Energy Storage for Renewables Integration in the European Union

An IEEE European Public Policy Position Statement

Adopted 3 March 2018

Introduction

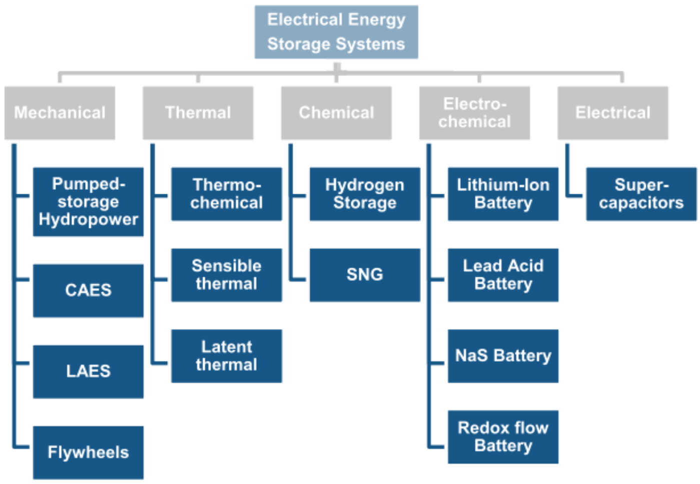
The “Clean Energy for all Europeans” legislative package (also known as the Winter Package), currently under discussion, includes a great number of legislative proposals that intend to drive the European energy system towards a very low carbon and very efficient one. Whereas the focus is in targets rather than specific technologies, it is clear that energy storage (ES) is, as stated in a study recently issued by the European Parliament Research Service[i], one of the top ten technologies that will drastically change our lives. Indeed, in a future decarbonised society, efficiently (i.e., cheaply and compactly) storing the energy delivered by sustainable but variable renewable energy sources (RES), mainly wind and solar, will be of paramount importance if we want to preserve our living standards. This applies particularly to the European Union (EU), where a large proportion of our primary energy needs today are met by imports.

It is important to recognize that ES comprises a great number of very different technologies, able to store very different amounts of energy and working on very different time-scales, from seconds to hours, days, or even seasons. The focus of this paper is not a technical description of these technologies; however, basic knowledge of them is assumed. Box 1 classifies the different ES technologies according to the harnessed physical processes, as well as their technological maturity.

This paper is organized around the different areas where ES can play a significant role. The identified areas are: Grid operation and control, integration of renewable energy sources (RES) in wholesale markets, ES systems installed by active customers, ES role in local communities, electromobility, and finally, R&D issues. The paper ends with a list of issues and recommendations organized around these areas.

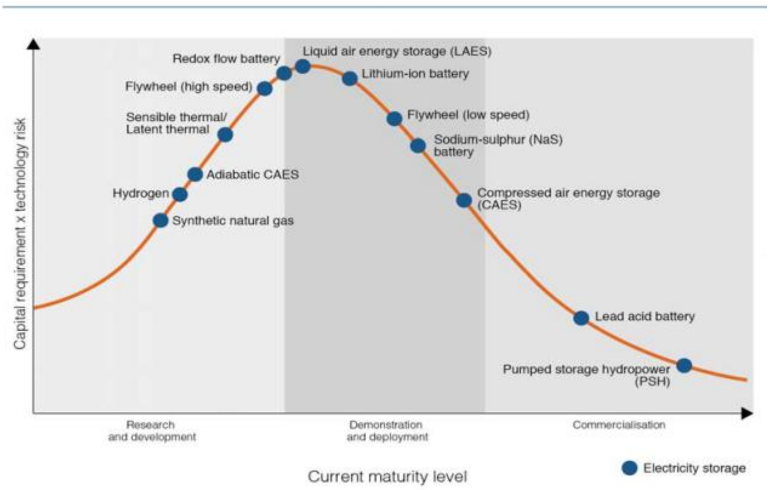
Box 1: Classifying ES technologies

ES technologies can be classified according to the physical process they harness, as shown in the figure below[ii].



Both the amount of energy they can store as the response speed span several orders of magnitude. A correlation between these two attributes does exist. For instance, supercapacitors are able to store up to about 1 kWh to release in about 1 second, whereas pumping stations can store 10 GWh or more on daily or weekly cycles. Some technologies, such as hydrogen electro-synthesis, would be able to store even greater amounts of energy for even longer periods.

