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Harnessing electricity storage for systems with intermittent sources of power: Policy and R&D needs

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HIGHLIGHTS

- Electricity storage can help integrate intermittent energy resources.
- R&D is needed to characterize and reduce electricity storage costs.
- Markets should more appropriately and fully value the services storage provides.

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ABSTRACT

A central challenge for grid operators is matching electricity supply to demand, especially when the electricity supply is composed in part of intermittent resources. Several system options could help balance electricity supply and demand given different mixes of intermittent, baseload and load-following generation capacity; of these, electricity storage is especially interesting. If electricity storage could be deployed widely, grids of any size could sustain a wide range of profiles of intermittent and baseload power. Currently, most installed electricity storage worldwide is pumped hydro. Flywheels, compressed air and batteries represent interesting technologies that could provide grid-scale storage, especially if technology costs come down. A significant amount of storage R&D worldwide is appropriately focused on lowering these costs, but more is needed. Ultimately, storage will only achieve high levels of penetration if it can compete for service provision in electricity markets, and policy adjustments are needed in many countries to ensure this is the case.

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1. Introduction

A central challenge for grid operators is matching electricity supply to demand. The challenge increases when more of the electricity supply is composed of intermittent renewable resources, and the trend is up for renewables on many nations' electricity grids. Besides this operational challenge, intermittent renewables pose market challenges for baseload resources. For example, at night when the wind blows strongly and electricity demand is low, prices are suppressed, but nuclear units generally cannot power down. If more renewables lead to more sustained price suppression, baseload units have trouble recovering their costs (Renewable Analytics, 2013).

Several system options could help balance electricity supply and demand given different mixes of intermittent, baseload and load-following generation capacity. One alternative is to match each renewable installation with full backup capacity (typically natural gas) such that all the combination of renewables and backup is reliable and dispatchable. This, however, would increase the cost of renewable generation and reduce the environmental benefits of renewables. A second option is to build substantial transmission capacity, so a drop in renewable electricity generation in one area (e.g. due to clouds over solar panels) could be compensated for by electricity production in another region. In the U. S., studies have shown that 45% penetration of renewables is achievable with the current transmission system (IEA, 2011), and as much as 80% renewable penetration can be achieved by expanding transmission capacity, including increasing the number of ties between the Eastern and Western grids and building transmission backbone lines to bring Midwest wind to the coasts (Mai et al., 2012). Smaller grids, however, may not have sufficient capacity or geographic diversity to accommodate sudden, large shifts in supply. Furthermore, in the U. S., cost and permit issues are major barriers to achieving significant transmission capacity expansion. A third option for managing intermittency is to increase cycling of baseload plants, but this can be challenging and costly, especially for nuclear power. Demand response (DR), or

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contracting with consumers to reduce demand when the grid is short on supply, is yet another option to ensure a supply and demand match; large DR potential remains in many countries and has relatively few drawbacks, other than challenges with consumer acceptance and eventual limitations for how much DR the system can sustain.

An important additional option to integrate varied generation sources, match electricity supply and demand, and allow generation sources to dispatch power at a profit is electricity storage.[1] In theory, if electricity storage could be deployed widely, grids of any size could sustain a wide range of profiles of intermittent and baseload power. Storage systems enable arbitrage of renewable generation, in which power is bought at times when demand is low, power is cheap, and renewables are generating, and then sold back when power prices are high. They can also provide ancillary services to the grid. At the consumer level, they can provide backup power and help maximize use of distributed generation systems. Storage, however, is currently costly, and most market structures worldwide do not favour its adoption because they do not allow adequate remuneration for the flexibility benefits storage provides. Because neither storage nor the other options described above are without drawbacks, integrating high levels of renewables with baseload power may require a combination of strategies to meet multiple objectives. Among these strategies, electricity storage is of particular interest because storage systems are flexible, may be carbon-free, and are scalable. However, high costs are currently a barrier.

This paper is a literature and data review on the status of electricity storage deployment and R&D, and highlights barriers that need to be overcome in order for storage to contribute significantly to bulk power operations.

The next section gives an overview of grid-scale storage technologies in various stages of development and deployment. Following sections discuss existing electricity storage installations, valuing energy storage on the grid, and R&D efforts on storage. The emphasis throughout this paper is on large storage systems that have the ability to provide grid-level renewables integration services, including electricity arbitrage and ancillary services like frequency regulation.

