturity of each technology is important: the uncertainties in technical and economical parameters are less if there is more data from commercial use. The confidence level of the data is higher in these cases (better estimations). The maturity could be classified to 3 main categories:

- commercial: significant experience from several operating units
- demonstration and pilot projects: the concept of a system is verified by an integrated unit or a small pilot facility
- research and development: a concept is verified by studies and measurements, initial hardware development achieved [3]

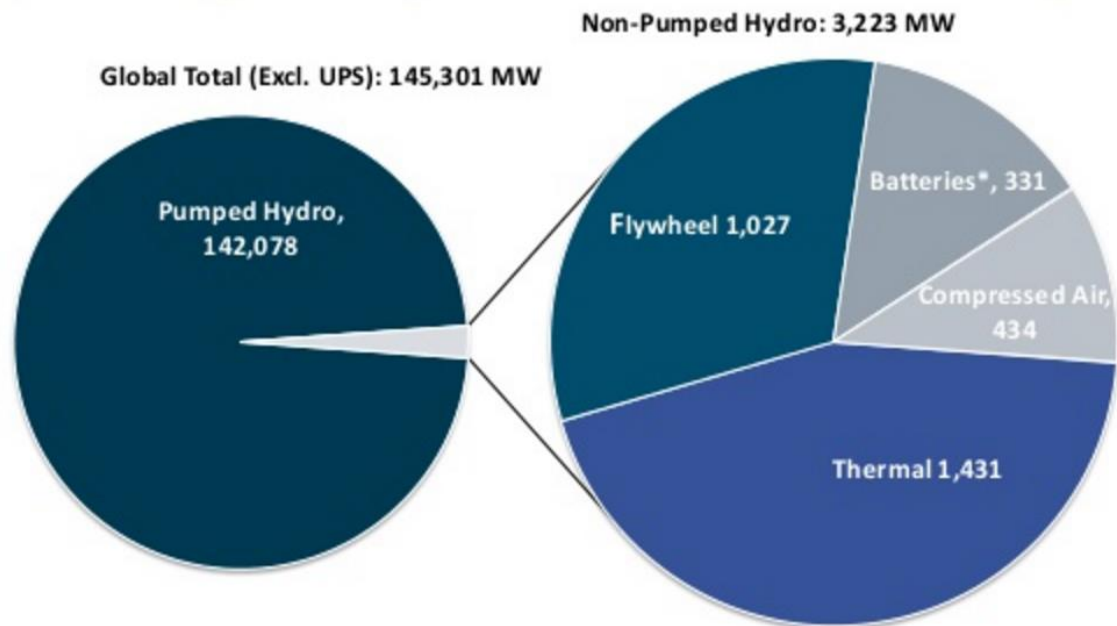
7. Figure represents the main technologies, even a lot of thermal storage possibilities. It shows the evaluated maturity stage of the different technologies (in 2014) and the associated risk of the investment considering the capital costs and the uncertainty of the technology. PHS systems are the most advanced type from this aspect, but battery technologies are developing fast. [3][4][12]

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7. Figure: Maturity of energy storage technologies [4]

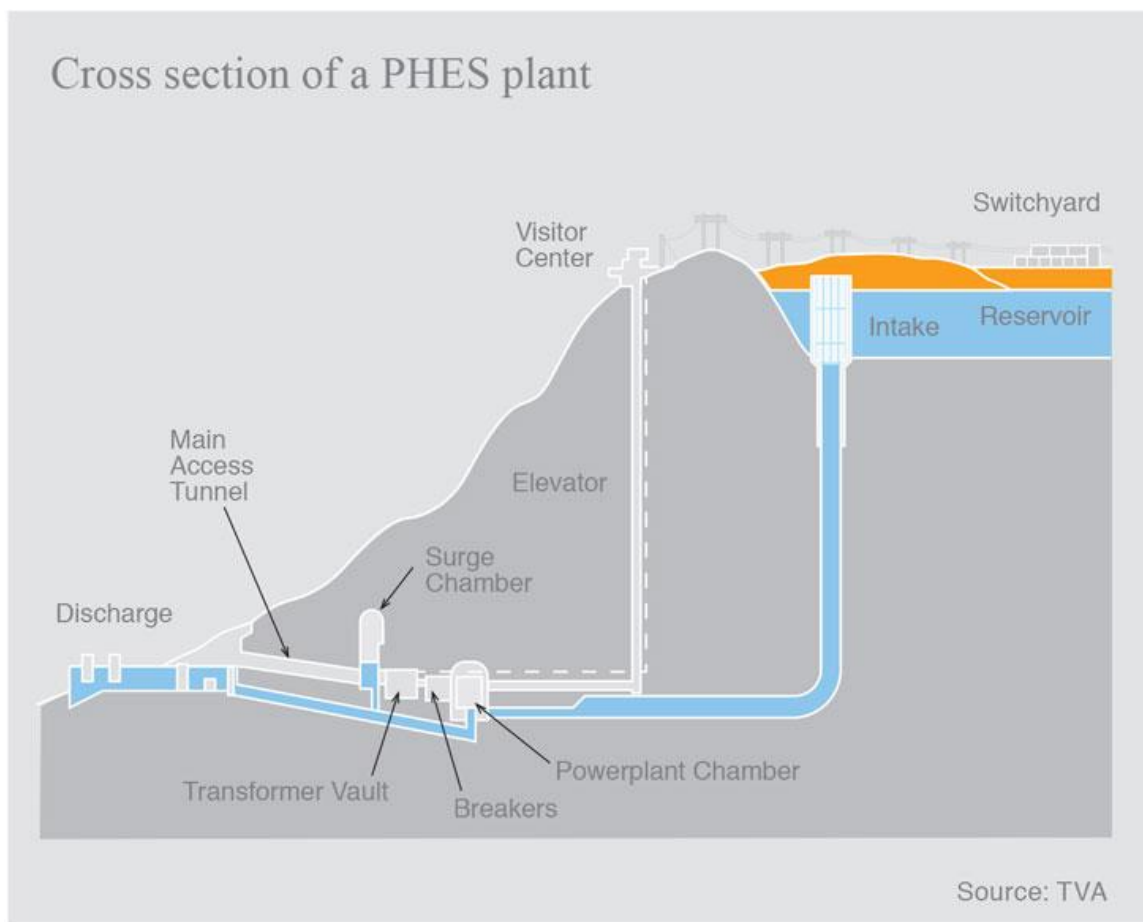
Despite the large anticipated need for energy storage solutions within the power industry, very few grid-integrated storage installations are in actual operation. 8. Figure shows the installed storage capacity worldwide, based on data collected by the Fraunhofer Institute and the Electric Power Research Institute (EPRI). The vast majority (99%) of this capacity is PHS, while the other 1% includes a mix of battery, CAES, flywheels and thermal storage. There are remaining data gaps in this analysis, especially in distributed energy storage applications used in the existing grid but the order of magnitude and the proportions are substantial. [3][4][12]



8. Figure: Installed capacity worldwide [DOE]

Pumped Hydro Storage (PHS)

With over 120 GW, pumped hydro storage power plants represent around 99% of the world's electrical energy storage capacity. These plants can start up within a couple of minutes and can thus be used to provide balancing and reserve to systems with variable renewables. The advantages are the very long lifetime, huge capacity and practically unlimited cycle lifetime. Their main drawback is their relatively low round-trip efficiency of around 70-80%, as well as geographical restrictions. These are dictated by the need for relatively large water reservoirs and large elevation variations between lower and upper reservoirs to provide sufficient capacity. Conventional PHS systems use two water reservoirs at different elevations to pump up water during the off-peak hours from the lower to the upper reservoir (charging). When required, the water flows back from the upper to the lower reservoir, powering a turbine with a generator to produce electricity (discharging) (See 9. Figure). It is



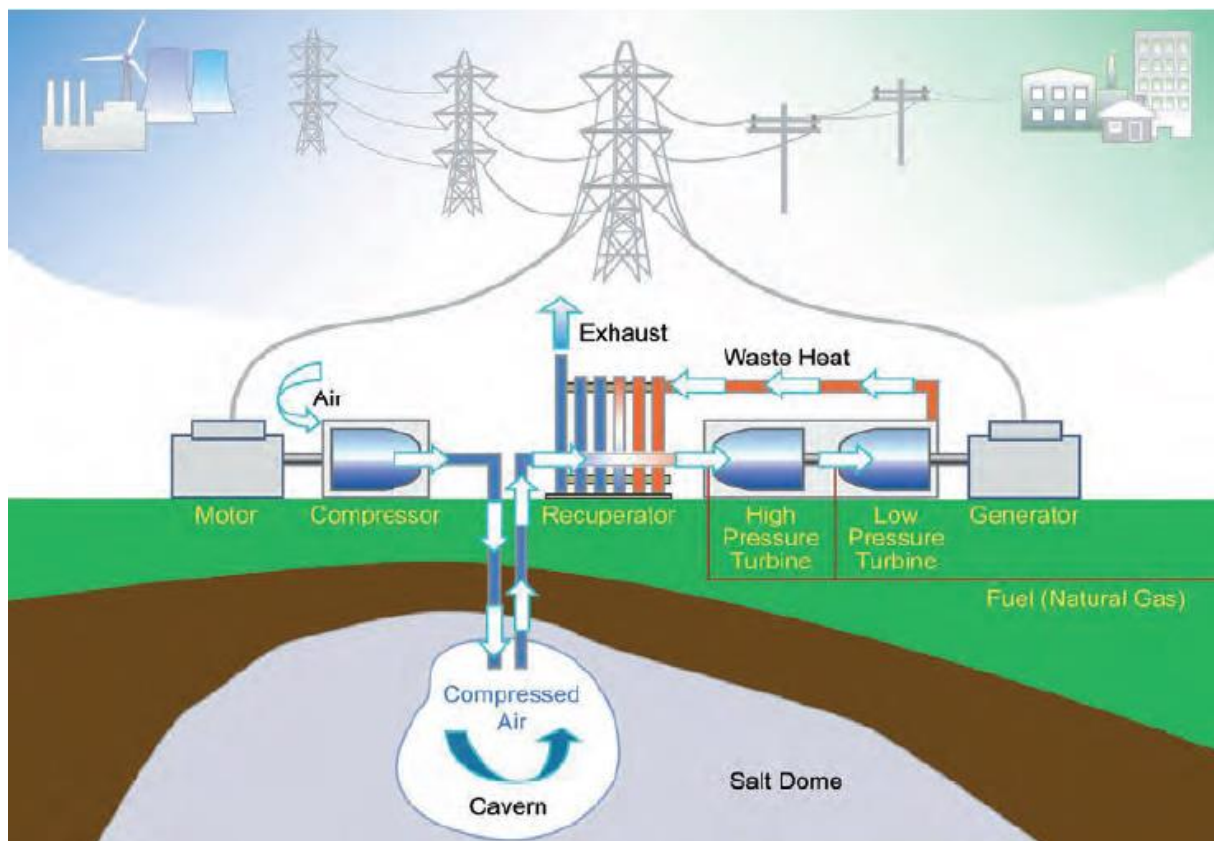
a mature and commercially used technology which is able to provide huge capacity. PHS has existed for a long time: the first plants were used in Italy and Switzerland in the 1890s. Projects may be practically sized up to 4000 MW. While the siting, permitting and associated environmental impact processes can take many years, there is growing interest in re-examining opportunities for PHS. [2] [11] [12]

9. Figure: Cross section of a Pumped Hydro Energy Storage plant [12]

Compressed Air Energy Storage (CAES)

CAES systems use off-peak electricity to compress air and store it in a reservoir, either an underground cavern or aboveground pipes or vessels. This air is later heated, expanded and released to a combustor in a gas turbine to generate electricity during peak periods (See the schematic of this technology in 10. Figure). This is the only commercial bulk energy storage plant available today, other than PHS (there are 2 operating systems: one in Germany and one in Alabama, USA). If the heat released during the compression is dissipated by cooling and not stored, the air must be reheated prior to expansion in the turbine. This process is called diabatic CAES. The main problem with this technology is the low efficiency (less than 50%), but the possible use of an adiabatic thermal process to lose less heat. These plants could operate around 70% efficiency.

