IEA Experts' Group on R&D Priority Setting and Evaluation (EGRD)

The Role of Storage in Energy System Flexibility

Berlin, Germany, 22-23 October 2014

Hosted by the German Ministry of Economic Affairs and Energy

Workshop Summary

Research, development, and deployment of innovative technologies are crucial to meeting future energy challenges. The capacity of countries to apply sound tools in developing effective national research and development (R&D) strategies and programs is becoming increasingly important. The Experts' Group on R&D Priority Setting and Evaluation (EGRD) was established by the IEA Committee on Energy Research and Technology (CERT) to promote development and refinement of analytical approaches to energy technology analysis, R&D priority setting, and assessment of benefits from R&D activities.

Senior experts engaged in national and international R&D efforts collaborate on topical issues through international workshops, information exchange, networking, and outreach. Nineteen countries and the European Commission participate in the current program of work. Results provide a global perspective on national R&D efforts that aim to support the CERT and feed into the IEA Secretariat's analysis.

For further information, see: http://www.iea.org/aboutus/standinggroupsandcommittees/cert/egrd/.

For information specific to this workshop, including agenda, scope, and presentations, see: http://www.iea.org/workshop/egrd-role-of-storage-in-energy-system-flexibility.html.

This document reflects key points that emerged from the discussions held at this workshop. The views expressed in this report do not represent those of the IEA or IEA policy nor do they represent consensus among the discussants. This report has been prepared by the U.S. Department of Energy's Office of International Science & Technology Collaboration, in the DOE's Office of International Affairs.

The IEA Experts' Group on R&D Priority-Setting and Evaluation (EGRD) convened a workshop on 22–23 October, 2014, in Berlin, Germany, hosted by the German Ministry of Economic Affairs and Energy, to illuminate the status and emerging trends of grid-scale energy storage and to advance solutions. A focus of the workshop was to identify research, development and demonstration (RD&D) needs related to energy storage, especially considering the increased integration of renewables into the grid. In addition, barriers to greater technology deployment and potential remedies were explored.

About 50 participants representing various EGRD national experts, government representatives, RD&D decision makers, strategic planners, and program managers from industry met to discuss the current challenges facing the industry and the research and development (R&D) strategies required for energy storage and electricity grids to make storage a commercial reality. Workshop participants discussed the current status of energy storage technologies; highlighted the technical, market and regulatory challenges faced by storage, including those presented by alternatives to storage and the lack of a viable business model for storage; identified current efforts to develop the more promising technologies in various countries; and importantly, discussed R&D and commercialization and deployment needs for storage technologies.

Overview

Governments around the world are increasingly using renewable energy sources for the generation of electric power. This creates both opportunities and challenges for energy systems, especially in terms of ensuring that the future power energy system is a reliable and affordable one. Increased use of renewable energy helps countries achieve their energy security and emissions reduction goals. However, integrating renewables into current grid systems creates many challenges. As opposed to traditional sources of energy, such as coal-fired or nuclear power plants, renewable energy's intermittent nature does not follow any social patterns of demand for electricity. This can lead to issues related to grid quality and reliability. Geothermal energy and bioenergy can be used to compensate for these fluctuations, but since they are available only in certain regions, these energy sources do not offer a general solution to fluctuations. Grid interconnection on a continental level could also make it easier to cope with diurnal load shifts, as different time zones have different peaks, but realization of such a grid also faces substantial technical and business-related challenges in some instances. As such, additional solutions should be examined for addressing quality and reliability issues associated with integrating large amounts of renewables into the grid.

Energy storage technologies offer promising solutions that can manage variability and potentially decouple short-term variations of supply from demand. Benefits of storage technologies include improving resource use efficiency in energy systems; integrating higher levels of variable renewable resources and end-use sector electrification; supporting greater production of energy where it is consumed; increasing energy access; and improving electricity grid stability, flexibility, reliability, and resilience.