Some technologies, such as pumped storage, are quite mature whereas other ones, such as Compressed Air Energy Storage (CAES), are still in its R&D phase. The figure below[iii] shows the technological maturity of the different technologies:



Grid Operation and Control

ES technologies can contribute in both the bulk transmission as well as the distribution levels. It should be noted that grid requirements are dependent on the nature of both generation and consumption. As ES are also to be deployed in these segments, the burden placed on the grid might be less, and the required reliability level cheaper to obtain than otherwise.

Actually, for the expected levels of RES penetration in Europe beyond 2050, the operation of the bulk transmission system will face major challenges. These include keeping the system synchronised in the presence of a generation mix with much lower mechanical inertia, which needs to be able to withstand sudden and steeper up/down ramps, as well as many more start-ups/shut-downs of peak generators. More drastic and frequent changes in power flow patterns, including those of tie lines, will take place, creating unprecedented difficulties for system operators and the need for more versatile ancillary services. In this potential scenario, sufficiently flexible ES systems, particularly those connected through fast-response electronic interfaces, would ideally complement to generation portfolio that will possibly include both low carbon thermal resources (e.g., nuclear and fossil fuel generators equipped with carbon capture and storage technologies) as well as extensive non-controllable and partly unpredictable RES. In particular, various ES technologies are expected to potentially provide a wide range of advanced services (mostly related to system integrity and stability, for instance synthetic/virtual inertia, frequency containment, frequency restoration and restoration reserves, ramping support, and energy balance; but also energy arbitrage over different time scales, from intra-daily to seasonal).

At the power distribution network level, electrical ES can support integration of RES, such as wind and photo voltaic (PV), in conjunction with or replacing other active network management schemes by storing electricity, in constrained networks for later reutilization. This applies particularly at the medium voltage (MV) level, in the case of long rural feeders where a generation from concentrated wind and PV farms can cause voltage rise issues. The same may occur in the case of PV connected to the low voltage (LV) network (for example, in domestic buildings), especially in the presence of high concentration within a feeder and at times of low local demand.

Relevant technologies typically include various types of electrochemical batteries and/or super capacitors, being connected to the network through fast-response AC/DC power converter systems. These systems lend themselves to sophisticated control strategies, e.g. taking into account voltage levels or fluctuations and/or price signals. They can contribute to maintain grid voltage levels within bounds, increase network capacity, and reduce losses. Therefore, their deployment might avoid or defer investments in traditional grid assets, regardless of other regulatory or economic considerations. Utilities are also considering the use of flywheels at primary or secondary substations as a means of improving the quality of service and/or postponing investments in new assets[iv].

Wholesale Integration of Intermittent RES Integration

As intermittent RES generation is deployed, challenges related to mismatch between energy generation and consumption become more and more relevant. Massively deployed ES systems can play a major role in both huge interconnected energy markets, in close cooperation with interconnectors, and small isolated ones. Recent studies[v] have shown that ES facilities, when properly scheduled, are capable of assuring firm power (up to 90% on average of their nameplate capacity) during peak loading conditions. By charging during valleys of "net demand" (i.e., gross demand minus "must-run" RES generation) and discharging during peak hours, ES systems can make a profit from the differences in energy prices while at the same time enhancing the overall load factor, thereby reducing the need for expensive peak generators, and preventing renewable energy from being spilled. This should be supported by enhanced forecasting and control techniques, and be fully coordinated with demand-side flexibility. Additional markets that could enhance the business case for storage might also emerge in the near future; for example providing advanced grid functions like synthetic/virtual inertia/frequency regulation to support system stability. This "bridge" role of ES can be played also by "second life" batteries, especially those ones having performances that are no more adequate to electrical mobility purposes, in collecting energy from RES and releasing it to the grid, or to high power charging stations for electrical vehicles. Some car manufacturers, such as Renault and other producers, already propose examples of this "second life" ES use.