Typical underground storage options are caverns, aquifers or abandoned. The advantage of CAES is its large capacity, the disadvantages are low round-trip efficiency and geographic limitation of locations. [2][3][4][12]

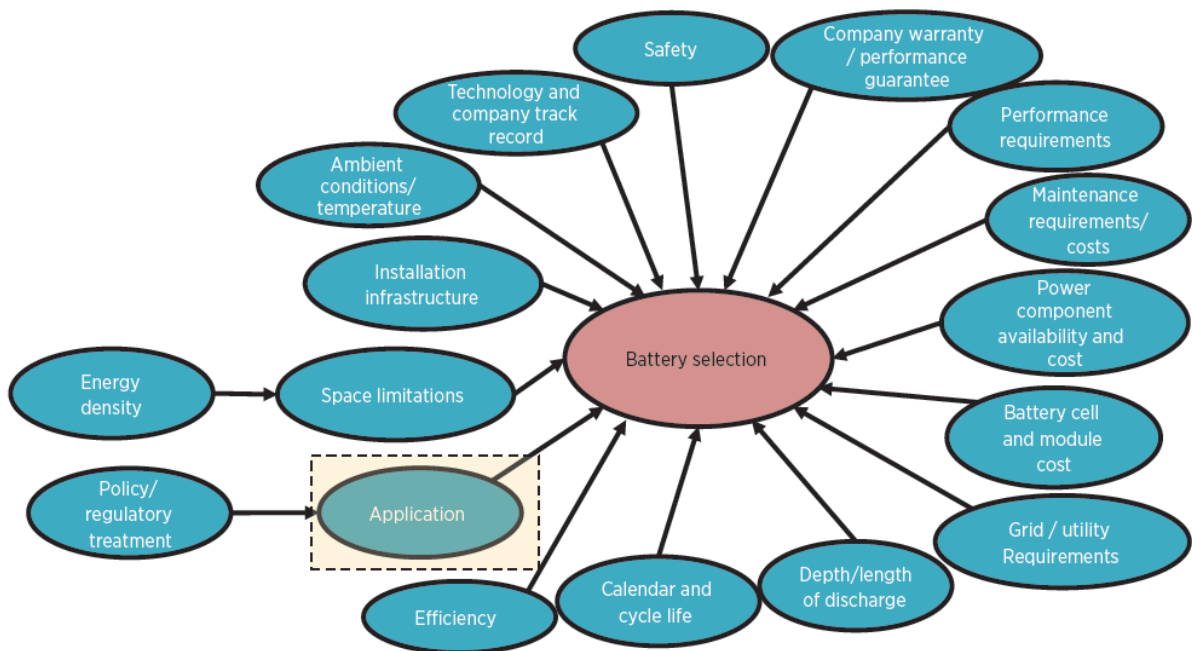


10. Figure: Schematic of a CAES plant with underground cavern storage

Battery Technologies

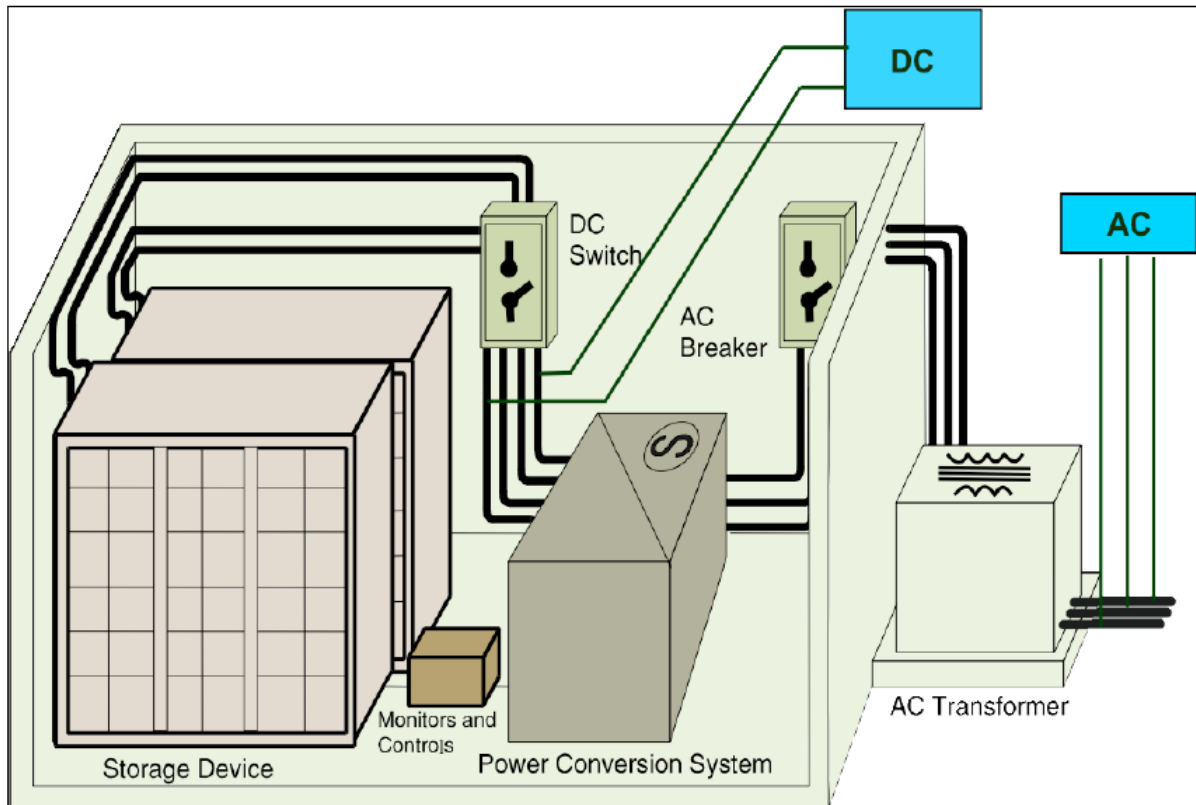
The types of batteries discussed below are secondary (rechargeable) batteries, unlike the non-rechargeable ones used in some consumer applications. These batteries store energy chemically. The component materials are sourced from various locations around the world, and their availability or scarcity has an impact on the cost and sustainability of the battery. These technologies are able to mitigate both the short (defined as seconds) and long-term (several hours) fluctuations.

In batteries the cathode (the positive part) is separated from the anode (the negative part) by a porous separator, and ions are allowed to flow between the two charges via an electrolyte. The chemical reaction creates current and voltage (which together create power) that can be supplied to a load. In flow batteries, the electrolyte is stored in external tanks and is pumped through a central reaction unit. This consists of a cathode and anode through which a current is either taken in (charged) or supplied (discharged) to the external demand/supply source. Since batteries are composed of chemicals, the manner and conditions under which they are used affects their performance, cost and life time. There are a lot of important aspects of selecting a battery energy storage system (BESS) (11. Figure.) [10]



11. Figure: Important considerations for battery selection [10]

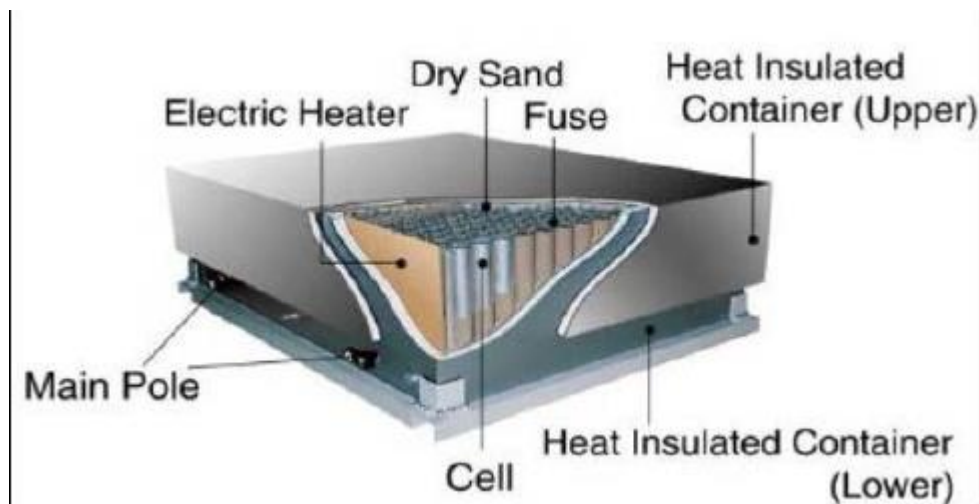
12. Figure shows a schematic of a BESS. The battery alone is not sufficient to connect and operate to the grid. The alternating current of the systems must be converted (with an inverter) and safety applications are also needed (circuit breakers, switches). With a controlling and monitoring unit, the system could be used as an energy storage installation. [2][10][12]



12. Figure: Schematic of a battery energy storage system [2]

Sodium-sulfur Battery (NaS)

Sodium-sulfur batteries are commercial energy storage technology finding applications in distribution grid support, wind power integration and high-value grid services. This technology holds potential for use in grid services because of its long discharge periods (up to 6 hours). The NaS batteries use hazardous materials including metallic sodium, which is combustible if exposed to water. Therefore, construction of NaS batteries includes airtight, double-walled stainless-steel enclosures that contain the series-parallel arrays of NaS cells. Each cell is hermetically sealed and surrounded with sand both to anchor the cells and to mitigate fire as shown in the 13. Figure.



13. Figure: NaS [2] battery layout [2]

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These batteries could respond quickly and have been demonstrated at around 200 sites in Japan, Germany, France, UAE. In the United States there are MW scale applications for reliability improvements which could switch a microgrid into islanding operation in most of fault cases. There are also MW scale services for peak shaving, investment deferrals and frequency regulation according to NGK². This technology could become the #1 choice for grid-scale battery storage as it is a market leader right now and has all the technological parameters to remain the best solution. The main drawback is that to maintain operating temperatures a heat source is required, which uses the battery's own stored energy. Due to its physical and chemical parameters, this technology could be really interesting for stakeholders in the future. [2][3][4][12]



14. Figure: XCELL batteries supporting wind turbines (USA) [2]

Lead-acid batteries

Lead-acid batteries are the oldest form of rechargeable battery technology, therefore it is commercially mature. They are widely used to power engine starters in cars, boats, planes etc. The positive electrode is composed of lead-dioxide, while the negative electrode is composed of metallic lead. The active material in both electrodes is highly porous to maximize surface area. The electrolyte is sulfuric acid. [2]

Their typical applications are emergency power supply systems, stand-alone systems with photovoltaic generation, battery systems for mitigation of output fluctuations from wind power and as starter batteries as mentioned before. [12][3]

Disposal of lead-acid batteries is an important part of the life cycle. The environmental and safety hazards associated with lead require a number of regulations concerning the handling and disposal of lead-acid batteries. Lead-acid batteries are among the most recycled products in the world. Old

² NGK Insulators LTD. NAS Division, Power Business Group, Japan

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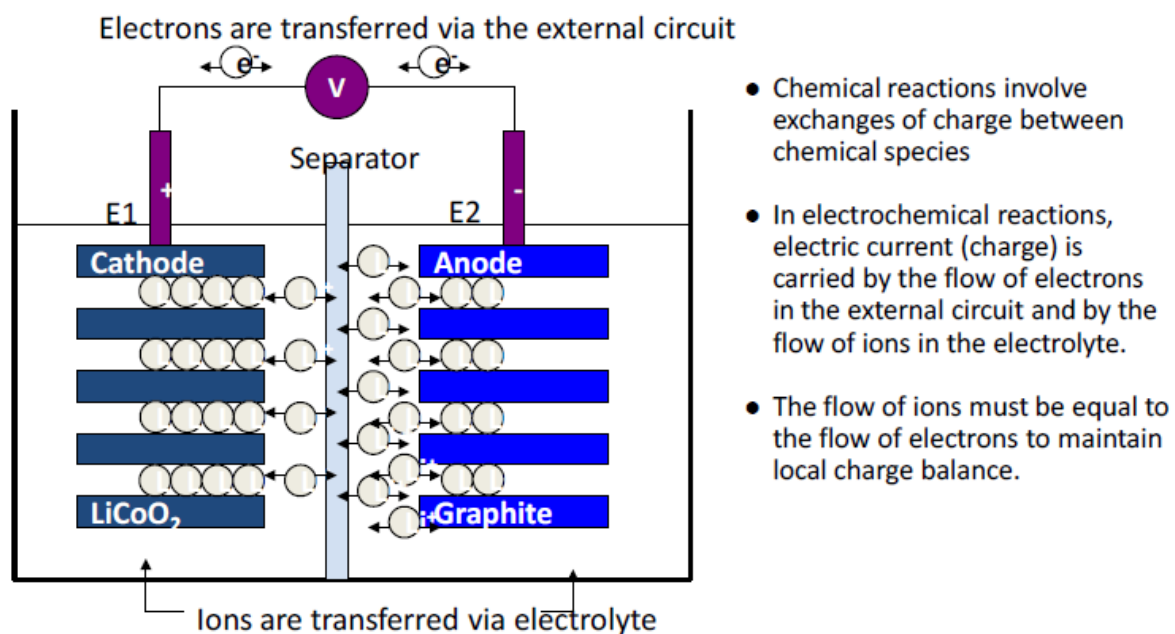
batteries are accepted by lead-acid manufacturers for recycling. Batteries are separated into their component parts. The lead plates and grids are smelted to purify the lead for use in new batteries. Acid electrolyte is neutralized, scrubbed to remove dissolved lead, and released into the environment. Other component parts are also recycled.[2]

The main drawback of the technology is the capacity decrease when high power is discharged. The low energy density is also worth to mention. [12]

Li-ion batteries

Li-ion battery technology has emerged as the fastest growing platform for stationary storage applications. It is also commercially proven and mature for consumer electronic applications and also being positioned as the leading technology platform for plug-in hybrid electric vehicles (PHEV) and all-electric vehicles.

There are many different Li-ion chemistries, each with specific power-versus-energy characteristics. A Li-ion battery cell contains two reactive materials capable of undergoing an electron transfer chemical reaction. To undergo the reaction, the materials must contact each other electrically, either directly or through a wire, and must be capable of exchanging charged ions to maintain overall charge neutrality as electrons are transferred. A battery cell is designed to keep the materials from directly contacting each other and to connect each material to an electrical terminal isolated from the other material's terminal. These terminals are the cell's external contacts (15. Figure).



15. Figure: Principles of a Li-ion battery [2]

The large manufacturing scale of Li-ion batteries (estimated to be approximately 30 GWh by 2015) could result in potentially lower-cost battery packs – which could also be used and integrated into systems for grid-support services that require less than 4 hours of storage. Many stationary systems have been deployed in early field trials to gain experience in siting, grid integration, and operation.[2]

This technology has a high cell voltage level (3,7 Volts) which means that the number of cells in series with the associated connections and electronics can be reduced. It has a relatively high energy density and very high efficiency (95-98%). Since lithium ion batteries are currently still expensive,

they can only compete with lead acid batteries in those applications which require short discharge times.