Current and Future Landscape of Storage Technologies

The U.S. Department of Energy's (DOE's) publicly available database on global energy storage technologies (www.sandia.gov/ess/database) provides an overview of the storage technologies in use. The database identifies over 50 energy storage technologies currently in use around the world, representing 145 GW. Pumped hydro dominates, with 142 GW. The remaining 3 GW is distributed among thermal (1.6 GW), flywheel (0.9 GW), batteries (0.5 GW), and compressed air (0.4 GW). Leading regions in terms of capacity and projects are China, the European Union, Japan, and the United States.

Pumped hydro storage—a well-established technology—is widely used in mountainous regions or regions with significant elevation change (e.g., European Alps, Pyrenees, and Scottish Highlands). Limiting its broader applicability is the fact that the technology is dependent on a region's geography, although newer designs have reduced the site specificity. Various battery technologies are also used, including lead-acid, lithium-ion, NaS/NaNiCl, and vanadium redox flow batteries (VRFBs). Several recent projects are, collectively, implementing a wide range of innovative battery technologies that show promise, such as projects investigating Fe-Cr flow batteries and their possible uses in combination with photovoltaics (PV); research collaborations investigating novel materials and mixed acid electrolyte; and efforts to develop solid polymer electrolyte, metal-air, lithium-sulfur, anodes with silicon, sodium-ion, and liquid air. Apart from batteries, other storage technologies that could address grid-scale storage needs, directly or indirectly, include compressed air energy storage (CAES, of which the adiabatic variety is currently under development) and a range of "smart" heat storage options, including phase-change materials.

Research is currently being conducted in different parts of the world to test the domain of applicability of these technologies. In the United States, the U.S. Department of Energy supports several large-scale demonstration and pilot projects testing different technologies in various locations across power networks. Megawatt-scale batteries and flywheel storage facilities are used to test frequency regulation in the distribution grid, and it has been found these can be commercially operated in U.S. Federal Energy Regulatory Commission (FERC)-compliant regions. Flow batteries are in operation or being tested in the states of California, Vermont, and Washington. Other advanced battery systems are installed and being tested in Australia and the United States (California, New Mexico, and Pennsylvania).

In Germany, several pilot projects are underway to examine which technology best meets the needs of the distribution grid and which battery systems can be operated economically. One of these publicly funded projects, the Modular Multi-Megawatt Multi-Technology Medium Voltage Battery (M5BAT) Project, is constructing and operating a pilot hybrid battery storage system with realistic operation and market participation in multiple applications. The M5BAT hybridizes lithium-ion, lead-acid, and sodium-nickel chloride batteries. The project includes evaluation of technical and economical results and development of recommendations for design and operation of hybrid battery systems.

Recent studies have estimated that energy storage commercial markets may reach or exceed $15 billion/year by 2024.[1] For the right product, with the right pricing regimes, the market potential for these technologies is high.

Barriers Inhibiting the Growth of Storage Technologies

In spite of the potential exhibited by storage technologies, challenges remain. While some storage technologies, such as pumped hydro are mature, most others command limited deployment or are still in the nascent stages of development.

Many energy storage technologies are costly and not well-adapted to local circumstances. Energy storage faces stiff competition from alternatives. Furthermore, a viable business model for storage technologies that can provide multiple grid services has yet to be determined. Complicating matters is the lack of a supportive regulatory and standards environment to reduce complexity and help monetize grid services provided by the use of these technologies.

Denmark provides an illuminating example of the competitive challenges faced by utility-scale storage as the country's grid transitions from a centralized to a decentralized energy supply system. In 2012, about 25% of Danish gross energy consumption (nearly 40% of electricity consumption) was from renewable energy, with wind comprising the majority share. Denmark has set for itself aggressive renewable energy goals, striving for 100% renewables by 2050. The rapid decentralization of its energy system calls for increased flexibility, especially needed to balance the intermittency of wind and solar power. However, rather than investing in energy storage options, Denmark has found that it is more economic to utilize its robust network of grid interconnections with Norway, Sweden, Germany, and beyond to balance supply with demand.[2] Much of the externally supplied power is derived from hydropower and other low-carbon sources, and Norwegian hydro is relied upon as a source of flexibility.