Technologies of interest include pumped hydro, CAES, electrochemical batteries (conventional and flow-based cells) and thermal storage (either standing alone, in combination with concentrated solar power or with other technologies). Pumped hydro is well established, efficient as well as versatile, and has been around for nearly hundred years; however, its expansion is limited by geographical, as well as environmental, constraints. Many of the suitable locations for hydro dams are within protected areas, where constructing a dam wall will have an important impact on the eco-system. Underground pumped hydro seems to be a promising alternative in flat regions, but it is still at the design or prototype stage. Compressed air (combined with natural gas for incineration in gas turbines) appears on all candidate lists, yet only a handful of industrial facilities exist worldwide. Research efforts currently underway on the much more efficient adiabatic CAES systems that store the heat generated during compression, to re-inject it during expansion still raise concerns about the technical and economic feasibility of such facilities. Electrochemical batteries are perhaps the most versatile technology (given their outstanding ramping and start-up/shut-down capabilities), but their costs need to be significantly reduced and their life cycle extended.

Conversion to other energy carriers, such as hydrogen or even synthetic methane, opens the possibility not only to store RES electricity but interestingly to allow greater penetration of low carbon energy to be used by more traditional devices, such as those in heating (e.g. boilers) or transportation (e.g. gas internal combustion engines), or even in less traditional ones (e.g. hydrogen fuel cells). If used as a pure storage technology to convert back the energy content in electricity it might suffer from relatively low efficiencies, although it might also benefit from advanced conversion devices if centralized facilities are built. The possibility of using the synthetic fuel as a second energy vector falls outside the storage concept proper and will not be further pursued here.

Some generation technologies, such as thermal solar, already benefit from in-situ thermal storage, sometimes (e.g. large thermos-solar plants) based on phase change materials. Integrated storage systems might be also of interest for other intermittent generators easing power system concerns. In-situ integration of batteries with thermal generators might likewise improve their flexibility. From the system viewpoint, they would appear as traditional thermal plants able of steeper ramps and faster dynamic responses.

Storage by Active Consumers

Small-scale ES technologies are finding their place in households or small business. There might be two main reasons. On the one hand, they can store self-generated energy, typically from PV systems, for later consumption. On the other hand, if connection (€/kW) tariffs are in place, they might be used in order to decrease the network connection sizing, to support consumption at peak times by storing network energy at valley times, regardless of a self-generation system being installed or not. Economics of both applications are dependent of the tariff structure (e.g. energy €/kWh and power €/kW prices). Technologies prominently include various types of electrochemical batteries. Moreover, given the increasing interaction of electricity with other energy sectors, for instance due to electrification of heating, thermal storage could also represent an important form of energy storage in the so-called electro-thermal applications. Included among these technologies are resistive water heaters, hot water tanks coupled to electric heat pumps, and ice-based cooling storage coupled to air conditioning devices.

Up to now, most of the penetration has taken place in single-family households and single-building business. However, many of these technologies may find a place in multiple family dwellings or multiple business buildings. That would require, for example, PV panels installed on common roofs or electric vehicle (EV) chargers in common parking lots. Although the technologies are essentially the same ones as in the single family or single business cases, there is often lack of regulation addressing permits and payments. Current legislative proposals on local communities (see below) might address this one as other regulatory problems relative to this kind of buildings. More generally, efficient ES deployment for small and medium consumers (as well as that of other new technologies) can be benefited from efficient tariff and pricing schemes made possible by new metering and control devices (e.g. dynamic access tariffs or possibly blockchain based peer to peer trading).

Even if most discussions tend to focus on small and medium consumers, huge consumers that often have direct access to wholesale markets can play a significant role. For instance, district heating and other combined heat and power (CHP) facilities offer significant opportunities to thermal storage. Another set of technologies of great interest are power to gas conversion (e.g. synthesis of hydrogen or methane from electricity), though currently it suffers from reduced round-trip efficiencies.

Local Communities

Local communities and local renewable communities are two new regulatory concepts advanced in the current drafts of the Electricity and Renewable Directives. Regardless of the precise final regulatory shape, the possibility of closely integrating operations of small networks, on the scale of a building to a village or even a town, raises interesting technical questions. These communities would likely require advanced metering and settling tools (e.g. smart meters and blockchain technologies) that might integrate operations through local markets.

ES can facilitate system operations. While there are generally no markets that are systematically set up below the bulk power level, it is envisioned that local markets will indeed appear in the transition towards a fully sustainable energy system with large-scale penetration of distributed RES and demand-side resources. Microgrids and local community energy systems might be operated as local markets, while a distribution system operator could play a role similar to that currently performed by the transmission system operator, guaranteeing security at the local level. In this context, in addition to participating in potentially new markets such as for power quality services, ES could be effectively used as a market entity for energy arbitrage, network capacity support, and reliability services.