Safety is a serious issue in lithium ion battery technology. Most of the metal oxide electrodes are thermally unstable and can decompose at elevated temperatures, releasing oxygen which can lead to a thermal runaway. To minimize this risk, lithium ion batteries are equipped with a monitoring unit to avoid over-charging and over-discharging. [3][4][10][12]

Other battery technologies

- Sodium-nickel-chloride (NaNiCl₂): it is a high temperature battery device. It is safer than other batteries, and if fault occurs in one cell, the others can maintain their power instead of a premature failure of the complete system. It is also known as Zebra (from the Zero Emission Battery Research)[2][12]
- Vanadium redox: vanadium reduction and oxidation (redox) batteries are of a type known as flow batteries, in which one or both active materials is in solution in the electrolyte all times. In this case, the vanadium ions remain in an aqueous acidic solution throughout the entire process. Vanadium redox systems are capable of stepping from zero output to full output within a few milliseconds, if the stacks are already primed with reactants. In fact, the limiting factor for beginning battery discharge is more commonly the controls and communications equipment. It can be recharged quickly, and cannot suffer capacity loss. [2][3][12]
- Zinc-air: Zinc-air batteries are a metal-air electrochemical cell technology. Metal-air batteries use an electropositive metal, such as zinc, aluminum, magnesium, or lithium, in an electrochemical couple with oxygen from the air to generate electricity. Because such batteries only require one electrode within the product, they can potentially have very high energy densities. In addition, the metals used or proposed in most metal-air designs are relatively low cost. This has made metal-air batteries potentially attractive for electric vehicle (EV) and power electronics applications in the past, as well as raising hopes for a low-cost stationary storage system for grid services. [2][3][12]
- Nickel cadmium and nickel metal hydride battery (NiCd, NiMH): Before the commercial introduction of nickel metal hydride (NiMH) batteries around 1995, nickel cadmium (NiCd) batteries had been in commercial use since about 1915. Compared to lead acid batteries, nickel-based batteries have a higher power density, a slightly greater energy density and the number of cycles is higher; many sealed construction types are available. From a technical point of view, these are very successful products, these are the only batteries capable of performing well even at low temperatures (-40 °C). [12][3]

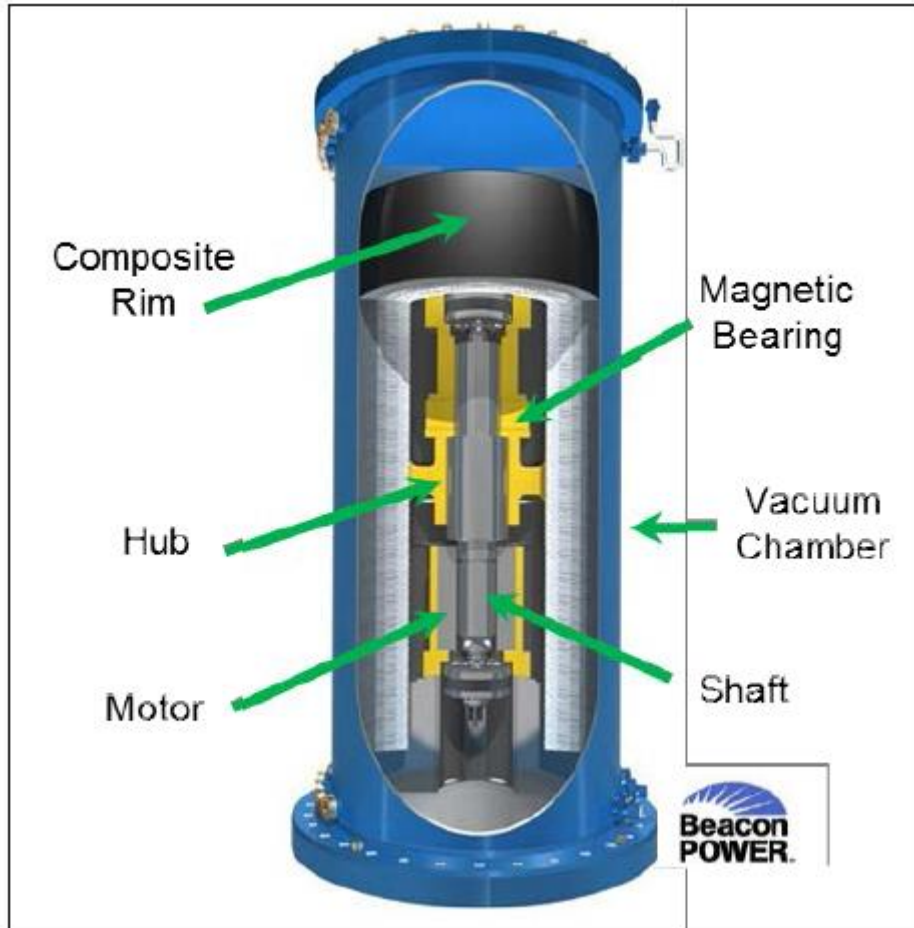
Flywheel

Flywheels store energy in the form of the angular momentum of a spinning mass which called rotor (a massive rotating cylinder). The work done to spin the mass is stored in the form of kinetic energy. A flywheel system transfers kinetic energy into AC power through the use of controls and power conversion systems (See 16. Figure).

Round-trip efficiency and standby power loss become critical design factors in energy flywheel design because losses represent degradation of the primary commodity provided by the storage system (energy). However, they are largely irrelevant in power flywheel design, although standby losses are a factor in operating cost in comparison with other power technologies that have significantly lower losses. For these reasons, energy flywheels usually require more advanced technologies than power flywheels.

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Flywheels can be charged relatively quickly. Recharge times are comparable to discharge times for both power and energy flywheel designs. High-power flywheel systems can often deliver their energy and recharge in seconds. Flywheels generally exhibit excellent cycle life in comparison with other energy storage systems. Most developers estimate cycle life in excess of 100,000 full charge-discharge cycles and this technology has negligible maintenance needs. Because flywheel systems are fast-responding and efficient, they are currently being positioned to provide frequency-regulation services [2][3][4][12]



16. Figure: Integrated flywheel system package cutaway diagram [2]

Supercapacitors (DLC)

Electrochemical double-layer capacitors (DLC) fill the gap between classical capacitors used in electronics and general batteries. This technology still exhibits a large development potential that could lead to much greater capacitance and energy density. The two main features are the extremely high capacitance values, of the order of many thousand farads, and the possibility of very fast charges and discharges due to extraordinarily low inner resistance which features are not available with conventional batteries. Still other advantages are durability, high reliability, no maintenance, long lifetime and operation over a wide temperature range and in diverse environments (hot, cold and moist). The lifetime reaches one million cycles (or ten years of operation) without any degradation, except for the solvent used in the capacitors whose disadvantage is that it deteriorates in 5 or 6 years irrespective of the number of cycles. They are environmentally friendly and easily

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recycled or neutralized. The efficiency is typically around 90 % and discharge times are in the range of seconds to hours. [3] [12]

Superconducting magnetic energy storage

Superconducting magnetic energy storage (SMES) systems work according to an electrodynamic principle. The energy is stored in the magnetic field created by the flow of direct current in a superconducting coil, which is kept below its superconducting critical temperature. The main component is a coil made of superconducting material. The main advantage of SMES is the very quick response time: the requested power is available almost instantaneously. Moreover the system is characterized by its high overall round-trip efficiency and the very high power output which can be provided for a short period of time. [3][12]

Thermal Storage

Thermal energy storage systems store available heat by different means in an insulated repository for later use. Thermal storage can be subdivided into different technologies: storage of sensible heat, storage of latent heat, and thermo-chemical and absorption storage. [12]

The storage of sensible heat is one of the best-known and most widespread technologies, with the domestic hot water tank as an example. The storage medium may be a liquid such as water or thermo-oil, or a solid such as concrete or the ground. Latent heat storage is accomplished by using phase change materials (PCMs) as storage media. Sorption (adsorption, absorption) storage systems work as thermo-chemical heat pumps under vacuum conditions and have a more complex design. [12]

Combined heat and power Plants (CHP) could detach heat generation from demand such as electrical energy storage does to electric power grids. Heat storage has more commercial level projects so it is important to consider it as an opportunity.

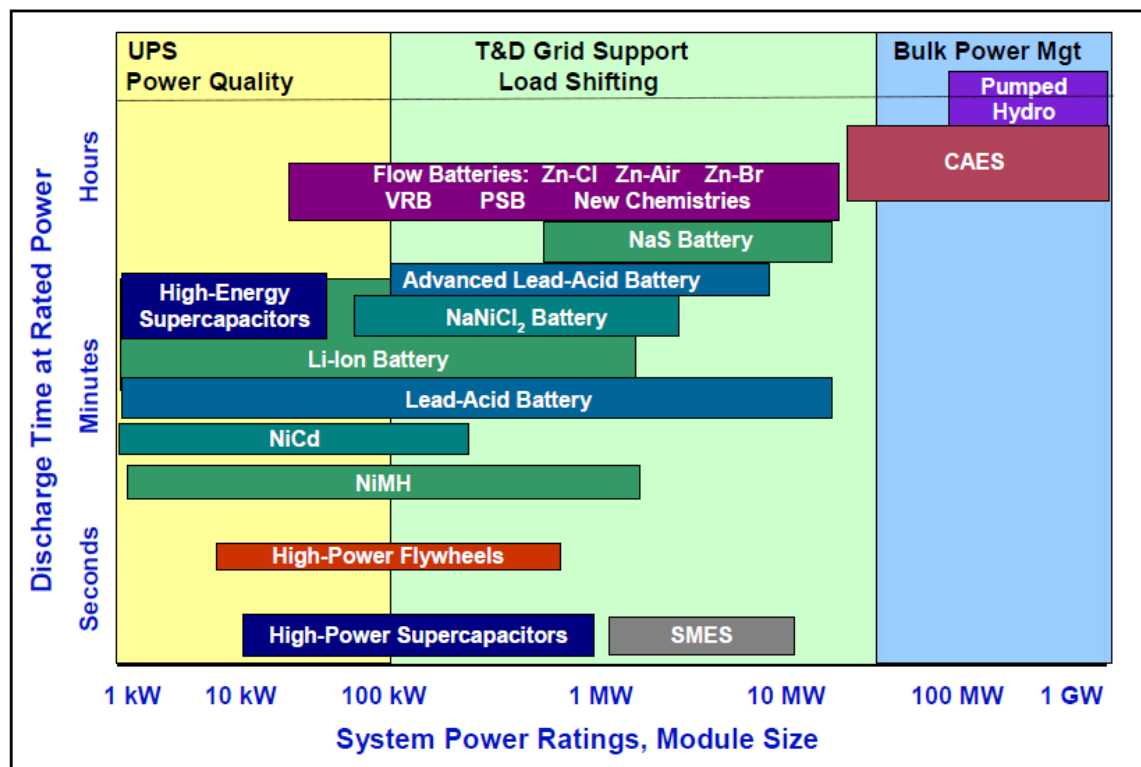
Comparison of technologies

The portfolio of energy storage technologies can be considered for providing a range of services to the power grid and can be positioned around their nominal power and capacity relationship. Figure 17 shows that compressed air energy storage and pumped hydro are capable of discharge times in tens of hours, with correspondingly high sizes (~1000 MW range). In contrast to the capabilities of these two technologies, batteries and flywheels are positioned around lower power and shorter discharge times. However, those comparisons are very general, intended for conceptual use only, many of the storage options have broader duration and power ranges than shown. Table 1 summarizes all the relevant technical parameters for energy storage systems.

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Technology	Response time	Energy density Wh/Kg	Power density W/l	Discharge time	Efficiency	Lifetime	Cycle lifetime
PHS	min	0,2-2	0,1-0,2	hour	70-80	>50	>15000
CAES	min	-	0,2-0,6	hour	41-75	>25	>10000
Flywheel	<sec	42154	5000	sec	80-90	15.0-20	20000-1000000
Lead-acid battery	<sec	30-45	90-700	min	75-90	3.0-15	250-1500
NiCd battery	<sec	15-40	75-700	hour	60-80	5.0-20	1500-3000
NiMH battery	<sec	40-80	500-3000	hour	65-75	5.0-10	600-1200
Li-ion battery	<sec	60-200	1300-10000	hour	85-98	5.0-15	500-10000
Zinc-air battery	<sec	130-200	50-100	hour	50-70	>1	>1000
NaS battery	<sec	100-250	120-160	hour	70-85	10.0-15	2500-4500
NaNiCl battery	<sec	100-200	250-270	hour	80-90	10.0-15	~1000
Vanadium-redox battery	<sec	15-50	0,5-2	hour	60-75	5.0-20	>10000
Hydrogen <i>Centralized</i> <i>Decentralized</i>	sec-min	33330	0,2-2 2,0-20	hour-day	34-44	10.0-30	1000-10000
Syngas	min	10000	0,2-2	hour-day	30-38	10.0-30	1000-10000
Supercapacitor	<sec	1,0-15	40000-120000	sec	85-98	4.0-12	10000-100000
SMES	<sec	-	2600	sec	75-80	-	-

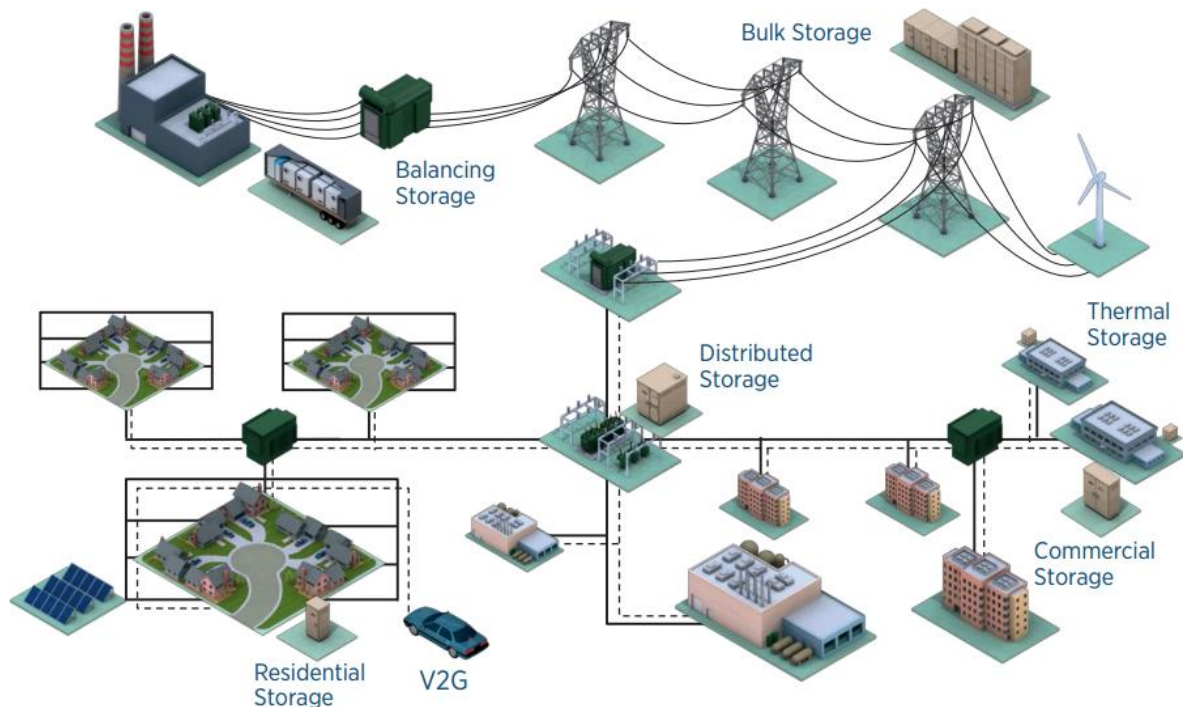
1. Table: Technical parameters of energy storage systems [12][3][4]



17. Figure: Energy storage system comparison: Discharge time at System power ratings [2]

Energy Storage Applications

To determine the potential role of storage in the grid/system of the future, it is important to examine the technical and economic impacts of the deployments. Operational changes to the grid have created an opportunity for storage systems to provide unique services to the evolving grid. Energy storage systems can provide a variety of application solutions along the entire value chain of the electric power system (18. Figure).