Alternative Competing Technologies

Storage technologies also face competition from other well-established alternatives. Among these, flexible conventional generation is most commonly used today to provide the services with which energy storage competes. Demand response, a system used to manage variability by adjusting the load on the demand side, is a less widespread but emerging alternative. Various technologies can be used for demand response in the power grid, such as thermal storage devices, electric vehicles, or load shifting. Worldwide, a number of pilots and field tests are presently studying the practical implementation of different demand response technologies. Japan established an initiative in which large-scale energy management systems are tested in four demonstration regions. In the United States, a number of smart grid demonstration projects have been conducted under DOE funding as part of an economic stimulus program initiated in 2009.

---

[1] Source: Navigant Research, "Energy Storage for the Grid is Expected to Reach $15.6 Billion in Annual Revenue by 2024," September 2014.

[2] Denmark is also considering an interconnection with the U.K., which has implications for economic viability of energy storage in both countries. The U.K. is already interconnected with France (2 GW), Netherlands (1 GW), and Ireland (<1 GW), and there are plans to expand the capacity of these interconnections and add a 1.4 GW link with Norway.

Power-to-gas (with gas storage) technology is an alternative to electric energy storage on the grid as well, providing a means of balancing inter-seasonal fluctuations and enabling storage over longer timeframes. Adopting flexible methods for operation, especially combined heat and power and biomass plant, is a strategy that serves a purpose similar to storage. Renewable energy curtailments, grid expansion, smart grid technology solutions, and coupling electricity and district heating grids are all options being explored by the industry as alternatives to storage.

Another avenue relates to fuels for the transport sector that seeks to be fully, or near fully, renewable in the long term. If present limitations of batteries preclude full electrification, then relevance increases for conversion of electricity to fuels, e.g., hydrogen, methane, and dimethyl ether. Conversion could become a significant aspect of the storage sphere, especially when the high financial value of transport fuels is considered. In some instances, electricity is so abundant that it has a negative cost. Inexpensive electricity can sometimes be exported, but at times, it may make more sense to use electricity to create combustible fuels that can then later be consumed.

Competitive Markets and Pricing Models

Against this backdrop, the future for energy storage is unclear. Whether a strong business model for commercial storage will fully develop is debatable. In general, current electric service revenue structures do not provide a sufficiently diverse suite of revenue streams to support economic viability of storage, even though its societal value might be high. Rather, there is a need for a rational pricing model that accounts for a variety of services provided by storage, perhaps, in the form of “bundled values.” Values need to be assigned for various contributions in real time and for long-term system efficiency, cost avoidances, and a host of other services, such as reactive power, voltage control and frequency regulation. If the many and often unique contributions are given market values, storage may become a cost-effective solution at many sites.

California is an interesting case study. The increased use of renewables there, motivated by mandates and subsidies, has created challenges for balancing of supply and demand. Battery energy storage is seen as offering several advantages, such as quick response and flexible range per megawatt, but is also costly. In a move to address the issue and spur innovation, California regulators required its three primary investor-owned utilities, in total, to acquire 1,328 MW of energy storage by 2020. Initial results from the competitive solicitations suggest that, if rationally evaluated, battery energy storage can be purchased and operated economically in this specific market situation.

In contrast, electricity market models developed through European Union collaborative projects suggest that in the mid-term, grid extension and stronger market integration are more economically attractive solutions than electricity storage.

While modelling exercises may indicate that achieving a viable, economical business model for storage technologies is challenging today, there are emerging developments that suggest the success of these technologies may be improving in the coming years. For example, the need for security of supply may generate markets that may lead to an uptake of the technology. New technologies are arising, others are improving, and costs are falling with increased deployment and competition. It is expected that grid storage can increase its economic value considerably by bundling value streams, e.g., a combination of arbitrage, balancing and ancillary services, electric grid investment deferral, capacity, and outage mitigation. By offering these services to utilities, market projections for battery energy storage increase substantially and encourage the realization of storage systems. Whereas in the short to mid-term, grid integration may offer the most economical solution, the demand for battery energy storage is expected to increase in the longer term, especially for decentralized storage (for more discussion of the California experience, see Discussion and Conclusion section of the full report).