Electromobility

EVs, including transitional technologies such as plug-in hybrids, are expected to play a relevant role. EVs, as their fossil fuel counterparts, are expected to be parked most of the time. As a consequence, there is considerable leeway to decide on the charging periods that should be chosen in order to profit from low price energy (e.g. during hours on high intermittent RES generation) and/or low network use (e.g. during the small hours). In that way, RES penetration can be eased and expensive network reinforcements needed to supply the new loads deferred or avoided. It might even be possible to harness EV batteries in order to provide reserves and balancing services to the power system, although advanced control and metering technologies[vi], as well as new regulations enabling EV aggregation and responsibility allocation, among other matters, will be needed. In any case, the economic case must be made, as there are other technical possibilities.

R&D

Except for a few notable exceptions, such as pumped hydro, energy storage technologies are still in their infancy, and significant improvements and cost reductions are expected within a decade as they follow their anticipated learning curve. Currently, significant R&D efforts, both privately and publicly funded, are underway in the USA and Asia. EU countries risks to lag behind in the ES technology race, at least in some segments[1]. It should be stressed that not all the relevant R&D is carried out in the power sector. Importantly, most battery research

[1] As a symptom, there is no significant manufacturing of electric car batteries in Europe, being acquired by European car manufacturers to Asian companies such as Samsung, LG or Panasonic.

has been focused on personal electronics applications and, lately, EVs[2]. Whereas the energy sector benefits from these efforts, there are also specific needs. For instance, R&D is needed in order to co-opt devices originally developed for other uses (e.g. “second life” EVs batteries, as power system applications require the use of batteries of different qualities and degradation levels), to develop new management systems that optimize ES performance so as avoid degradation and allow smart grid and microgrid coordination, to develop batteries with unusual specifications (e.g. batteries for use in power systems typically would have higher kWh/kW ratios that those for EV), or even in order to develop altogether different technologies.

Commercial and Regulatory Issues and Recommendations

Use of ES offers great promise. However, its fulfilment is contingent on the future evolution of cost and performance. As a consequence, uncertainties on the extent, type and timing of ES deployment often prevents detailed recommendations. However, we are confident that ES will significantly grow, and that a number of non-regret polices can be started now.

Integrating huge amounts of ES into future power systems will require current regulation of energy markets and network operation procedures be fully reconsidered. More specifically, the following issues will have to be addressed.

- A preliminary relevant issue has to do with the regulatory character of the ES assets. European legislation establishes a clear difference between regulated and market activities. Companies must keep these activities clearly separated and are subject to very different regulatory regimes. On the other hand, the same ES system can be of use for both regulated and market agents. For instance, the same battery can provide “regulated” services (e.g. voltage control analogously to transformers) as well as “market” ones (energy arbitrage between periods of high and low prices). These delicate issues of use and ownership must be properly addressed.
- Use of ES as a tool for grid operation and control might lead to significant savings in traditional network assets, typically regulated. On the other hand, and as opposed to more traditional devices, costs and sensible reliability expectations are only approximately known. From the regulatory point of view, these facts might require to reform the economic regime of regulated assets, in order to properly incentivize grid companies to invest in these assets avoiding excessive profits. From a more technical point of view, some aspects of existing grid codes, both at the transmission and distribution levels, will have to be developed so that the technical constraints they will have to fulfil at the point of connection (e.g., how inertia is emulated under contingencies) are clear for emerging and heterogeneous ES systems. The System Operation Guideline[vii], which has entered into force on 14 September 2017, sets a good basis for handling the topic of inertia at the transmission level: at a first level Transmission System Operators s in each European synchronous area will have to

[2] For an historical note, see “The Development and Future of Lithium Ion Batteries”, George E. Blomgren, J. Electrochem. Soc. 2017 volume 164, issue 1.

perform a study together to detect the real needs on inertia/dynamic stability and, based on that, introduce new processes/methodologies in order to integrate its increasing influence in the grid.