18. Figure: Application possibilities on the entire value chain of the power system [11]

The applications could be classified by the scope of the benefits. The applications summarized below are based on the research paper of the Electric Power Research Institute' publications (reference [2] [3]).

- generation and system-level
- transmission and distribution system
- end-user applications

Generation and system level applications

Power plant operational cost savings

Some energy storage pilot projects have been located at fossil generation power plants specifically to reduce the variable operating and maintenance costs. Storage technologies can provide a rapid response to a regulation or dispatch signal, allowing the fossil unit to respond slowly. This application could result more flexible power plants that can perform as a load-following unit, what could be higher value on the market. [3]

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Reducing the size of the transmission system

Transmission lines are long-lived capital assets that are constructed in fixed size increments. With a proper use of energy storage, a more decentralized structure could be feasible where generation is near the consumption.

Reduce imbalance energy charges

Imbalance energy charges are assessed by the transmission system operator (or determined by the balancing markets) when load or generation deviates from its designated level (schedule) beyond a set range. With proper use of energy storage, industry stakeholders could shift their needs to avoid those charges. [3]

Renewable energy seasonal output shifting

Some energy storage devices such as pumped hydroelectric resources can store energy over long periods of time. Different parts of the electric grid have different seasonal peaking profiles. In warm climates, the peak season is during the summer when the air conditioning load is the highest. In cold climates, the peak season is often in the winter when electrical heating load is high. Large-scale energy storage could be used to shift the excess renewable energy produced in non-peak seasons to be available during peak times. [3]

Energy arbitrage

Energy prices are highly volatile, but tend to show a daily pattern. Electric energy time shift involves purchasing inexpensive electric energy which is available during periods when prices or system marginal costs are low, to charge the storage system so that the stored energy can be used or sold at a later time when the price or cost are high. Alternatively, storage can provide similar time-shift duty by storing excess energy production, which would otherwise be curtailed, from renewable sources such as wind or photovoltaic. [2][3]

The storage parameter ranges for energy arbitrage is highly dependent on the exact purpose, but (as for every other application) EPRI (in reference [2] and [3]) provided estimation:

Storage system size range: 1-500 MW

Target discharge duration range: <1 hour

Minimum cycles/year: 250+

The scale covers wide range of optimal power from smaller PV systems to larger operator controlled applications. Both storage variable operating cost (non-energy-related) and storage efficiency are especially important for this service. [3][2]

Black start

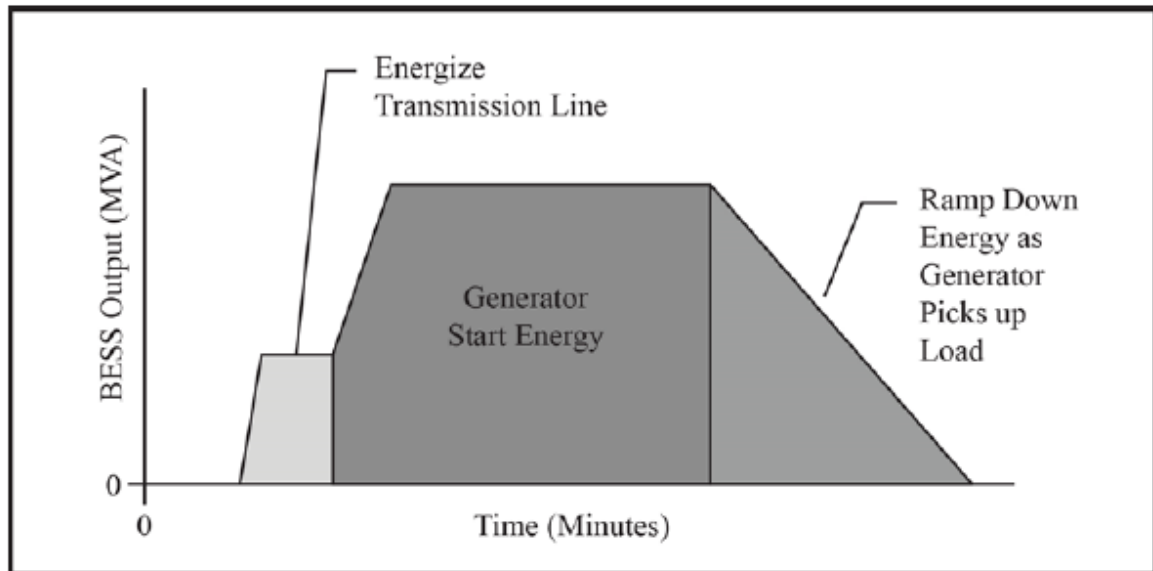
Storage systems provide an active reserve of power and energy within the grid and can be used to energize transmission and distribution lines and provide station power to bring power plants on line after a catastrophic failure on the grid. Storage can provide a similar startup power to larger power plants, if the storage system is suitably sited and there is a clear transmission path to the power plant from the storage system's location. Many power plants require electricity to perform start-up operations. Plants with the black start ability could get paid for the service. [2] [3]

Storage system size range: 5-50 MW

Target discharge duration range: 15 minutes- 1 hour

Minimum cycles/year: 10-20

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19. Figure: Black start service by energy storage [2]

19. Figure represents the black start operation. On axis Y, the Battery (or any other technology) energy storage system's power output is shown. The transmission line energizing process means that the line connects the generator to the grid needs to be at its nominal voltage (or near to it), to avoid transient processes which causes the protection system switches and unsuccessful starting of the generator.

Spinning and replacement reserves

Non spinning (or non-synchronized, replacement) reserves are generation capacity that may be offline or that comprises a block of curtailable and/or interruptible loads and that can be available within 10 minutes. Spinning reserves is generation capacity that is online but unloaded and that can respond within 10 seconds to compensate for generation or transmission outages. Generally, reserves are at least as large as the single largest generation unit minus the minimum load of them operating as spinning reserve unit.

Operation of the power grid requires reserve capacity that can be called upon when portion of the normal electric supply resources become unavailable unexpectedly. [2][3]

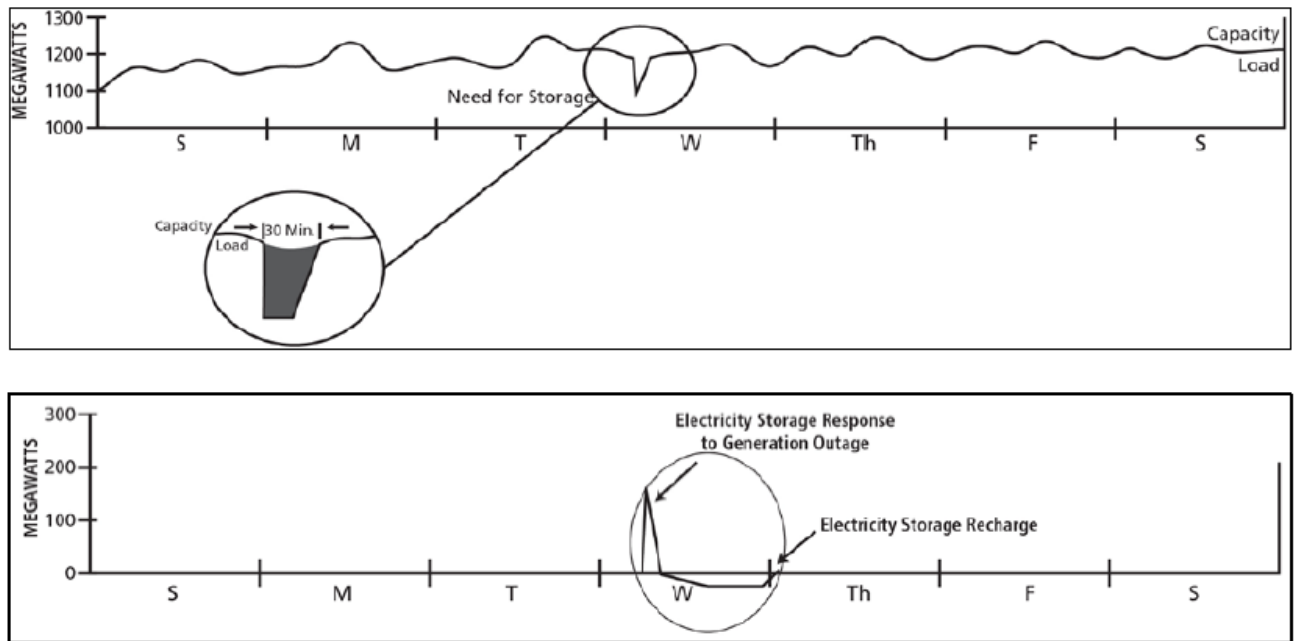
Storage system size range: 10-100 MW

Target discharge duration range: 15 minutes- 1 hour

Minimum cycles/year: 20-50

The power output of an energy storage system operating as a reserve can be seen on 20. Figure.

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20. Figure: Storage for reserve capacity [2]

Frequency regulation

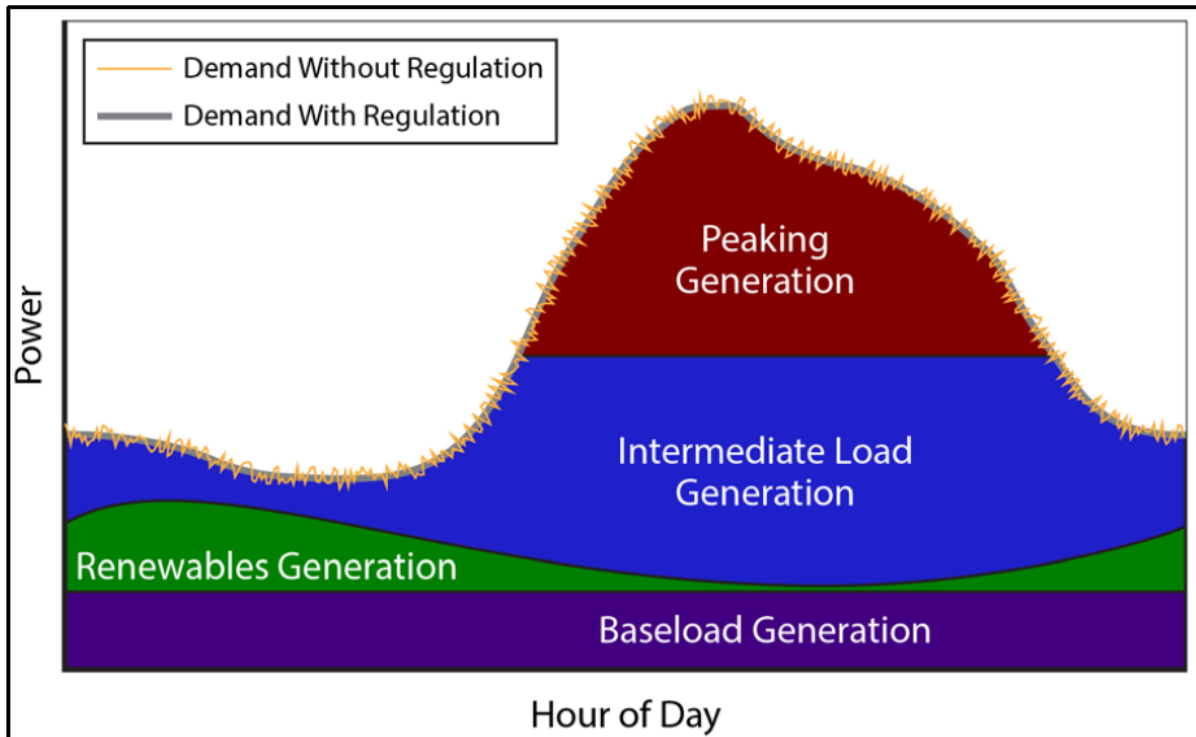
System regulation is one of the ancillary services for which storage is especially well-suited. Regulation involves managing interchange flows with other control areas to match closely the scheduled interchange flows and momentary variations in demand within the control area. The primary reasons for including regulation in the power system are to maintain the grid frequency, match extremely short-term fluctuations in the system load. The rapid-response characteristic of most storage systems makes it valuable as a regulation resource. [2] [3].