2. Overview of selected storage technologies

Cost estimates can be challenging for storage technologies, as costs vary widely by geography (especially for pumped hydro and compressed air systems) and are hard to estimate for emerging technologies. Table 1 provides an overview of technology costs, and each is discussed further (with references) below. Establishing comparative storage technology costs is difficult; estimates vary widely, and costs for projects underway and for emerging technologies are often proprietary. A primary recommendation for further work includes a comprehensive assessment of storage costs.

2.1. Pumped hydroelectric

Pumped hydro is the most mature, widely-deployed energy storage technology. Pumped hydro facilities include high and low water reservoirs, typically with elevation differences in the hundreds of meters range. During periods of electricity storage or "charging," water is pumped from the lower to the higher reservoir, and then when electricity is needed, the water flows from the high reservoir to the lower through a hydroelectric turbine. According to the Electricity Storage Association, these processes lose very little electricity, reaching round-trip efficiencies as high as 80%. The major challenges for pumped hydro include dependence on geography and public concerns about environmental degradation where new reservoirs are created.

Table 1
Summary of Storage Technology Capital Costs[a].

Technology	Cost/kW (power)	Cost/kWh (storage)
Pumped Hydro	\$1500-\$4300	\$250–430
Compressed Air	\$800-\$1500	\$125/kWh
Flywheels	up to \$4000	\$200-\$500
Lead-Acid	\$1700-\$4900	\$450-\$950
Li-ion	\$1000[b]	\$500-\$850
NaS	\$3100-\$3300	\$520-\$550
Flow Batteries	\$3100-\$3700	\$520-\$550
Hydrogen	\$500-\$1200	\$75

[a] Note that these are ranges compiled from published cost estimates for utility-scale installations in the U. S. from EPRI, BNEF, IEA, and peer-reviewed papers as of May 2014 (specific estimates with their sources are described below). Between May 2014 and 2015, several companies announced sales of battery systems available at lower cost; these examples are discussed below.

[b] Li-ion per-kW cost estimate from AES energy systems (St. John, 2014)

Current cost estimates for storage technologies vary by country and can vary by location within countries – especially for pumped hydro storage. EPRI estimates U. S. pumped hydro costs at \$2500-\$4300/kW (power) and \$420–430/kWh (storage) for small facilities with capacities less than roughly 5500 MWh, and \$1500-\$2700/kW and \$250–270/kWh for facilities up to 14,000 MWh (EPRI, 2010a). The national hydropower association reports slightly lower capital costs for pumped hydro (Manwaring et al., 2012).

The potential for building new pumped hydro varies by country as well. In the US, DOE and Oak Ridge National Laboratory are surveying potential for new facilities. Elsewhere, over 60 pumped hydro projects are under construction, most in Europe, China, India, and Japan (Manwaring et al., 2012). The potential for pumped hydro could be large, even in Europe: Gimeno-Gutierrez and Lacal-Arategui (2013) indicated the possibility for a ten-fold increase in storage capacity, and MacKay (2009) estimates up to 400GWh of potential in the UK. However, realizing this potential will likely require overcoming environmental challenges for specific geographies. In addition, in some regions, the economics for new pumped hydro facilities may be at issue, as more demand-side management and solar deployment shaves peak electricity prices and reduces arbitrage opportunities for storage plants. Switzerland has good examples of both. Following the decision to discontinue nuclear, the Swiss government published ambitious plans for increased hydro – which were immediately opposed by the cantons. Plans for increasing the capacity of pumped storage at the Grimsel have been put on ice because of the cheap midday wind energy flooding in from Germany.

2.2. Compressed air energy storage

Compressed air energy storage systems (CAES) pump air underground into geologic formations or (more rarely) into above-ground vessels and pipes. When electricity is needed, the air is released, heated, and expanded by natural gas to drive a turbine. Advanced CAES technologies include those that take advantage of electricity production during the compression phase, and those that recycle flue gas in order to minimize natural gas burns. Although CAES faces twin challenges of limited geography and greenhouse gas emissions, it is the third-most widely deployed

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[1] Note that storage can provide a wide range of grid services on many timescales, and some systems can provide more than one type of service. For purposes of this study, we focus on grid-scale storage with the ability to provide electricity arbitrage and regulation services, as these are of especially high importance for grid integration of renewable and baseload sources.

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