Standards and Regulations

The lack of a supportive, enabling regulatory environment has been an impediment to the growth of energy storage technologies. Disincentives to storage implementation exist, e.g., regulatory curtailment of renewables can obviate the need for storage as a balancing service. Policies remain in a nascent phase. Development of standards and regulations has been uncoordinated and sometimes conflicting. International standards for grid-connected storage systems are essentially non-existent. The very definition of "storage" remains in question (although efforts to define have been initiated, and the IEC now has draft standards for performance testing of grid energy storage).

A joint industry project, Gridstor, has recently been initiated to facilitate international guidelines for the optimal and safe implementation of energy storage. This initiative should lead to a standardization process that ultimately will enable producers of grid storage devices to develop products for standardized international markets. Additionally, there is a need to develop a guidebook that eases new entrants into the sector and establishes a framework standard for grid-connected energy storage.

RD&D Needs

Many promising advances in energy storage technologies are in early stages of discovery and development. RD&D needs are large in this space. These range from purely technical R&D needs, such as understanding the performance of battery stack design, to evaluating market drivers and commercial viability and reliability, especially under different regulatory regimes. Developing acceptance of these technologies within the industry is also critical to instill confidence from the private sector and for wider market adoption.

RD&D needs for storage technologies identified at the workshop are summarized below.

Technical Needs

- Achieve fundamental understanding of electrochemical phenomena, which is critical for the development of new efficient grid-scale batteries
- Actively pursue research in the development and optimization of new and alternative battery chemistries; the optimization of electrodes, electrolytes, membranes and critical components; and the development of novel cell/stack designs with engineered materials
- Conduct demonstration and pilot projects for the development and fabrication of new battery systems concerned with bench-top component and systems development testing, prototype development and test-bed evaluation or the refinement of manufacturing processes
- Develop technology cost models to guide R&D and assist innovators
- Refine manufacturing processes

Validated Reliability and Safety

- Conduct R&D on degradation, failure mechanisms, mitigation, and accelerated life testing
- Develop standard testing protocols and independent testing of prototypic storage devices
- Track, document, and make available performance data of installed storage systems
- Optimize power electronics and controls and battery management

Equitable Regulatory Environment

- Resolve grid benefits to guide technology development and facilitate market penetration
- Explore technology-neutral mechanisms for monetizing grid services provided by storage
- Develop industry and regulatory agency-accepted standards for siting, grid integration, procurement, and performance evaluation
- Encourage data cooperation
- Encourage supportive policy, e.g., purchase contracts, storage mandates, and competitive solicitations

Industry Acceptance

- Co-funded field trials enabling experience and evaluation of performance, especially for facilitating renewable integration and enhanced grid resilience
- Industry-accepted planning and operational tools to accommodate energy storage
- Storage system design tools for multiple grid services and energy management

Path Forward

Energy storage is today, and will continue to be, an increasingly important part of future energy systems. Grid-scale storage systems are being recognized, not just for their value as a storage option, but also for roles in improving system-wide efficiency, avoiding costly system expansion, and in ensuring that energy systems are reliable and stable. However, the path to full market potential is fraught with challenges.

Key actions needed to spur continued innovation and accelerate market adoption of energy storage over next decade include the following:

- Improve understanding of economics of storage technologies and facilities
- Establish a rational model for valuing storage across a full range of provided services
- Develop supportive markets, standards and regulatory environments
- Support targeted and strategic research, development and demonstration projects
- Establish a comprehensive set of international standards
- Develop tools to quantify the value of storage in specific regions and energy markets

A more comprehensive workshop report, including detailed information on individual sessions and presentations, has been prepared by the U.S. Department of Energy's Office of Climate Change Policy and Technology, in the Office of International Affairs, and may be consulted at:
http://www.ieadsm.org/egrd/