Storage system size range: 10-40 MW

Target discharge duration range: 15 minutes- 1 hour

Minimum cycles/year: 250-10000

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21. Figure: System load with and without regulation [2]

Local capacity, system capacity

Depending on the circumstances in a given electric supply system, energy storage could be used to defer and/or to reduce the need to buy new central station generation capacity and/or purchasing capacity in the wholesale electricity marketplace. Some areas of the grid are not easily served by existing generation and capacity resources. Local generation capacity with energy storage could help to find solutions in the most congested areas.

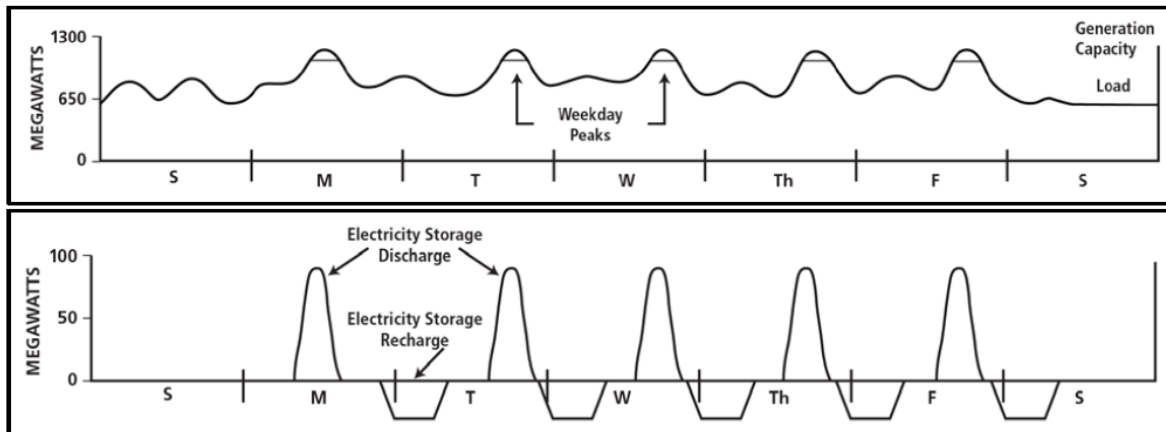
Storage system size range: 1-500 MW

Target discharge duration range: 2-6 hours

Minimum cycles/year: 5-100

The operating profile for storage used as supply capacity (characterized by annual hours of operation, frequency of operation, and duration of operation for each use) is location-specific. 22. Figure illustrates the capacity constraint and how storage acts to compensate generation deficit. [2][3]

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22. Figure: Storage for supply capacity

Renewable energy integration

Energy storage is eminently suitable for damping the variability of wind and PV systems and is being widely used in this application. Technically, the operating requirements for a storage system in this application are the same as those needed for a storage system to respond to a rapidly or randomly fluctuating load profile. Load following is characterized by power output that generally changes as frequently as every several minutes. The output changes in response to the changing balance between electric supply and load within a specific region or area. [2] [3]

Storage system size range: 1-100 MW

Target discharge duration range: 15 minutes- 1 hour

Minimum cycles/year: not applicable

Storage is well-suited to load following for several reasons. First, most types of storage can operate at partial output levels with relatively modest performance penalties. Second, most types of storage can respond very quickly (compared to most types of generation) when more or less output is needed for load following. Consider also that storage can be used effectively for both load following up (as load increases) and for load following down (as load decreases), either by discharging or by charging. (as explained in Chapter 1: changes in the electrical power grid) [2] [3]

Transmission and distribution system supporting applications

Voltage and reactive power support

A requirement for electric grid operators is to maintain voltage within specified limits. In most cases, this requires management of reactive power, which is caused by grid-connected equipment that generates, transmits, or uses electricity and often has or exhibits characteristics like those of inductors and capacitors in an electric circuit. To manage reactance at the grid level, system operators need voltage support resources to offset (provide or absorb) reactive effects so that the transmission system can be operated in a stable manner. To serve as a reactive power source, the power electronic devices of the storage system must be capable of operating at a non-unity power factor.

Storage system size range: 1-10 MVAR (mega volt-ampere reactive)

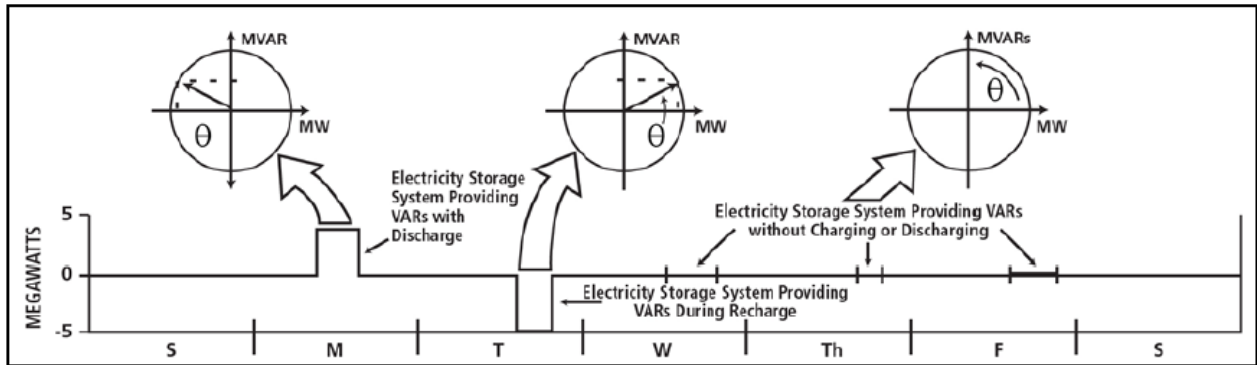
Target discharge duration range: not applicable

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Minimum cycles/year: not applicable

Normally, designated power plants are used to generate reactive power (VAR) to offset the grid element's reactive effects. These power plants could be displaced by strategically placed energy storage within the grid at central locations or taking the distributed approach and placing multiple VAR-support storage systems near large loads. 23. Figure shows some possible occasions where storage provides reactive support to the grid with the change of its power factor to compensate the reactive power flows on the grid. This solution could help to reduce voltage stability problems as well. [2][3]



23. Figure: Energy storage for voltage support services [2]

Transmission investment deferral

Transmission upgrade investments are necessary when transmission congestion limits the amount of electricity that can be sent through a pre-existing transmission line during peak hours. Transmission upgrade deferral involves delaying – in some cases avoiding entirely – transmission and distribution network investments by using relatively small amounts of storage. By reducing peak load growth, energy storage could defer the transmission upgrade investments for a few years.

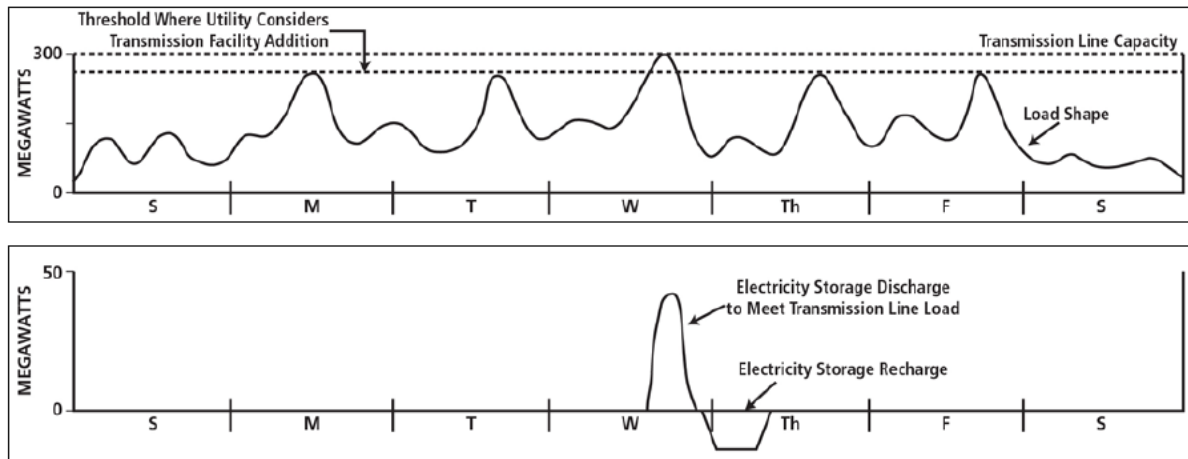
Storage system size range: 10-100 MW

Target discharge duration range: 2-8 hours

Minimum cycles/year: 10-50

The key consideration is that a small amount of storage can be used to provide enough incremental capacity to defer the need for a large lump investment in transmission equipment. Doing so reduces overall cost to ratepayers, improves utility asset utilization, allows use of the capital for other projects, and reduces the financial risk associated with lump investments. 24. Figure shows a possible way to use storage systems for investment deferral: when the load is over the current transmission line capacity, storage discharges and provides added capacity. When the load goes under the current transmission line capacity the storage could be recharged while all the consumers are supplied.

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24. Figure: Transmission and distribution system upgrading investment deferral

Notably, for most nodes within a transmission system, the highest loads occur on just a specific few days per year, for just a few hours per year. Storage could also be used for extending the lifetime of the network elements (asset management). [2][3]

Transmission congestion relief

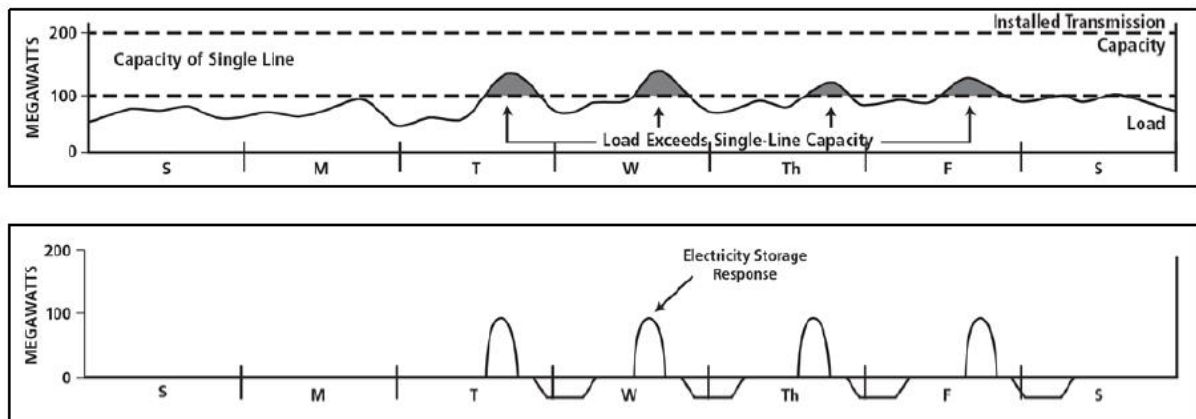
Transmission congestion occurs when available, least-cost energy cannot be delivered to all or some loads because transmission facilities are not adequate to deliver that energy. When transmission capacity additions do not keep pace with the growth in peak electric demand, the transmission systems become congested.

Storage system size range: 1-100 MW

Target discharge duration range: 1-4 hours

Minimum cycles/year: 50-100

Electricity storage can be used to avoid congestion-related costs and charges, especially if the costs become onerous due to significant transmission system congestion. In this service, storage systems would be installed at locations that are electrically downstream from the congested portion of the transmission system. Energy would be stored when there is no transmission congestion, and it would be discharged (during peak demand periods) to reduce peak transmission capacity requirements (25. Figure). [2][3]



25. Figure: Transmission congestion relief [2]

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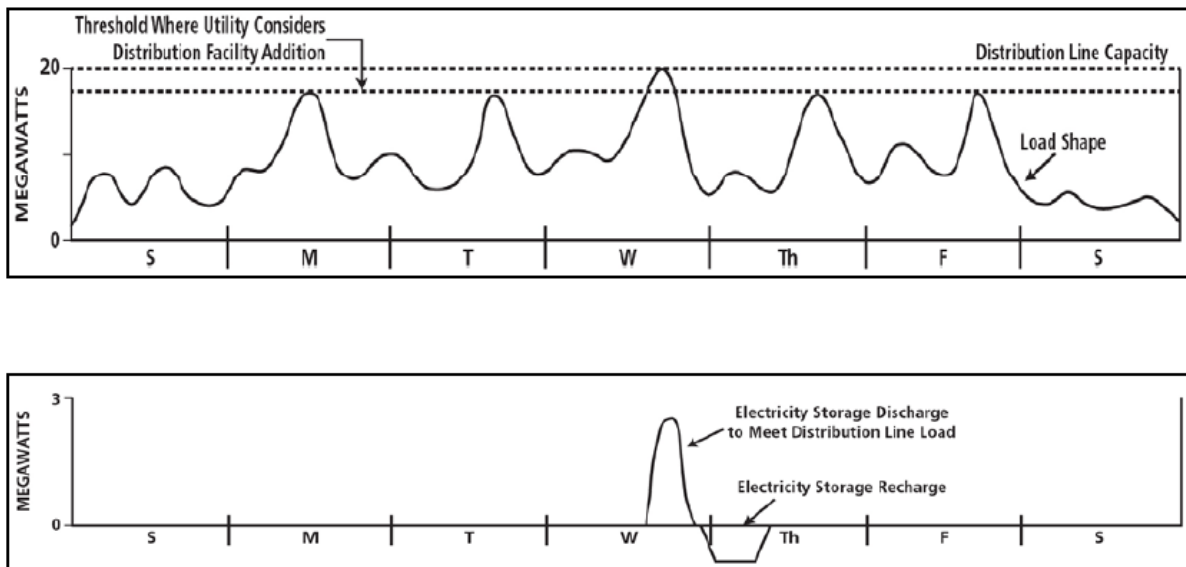
Distribution upgrade deferral and voltage support

Distribution upgrade deferral involves using storage to delay or avoid investments that would otherwise be necessary to maintain adequate distribution capacity to serve all load requirements. The upgrade deferral could be a replacement of an aging or over-stressed existing distribution transformer at a substation or re-conducting distribution lines with heavier wire. [2] [3]

Storage system size range: 0,5-10 MW

Target discharge duration range: 1-4 hours

Minimum cycles/year: 50-100



26. Figure: Distribution system deferral [2]

The lower plot on 26. Figure shows storage being discharged on Wednesday afternoon to compensate for the high load on the substation transformer, as shown in the upper plot. The storage is recharged when the feeder load reduces in the late evening.