- ES systems can play a number of roles in wholesale markets. They can provide both firm power and operational flexibility, with capabilities that gas turbines or other traditional equipment cannot. That might require reforms in several directions. On the one hand, short-term and ancillary markets should possibly be redesigned (e.g. reserves and frequency regulation) or even created (e.g. ramping or fast start-stop services) to be able to trade these services. In this way, the true value of ES systems might be better recognized and new business models, possibly involving different parties, created (although proper recognition for regulated services is also required).
- Penetration of ES systems in active customers facilities also requires new regulations. Efficient deployment of ES, as well as other new technologies, requires that the grid tariffs and energy price signals that the customers are exposed to reflect costs. These costs are time varying, which suggests possible use of dynamic pricing. Smart meters and other modern technologies make these new pricing schemes feasible.
- Development of local communities requires careful new regulation related both to the (distribution) system operator as well as to local markets, especially if based upon new distributed information technologies. A non-distorting price signal is necessary for ES systems deployment.
- Electromobility is to be mainly built around batteries. Possible benefits are manifold, but current regulations have generally been laid on the assumption of in-mobile loads. That should change, both regarding the possibility of trading energy and other system services in several locations as the EV moves around, as well as offering access tariffs that take mobility into account. Proper regulation for parties offering charging and intermediation services (e.g. aggregating all EVs in a parking lot in order to sell reserves to the system) must be developed.
- In order to boost the development and maturity of different ES technologies, suitable incentives might have to be considered for ES as a sustainable energy system enabler, in line with what is done with several RES. Further, in consideration of the strategic importance of developing, implementing and integrating ES technologies both to maintain the competitive advantage of our economy and to preserve the welfare of European citizens, the EU should develop a long-standing and ambitious framework specifically aimed at promoting and stimulating the joint cooperation of European partners on energy storage systems, much in the same way as in CERN or ITER strategic projects.
- Appropriate standardization along with best practice and guides relating to the implementation of ESS is needed. The series of IEEE 1547 and IEEE 2030 along with the IEEE 1679 series of standards are a solid beginning in this area. However, development of additional standards along with an understanding and development of appropriate safety standards is warranted. Intra EU and international interoperability, manufacturing economies, and distributed sourcing of key components and systems would be among the main benefits. Related to the above, future power systems will

include a substantially higher number of digital components. In order to reliably function in orchestrated systems, IT interoperability between the components must be established on a sufficient level of quality, in synchrony with other efforts in research and implementation, as the ones taking place for the Digital Single Market, supported e.g. by the Connecting Europe Facility (CEF) programme.

This statement was developed by the IEEE European Public Policy Committee (EPPC) Working Group on Energy and represents the considered judgment of a broad group of European IEEE members with expertise in the subject field. IEEE has nearly 60,000 members in Europe. The positions taken in this statement do not necessarily reflect the views of IEEE or its other organizational units.

Contact Information:

Should you want to get in touch with IEEE European Public Policy Committee or find out more about its activities, please go to: http://www.ieee.org/about/ieee_europe/index.html

About IEEE:

IEEE, with more than 423,000 members in 160 countries, is the world's largest technical professional organization dedicated to advancing technology for the benefit of humanity. It publishes 150 prestigious journals, organizes more than 1,800 conferences in 95 countries annually, has led the development of over 1,200 consensus-based global standards, and supports science and engineering education at all levels. IEEE has members in every European country, and over 200 European organizational units. The IEEE European Public Policy Committee provides opportunities for engineers and scientists from across the continent to share their expertise in the development of sound technology policies.

---

[i] "Ten technologies that could change our lives. Potential impacts and policy implications," European Parliamentary Research Service, January 2015

[ii] "E-storage: Shifting from cost to value. Wind and solar applications," World Energy Council, 2016, p. 10

[iii] "E-storage: Shifting from cost to value. Wind and solar applications," World Energy Council, 2016, p. 13

[iv] E.g. the hybrid battery-flywheel ES system to be tried at Offaly (Ireland) and operated by EirGrid; or the flywheel to be tested by Hawaiian Electric.

[v] "The Value of Energy Storage for Grid applications," P. Denholm at al, NREL Technical ReportNREL/TP-6A20-58465, May 2013

[vi] Electric vehicle fleet management in smart grids: A review of services, optimization and control aspects
J Hu, H Morais, T Sousa, M Lind - Renewable and Sustainable Energy Reviews, pp. 1207-1226.

[vii] https://www.entsoe.eu/major-projects/network-code-development/system-operation/Pages/default.aspx