A storage system that is used for upgrade deferral could simultaneously provide voltage support on the distribution lines. Operators control voltage within specified limits by tap changing transformers at the distribution substation and by switching capacitors to follow load changes. This is especially important on long, radial lines where a large load such as an arc welder or a residential PV system may be causing unacceptable voltage excursions on neighboring customers. [2]

Other possibilities

- Transmission stability damping: increase load carrying capacity by improving the dynamic stability of the system: the capacity of the system depends on the environment (moisture, temperature etc.). With a well-developed algorithm, transmission capacity could be higher than the static value used now. [2] [3]
- Reduce distribution losses: the most loss occurs when the system is congested. Researchers have found that energy storage systems could reduce distribution losses effectively. [3]

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End-user applications

Power quality, reliability

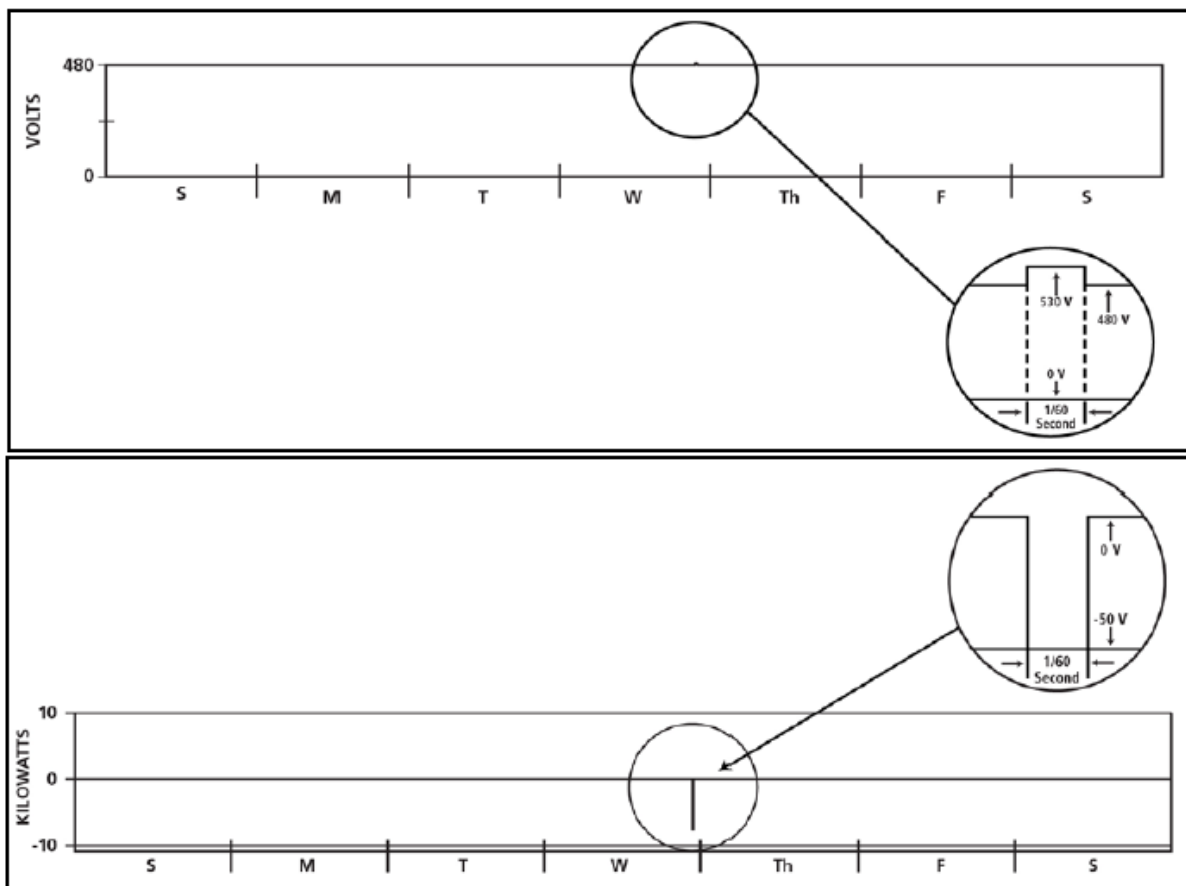
The electric power quality service involves using storage to protect customer on-site loads downstream from storage against short-duration events that affect the quality of power delivered to the customer's loads.

A storage system can effectively support customer loads when there is a total loss of power from the source utility. This support requires the storage system and customer loads to island during the utility outage and resynchronize with the utility when power is restored. The energy capacity of the storage system relative to the size of the load it is protecting determines the time duration that the storage can serve that load. [2][3]

Storage system size range: 0,1-10 MW

Target discharge duration range: 10 seconds - 15 minutes

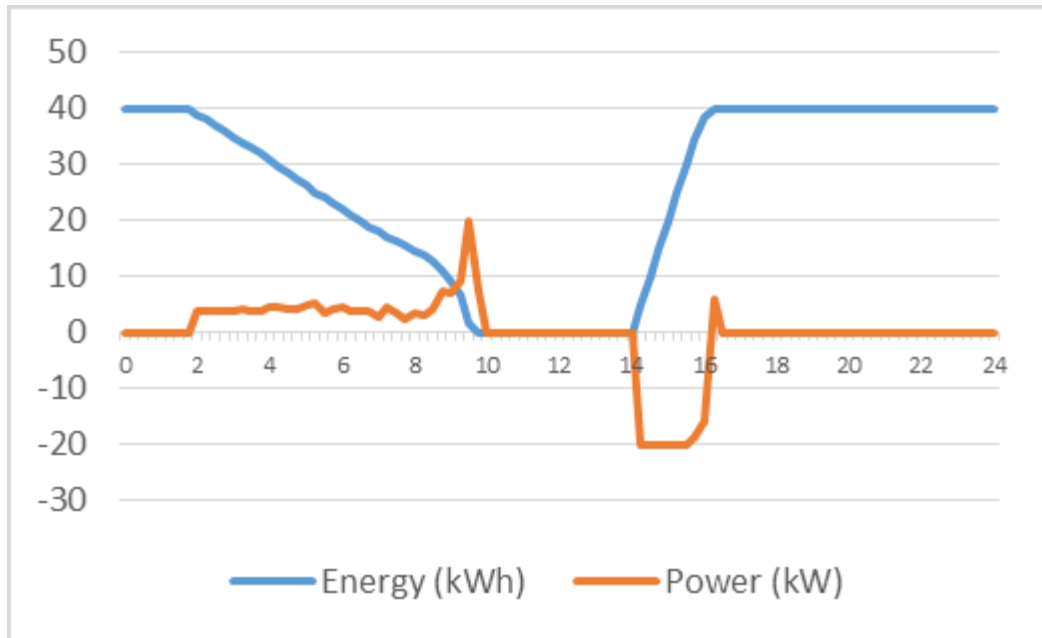
Minimum cycles/year: 50-100



27. Figure: Energy storage for customer-side power quality [2]

On the 28. Figure the storage system is operating as a reliability reserve. At 2:00 AM, a fault occurred and the storage system provided the needed load until 10 AM. After the system is fully restored at 2 PM, the storage device was being recharged.

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28. Figure: Energy storage system serving as a reliability reserve

Retail energy time-shift (Time of Use tariff)

Retail electric energy time-shift involves storage used by energy end-users to reduce their overall costs for electricity. Customers charge the storage during off-peak time periods when the retail electric energy price is low, then discharge the energy during times when on-peak time of use (TOU) energy prices apply. This application is similar to electric energy time-shift, although electric energy prices are based on the customer's retail tariff, whereas at any given time the price for electric energy time-shift is the prevailing wholesale price. [2][3]

Storage system size range: 1-1000 kW

Target discharge duration range: 1-6 hours

Minimum cycles/year: 50-250

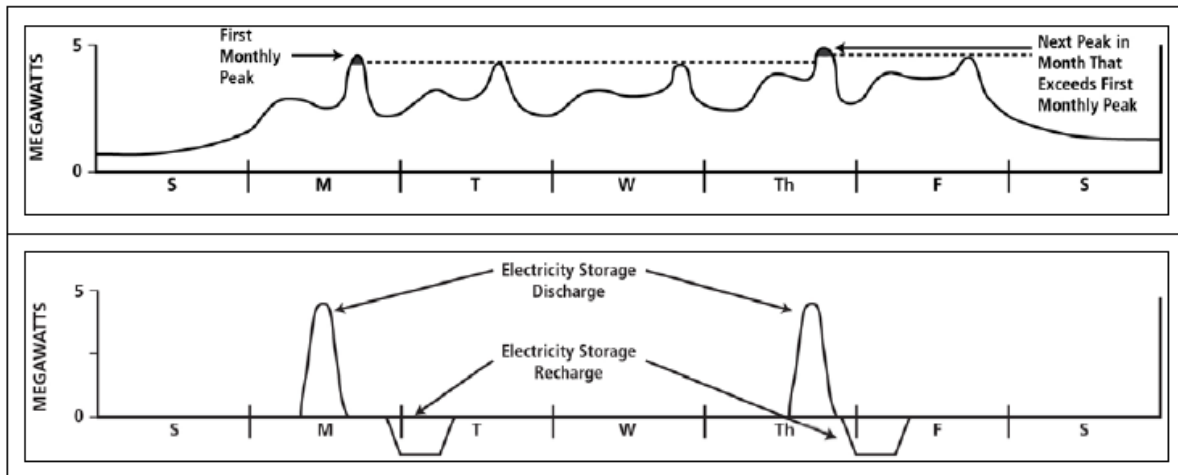
Demand side energy management

Energy storage can be used by end-users to reduce their overall costs for electric service by reducing their demand during peak periods specified by the utility. Through strategic load shifting with energy storage, such a customer can reduce their demand charges in future bills by consistently reducing the customer's peak load as measured by the meter. [2][3]

On 29.Figure, the storage plant discharge duration is based on a hypothetical applicable tariff. For example, a hypothetical TOU tariff defines six on-peak hours from 12:00 PM. to 6:00 PM. It is assumed that this requires five hours of storage duration.

The figure shows an example where the peak loads exceed the threshold set by the first peak of the month on Monday afternoon. That sets the level for the remaining month; loads must remain below that threshold to avoid demand charge penalties.

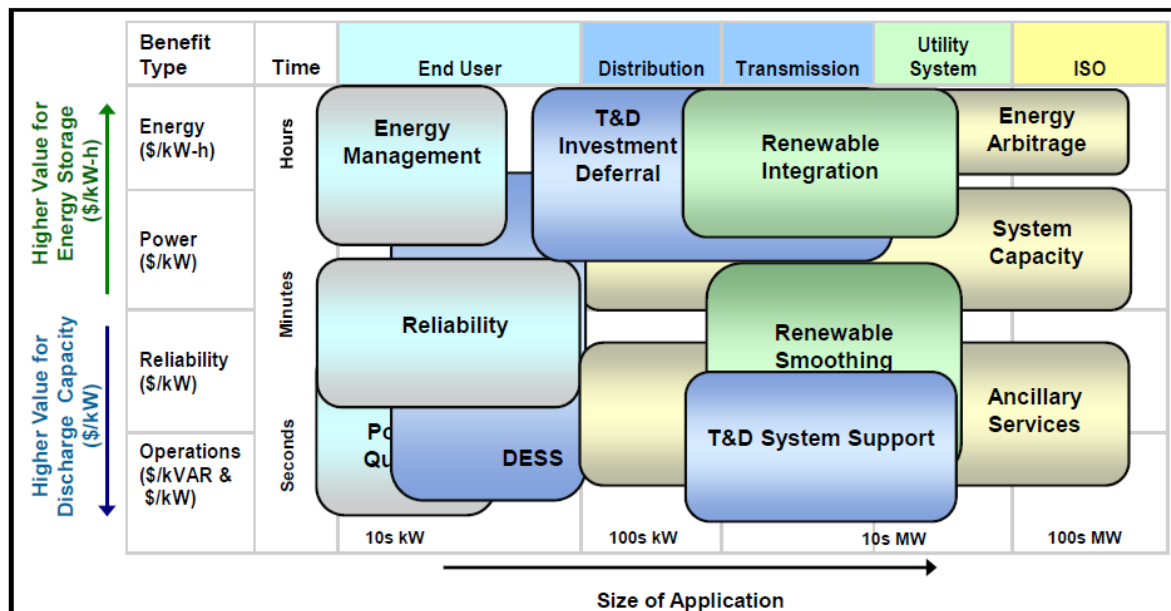
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29. Figure: Energy storage serving as a customer-side demand management

Summarization and connection with the technologies

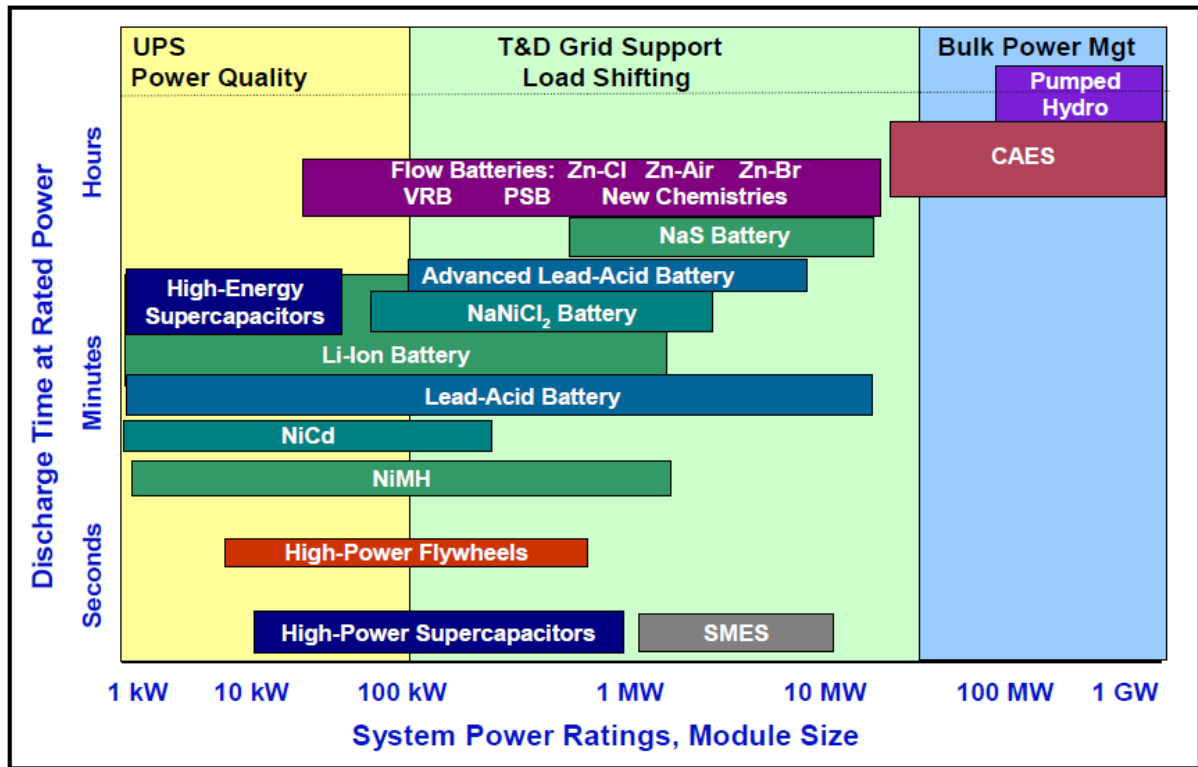
As it can be seen, energy storage systems offer wide-range of applications in the electric power industry. The applications are shown together in the 30. Figure.



30. Figure: Operational benefits monetizing the value of energy storage [3]

On the 31. Figure, the technology options are connected to the applications. It is always highly dependent on the actual needs. The high capacity need of bulk storage could be satisfied by PHS and CAES systems. Battery storage covers wide-range of applications from the smallest to the transmission level. Some special storage technologies like supercapacitors have special markets in the fast regulation and critical infrastructure services.

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31. Figure: Positioning energy storage technologies to applications [3]

Energy Storage as a Grid Component: Status, Regulatory Issues and Framework

Current situation

There is a low degree of regulatory acknowledgements of storage as a component of the power system, therefore a lack of storage specific rules and insufficient consideration of the impact of regulation on storage exist. In the absence of storage-specific regulation, storage is treated as a combination of power consumption and generation and has to conform to relevant rules for both operating modes. Because of this, energy storage solutions could not be competitive enough in the market today. The following information is collected from the stoRE and FCH JU survey results. [16][17]

	DE	FR	GB	IT	ES	GR ¹
						
	DE	FR	GB	IT	ES	GR ¹
	Can storage participate in the wholesale market?					
Time-shift	✓	✓	✓	✓	✓	✓
	Can storage participate in the frequency reserve market?					
Frequency reserve	✓		✓			
	Can TSO/DSO own and operate storage?					
T&D	✗	✗	✓ ²	✓ ³	✗	✗

32. Figure: Storage accessibility in national markets [16]

Storage can access time-shift market in all countries surveyed, but its ability to provide frequency reserve and T&D deferral is limited to certain countries.

Transmission and distribution grid investment deferrals are only possible in Italy and the UK currently in Europe, generally the system operators are not allowed to have control over an electricity-generating facility due to the unbundling principle. In the UK, storage – and small generating units as well – can obtain exemption from the obligation to hold a generation license on a case-by-case basis. This allows the system operators to deploy small storage systems on investment deferral purpose. In Italy, the system operators are allowed to operate a storage system if it is proven to be the most efficient solution for a problem.

The process of developing a single energy market for Europe is not a new idea. From 1996 to the “EU third energy package” directive in 2009 it is always considered. The most important directives are summarized considering the storage technologies in the reference [17].

Historically, large scale electricity storage plants were developed for storing electricity from base load plants during the night and supplying it during the daytime peak. Most of these plants were developed before the market liberalization, but they have been able to operate profitably in the open market based on the spread between off-peak and on-peak prices. The electricity storage facilities can have additional income streams that vary depending on the EU Member State in which they are operating. For example, electricity storage facilities can participate in reserve markets, ancillary services markets and balancing markets. But the revenues from these additional income streams are not always transparent and it is difficult to foresee how they will develop as they depend on fast evolving regulatory, market and technical variables.

Accessible researches (for example reference [18]) almost fully agree that at the moment it is uneconomic to build new PHS plant, the most developed large-scale electricity storage technology. Within the infrastructure package the possibility of financial support for electricity storage projects is foreseen, which could contribute towards overcoming the feasibility and financing difficulties described in the previous paragraph. However, pumped hydro projects are explicitly exempted from the opportunity to seek this financial support. Some advocate the view that the level-playing field should be achieved by removing the financial support for any type of electricity storage as it distorts competition with other options that can offer flexibility to the system. [17]

Regulatory framework

According to the EU Electricity Directive a Transmission System Operator (TSO) cannot have any type of control over an electricity generation facility. Therefore, to the extent that electricity storage is treated within the regulatory framework as generation, a TSO cannot have any control over an electricity storage facility. The intention is to prevent incentives for abusive behavior in the market. Several stakeholders think that it's a strict implementation of the unbundling principle because they believe that it is in line with the open market approach that delivers the most efficient results on a system level. Also for ancillary services a market based approach is foreseen or should be developed within the emerging regulatory framework. This group believes that control over both transmission and storage should be treated the same way as cross-ownership of transmission and generation. However, there is still legal uncertainty regarding the implementation of the unbundling principle on energy storage but it has to be officially clarified and an explicit amendment would be preferable from a legal certainty viewpoint. As mentioned above, a definition of electricity storage within the Electricity Directive would help to the clarity of the unbundling principle. [17]

Market design

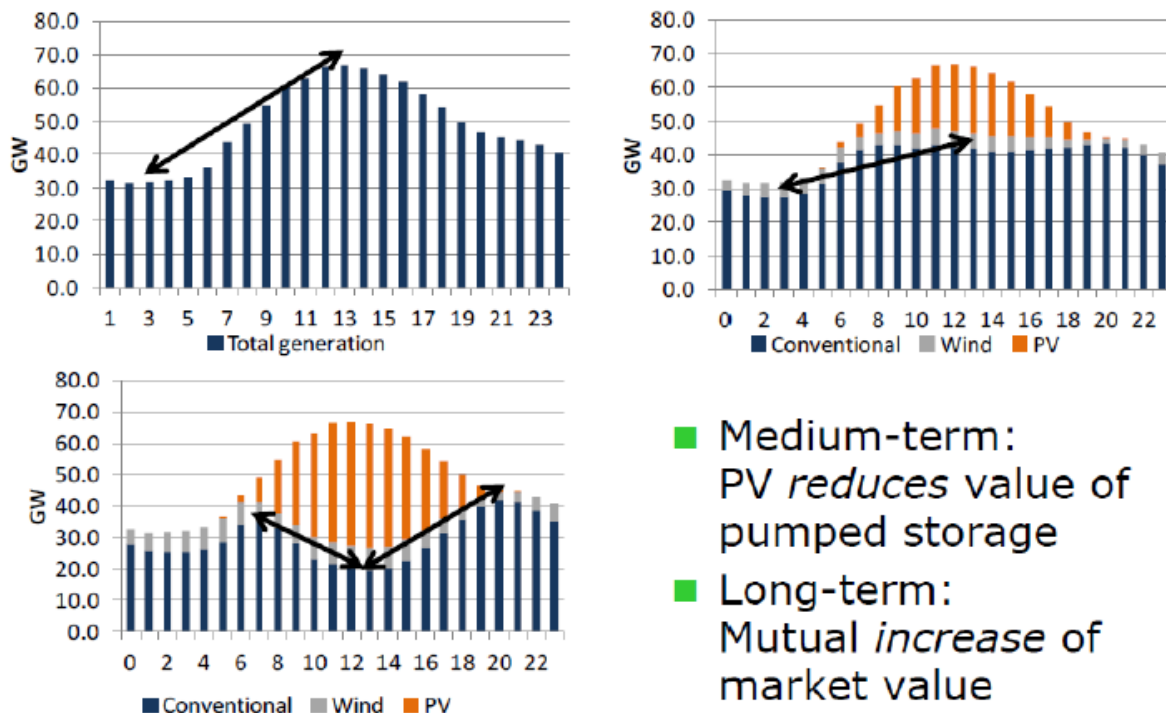
In an ideal electricity market all the required services are well defined and there are transparent, liquid and competitive markets allowing any entities and technologies to compete for the opportunity to provide those services. In such a market there would be clear signals to reflect the increased requirements for flexibility in balancing and ancillary services due to the increased penetration of intermittent renewable energy. These signals would be interpreted by electricity storage developers/operators, among others, to design, build and operate their facilities in order to capitalize on these market opportunities. Constructing an electricity storage facility with faster response times and increased ability to activate upwards and downwards reserves and provide other ancillary services involves increased capital cost.

To indicate a possible market failure, one stakeholder mentioned the example of the effect that the fast growth of PV in some European markets has on the viability of electricity storage. The solar

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Energy Storage as a Grid Component: Status, Regulatory Issues and Framework

energy is covering peak power during the day resulting in a smaller spread between peak and off-peak prices, reducing one of the main electricity storage income streams. (33. Figure) [17]



- Medium-term:
PV *reduces* value of
pumped storage
- Long-term:
Mutual *increase* of
market value

33. Figure: How solar energy might affect storage requirements [17]

Of course there is a risk in any type of investment and this should be borne by the developer, who will also reap the possible benefits. However, if the risk becomes too high to justify investments when the lack of infrastructure translates to a market signal, there will not be enough time for the necessary investments. [17]

Grid fees

One issue that many stakeholders brought to attention was the grid fees that electricity storage operators have to pay, which in several EU Member States are double as operators pay for being both consumers and generators. In addition to grid access fees, the connection fee is another issue where harmonization across Europe and reduction/elimination of the fee would positively affect the electricity storage devices viability.

Common rules should be applied regarding transmission access fees and use of system fees for electricity storage systems in order to avoid deployment of an electricity storage facility in one country with favorable rules in order to provide services in another country with less favorable rules. [17]

Balancing market

Electricity storage facilities participate in balancing mechanisms in a very effective way, as they have the ability both to absorb and inject energy to the system. Close monitoring and participation to the development of the network code on balancing is recommended for all stakeholders that are interested to see full access for electricity storage facilities to cross border markets. [17]

Recommendations for the future

The first step should be to include a clear definition of electricity storage and use this properly.

- Ensure the functioning of an open, fair and transparent market, by introducing clear restrictions to the use of electricity storage facilities by system operators if and when they are allowed some kind of control over them
- Facilitate the market selection of the most efficient solution when a decision has to be taken for transmission vs. storage
- The financial support for transmission infrastructure and for certain storage technologies is also not a market tool and adds distortions to the market based evaluation of storage projects
- The procurements of ancillary services is often based on bilateral contracts, with terms and conditions not publicly available, which does not contribute to the development of an open market
- Large scale storage systems have development times that can be over 10 years long, therefore for storage requirements in period 2020 - 2030, reliable markets signals should be available now

Developing guidelines for Cost Benefit Analysis (CBA) and incentivizing pilot projects is a step to gather more information about commercially working installations. Common rules should be implemented and defined to avoid further problems. The stoRE project's (listed as reference [17]) conclusion was that topics listed above (grid fees, balancing, unbundling, definitions and rules) should be introduced to directives. [17]

Conclusions

The increasing role of variable renewable sources (such as wind and solar) in the electricity system has prompted concerns about grid/system reliability and raised the question of how much these resources can contribute before enabling technologies such as energy storage are needed. Fundamentally, this question is overly simplistic. In reality, the question is an economic issue: It involves the integration costs of variable generation and the amount of various storage or other enabling technologies that are economically viable in a future with high penetrations of renewable energy sources. It is clear that high penetration of variable generation **increases the need for all flexibility options including storage**, and it also creates market opportunities for these technologies. Historically, storage has been difficult to sell into the market, not only due to high costs, but also because of the array of services it provides and the challenges it has in quantifying the value of these services – particularly the operational benefits such as ancillary services. [1]

The provision of the European infrastructure package to provide financial support for electricity storage projects could help in the timely development of storage infrastructure. A **market oriented approach** that would ensure fair remuneration and would give clear prospects of the electricity storage facilities profitability. Government support has been a key driver for **demonstration projects** all over the world, and these have built a productive foundation of operational knowledge, data and industry participation so incentivizing the pilot projects is important. Giving a regulatory status to energy storage that clearly differentiates it from energy generators and energy users is a common issue. Storage applications could serve stakeholders but **market models, roles and responsibilities should be defined clearly**. [10][17][6]

Energy storage system applications should **be seen as part of the development of a smarter electricity system**. The decentralized structure needs a two-way grid for optimum operation. A holistic approach considering all costs and benefits is needed in order to achieve energy targets and smoothly integrate renewable energy sources into a smart electricity system. [7]

Battery storage in the power sector needs to overcome many barriers before it can be integrated as a mainstream option. One barrier is the lack of monetary compensations schemes available for the benefits of battery storage systems. Cost competitiveness, validated performance and in some case safety issues are also have to be solved before battery can be seen as a real solution for wide range of applications mentioned before. Adequately adjusted regulatory environment could assist deployment of storage technologies. Similarly, general lack of industry acceptance is also a barrier. [10]

In order to reduce public opposition to large energy storage projects, especially pumped hydro, campaigns for the **information of the public** about the role of bulk energy storage should be developed, while the local population should be involved at an early stage before the development of new projects. [6]

Energy storage technologies have the potential to support our energy system's evolution, but realizing this potential will require government, regulator, industry, academia and financial stakeholders to work together to help overcome existing barriers. It is not the holy grail of the power grid (as referred in chapter 1), but the variety of solutions must be considered in the future. [4]

Appendix: Reference Installations of NGK

Reference Installations

Peak Reduction and Backup Reserve

1MW/7.2MWh NAS system at Yoho National Park
BC Hydro and Power Authority

British Columbia,
CANADA
(Operation since 2013)



A NAS system supplies clean backup power to a remote area in the Canadian Rockies during outages.



Stabilization of Huge Wind Farm

34MW/244.8MWh NAS system alongside 51MW wind farm
Futamata Wind Development Co., Ltd.

Aomori Prefecture,
Japan
(Operation since 2008)



A NAS system makes wind output dispatchable by charging from excess wind power and discharging so as to meet desired dispatch levels. Immediate smoothing and timeshifting can both be provided.



Maximization Renewable Energy Installations in Oki Islands

4.2MW/25.2MWh
Chugoku Electric Power Co Inc

Shimane Prefecture,
Japan
(Operation since 2015)



A NAS system absorbs large fluctuations of solar and wind power, which helped Chugoku Electric add more renewables to their grid.



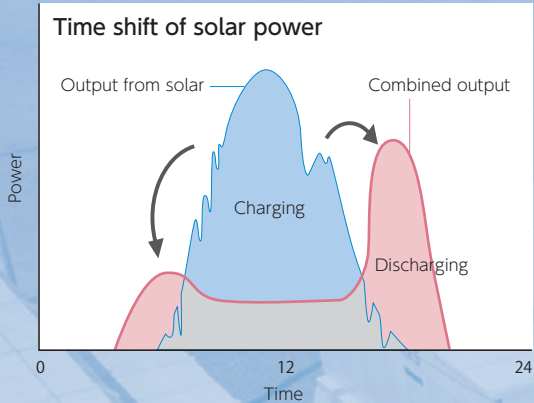
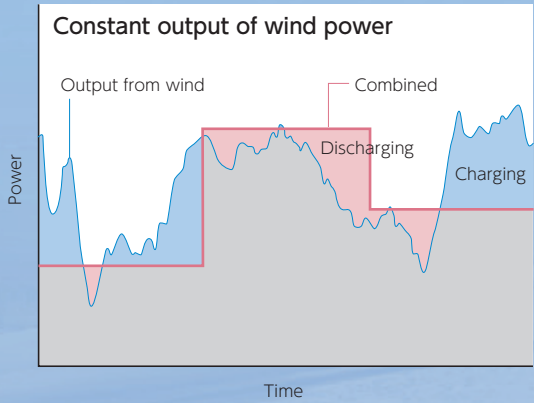
Application



Renewables / Power Plants

Renewable Stabilization

By absorbing fluctuating renewable energy such as wind and solar during off-peak times, a NAS system can provide additional power during periods of peak demand.



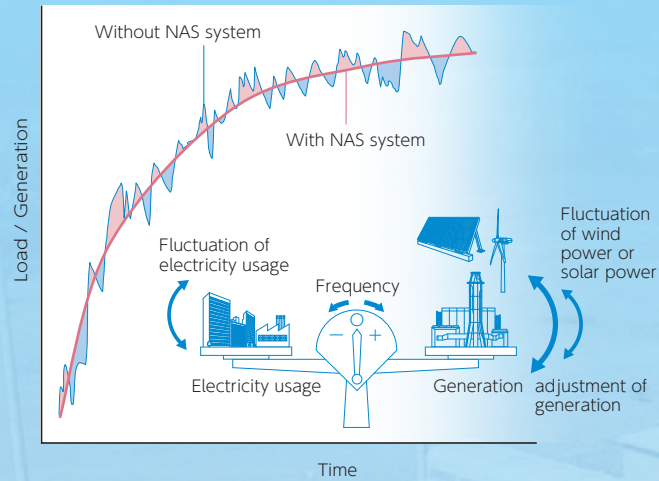
Fossil Peaker Plant Replacement

A NAS system can provide resource adequacy capacity of 6 hours or more per day, providing a green alternative to a fossil peaker plant. The same NAS system can also provide onpeak/offpeak price arbitrage, frequency regulation, ramping services, VAR support and other grid functions.

Transmission, Substation & Distribution

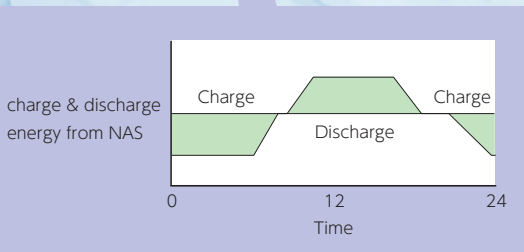
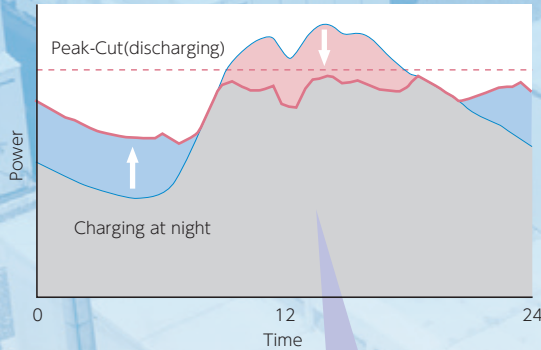
Ancillary Services

Imbalance between demand and supply could cause frequency fluctuation. NAS can achieve minimization of frequency fluctuation by utilizing its high-speed response.



Investment Deferral

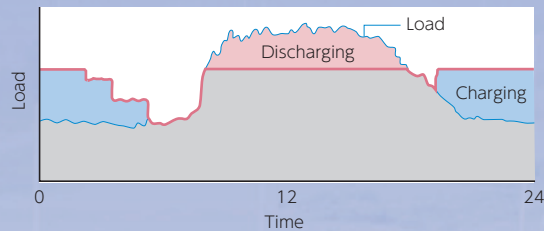
NAS systems can defer or eliminate the need for transmission and distribution upgrades. Power can be imported into a transmission constrained area when loads are light, charging a NAS system that is positioned near the load. During peak load, the NAS system is discharged to supplement the power from the at-capacity transmission lines.



Industrial,Commercial & Residential

Peak Shaving

NAS can reduce peak demand automatically simply by setting the desired peak threshold. This can be used to reduce demand charges for users with fluctuating loads.

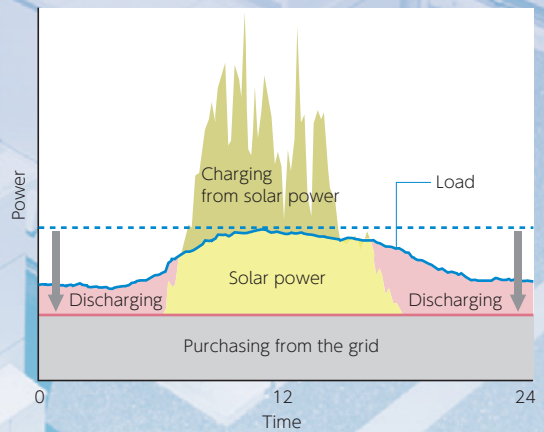


Backup Power and Resiliency

A NAS system can provide continuous power to critical loads for 6 hours or more in the event of grid outages. In addition to providing multi-hour backup, a single NAS system can also provide other functions, including peak shaving, demand charge reduction, solar storage, and management of power quality. With solar or other local generation, additional resiliency can be provided by using the NAS system in a microgrid configuration with islanding capability.

Storage of Local Solar Power

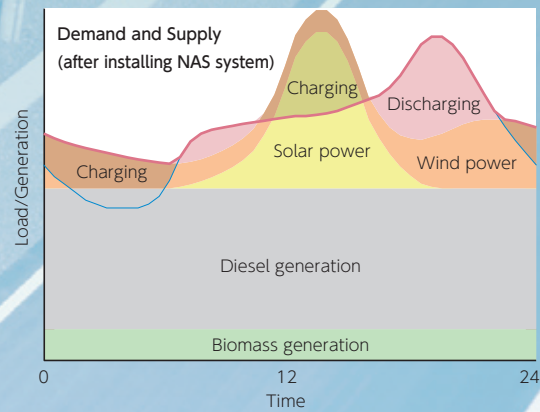
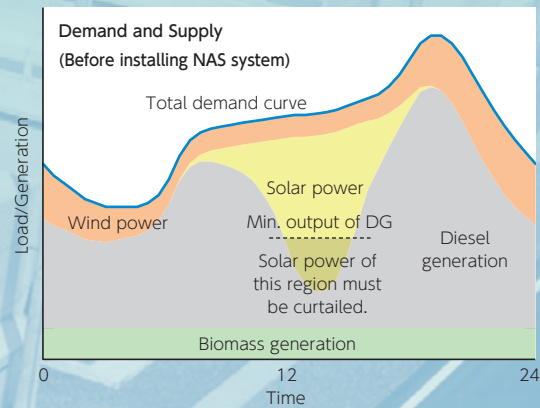
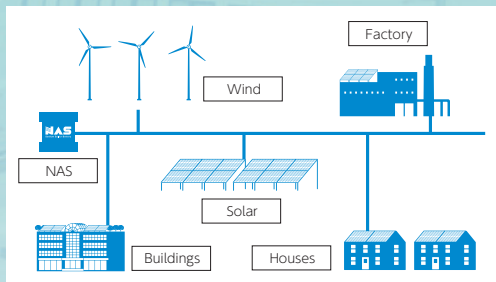
The rapidly declining cost of solar has led to widespread deployment of solar by end users. NAS storage can reduce or eliminate grid power usage by timeshifting excess solar energy from daytime to nighttime. A NAS storage system can cut grid costs for end users by simultaneously providing solar storage, peak shaving and demand charge reduction.



Islands, Remote Grids & Micro grids

Micro Grid

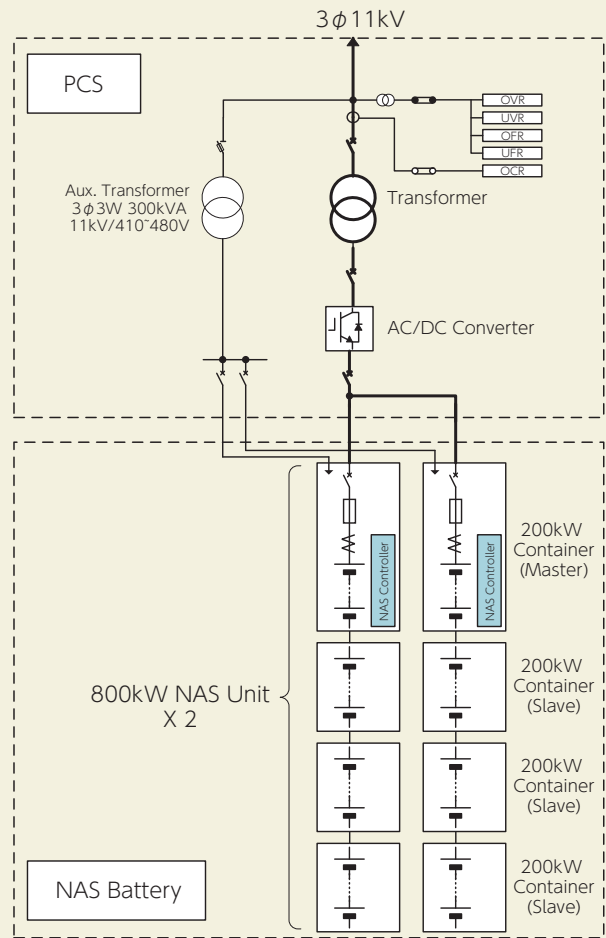
A NAS system can provide essential functions for smaller grids, such as microgrids, island grids, and grids in remote locations. These functions include support for higher levels of renewables, timeshifting and stabilization of wind and solar, voltage (VAR) support, frequency regulation, protection against frequency collapse during contingencies, black start energy and backup power. NAS storage allows fossil and biomass generators to be operated at a fixed output setting that minimizes fuel use and emissions. With NAS storage, the result is a greener grid with lower operating costs and higher reliability.



System Configuration

The NAS system is connected to the grid through a power conversion system (PCS). When the NAS system is charging, the PCS converts grid AC to DC and stores the DC energy in the NAS battery. When the NAS system is discharging, the DC energy from the NAS battery is converted to AC by the PCS and supplied to the grid. Interactions with the grid are through an integrated control system, which manages the NAS battery and the PCS, resulting in safe and efficient operation.

Typical Single Line Diagram for 1.6MW NAS Battery System



Safety

In designing NAS systems, NGK placed safety in paramount importance. The safety of NAS systems has been proven in testing by NGK, in testing by several third party authorities and from decades of field experience. NAS systems also comply with CE marking requirements which are essential for exportation to Europe.

	Test	Test Result
	Fire exposure	<Put module in fire> No leakage. No fire. Safety confirmed.
	Submerge	<Submerge module at operational temp> No leakage. No fire. Safety confirmed.
	Drop	<Drop module at operational temp > Module enclosure was damaged but no damage to cells. No leakage. No fire. Safety confirmed.
	Short circuit	<Short circuit module> Circuit was opened by internal fuses. No leakage. No fire. Safety confirmed.
	Self extinguish	<Ignite one cell inside module> No expansion of fire to adjacent cells. No leakage. No fire. Safety confirmed.

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