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Energy Storage: Technology Applications and Policy Options

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Abstract

This paper presents technology applications and policy options related to energy storage in energy systems or grids. Energy storage technologies are promising tools to achieve a low-carbon future since they allow for the decoupling of energy supply and demand. Energy storage technologies could potentially be deployed across the supply, transmission, distribution and demand portions of an energy system or grid. The services they provide are either based on a power application or an energy application; and they range from long-term seasonal storage to short duration spinning and non-spinning reserves. In terms of energy storage technologies, pumped storage hydropower systems are a mature technology and comprise over 99% of the current total global installed capacity of energy storage technologies, which is evaluated at over 141 GW. In order to achieve widespread deployment, policy options should seek to enable compensation for the multiple services performed across the energy system.

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Keywords: Energy storage, renewable energy, policy, power grids, thermal grids.

1. Introduction

Energy storage technologies are promising tools to achieve a low-carbon future. Specifically, they allow for the decoupling of energy supply and demand, which can provide a valuable resource to electricity system operators.

The most important drivers for increasing the use of energy storage are [1]:

- Improving the efficiency of energy system resources;
- Increasing the integration of variable renewable resources (notably wind and solar);
- Rising self-consumption and self-production (distributed generation) of energy (electricity, heat/cold);
- Increasing end-use sector electrification (e.g., electric vehicles);

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- Increasing energy access (e.g., off-grid electrification); and,
- Growing emphasis on grid stability, reliability and resilience.

By providing services in the energy system, energy storage technologies are valuable tools for operators of energy systems with supply and/or demand variability. While the latter has historically been part of the energy system, the former is an increasing concern as jurisdictions are looking to increase the penetration of variable renewable energy generation on their energy grids.

2. Energy Storage Technologies

In this section, a brief overview of energy storage technologies is presented. Energy storage is not limited to one single technology; rather, it encompasses a range of technologies, which include:

- Pumped Storage Hydropower (PSH);
- Underground Thermal Energy Storage (UTES);
- Compressed Air Energy Storage (CAES);
- Pit Storage;
- Molten Salts;
- Batteries;
- Thermochemical Storage;
- Chemical-Hydrogen Storage;
- Flywheels;
- Supercapacitors;
- Superconducting Magnetic Energy Storage (SMES);
- Solid Media Storage;
- Ice Storage;
- Hot- and Cold-Water Storage; and,
- Hydrogen Energy Storage.

For its part, Table 1 shows a summary list of energy storage technologies and their respective techno-economic data [1]. From Table 1, it can be seen that energy storage technologies can supply either electricity or thermal energy. In terms of their position in an energy system or grid, they could potentially be deployed across the supply, transmission, distribution and demand portions of an energy system or grid. Further, the capital costs of energy storage technologies range from 100 to 15,000 USD/kW of installed capacity. Finally, energy storage technologies can be used in a variety of applications ranging from short-term storage to long-term storage, along with low to high temperature applications.

2.1. Current Status of Energy Storage Technologies

Currently, the total global installed capacity of electricity storage technologies is at least 141 GW [1]. For their parts, PSH systems represent over 99% of the total global installed capacity of energy storage technologies, with approximately 140 GW of installed capacity worldwide. Other notable technologies with significant global installed capacity include CAES, various battery technologies and flywheel-based energy storage technologies [2]. In terms of thermal energy storage, global storage capacities are not known. However, it can be said that domestic hot water tanks are the most common of these technologies. Other notable technologies widely used are ice and chilled water storage, which is commonly used in Australia, the U.S., China and Japan; and UTES which is used in many European countries. It is estimated that approximately 1 GW of ice storage has been deployed in the U.S. in order to reduce peak energy consumption for areas that experience high cooling demands; while in Denmark, pit storage is commonly used in district heating networks [3].

Table 1. Overview of Energy Storage Technologies [1]

Technology	Position	Output	Efficiency	Capital costs (USD/kW)	Primary application
PSH	Supply	Electricity	50 - 85%	500 - 4,600	Long-term storage
UTES	Supply	Thermal	50 - 90%	3,400 - 4,500	Long term storage
CAES	Supply	Electricity	27 - 70%	500 - 1,500	Long-term storage; Arbitrage
Pit storage	Supply	Thermal	50 - 90%	100 - 300	Medium temperature applications
Molten salts	Supply	Thermal	40 - 93%	400 - 700	High temperature applications
Batteries	S&D	Electricity	75 - 95%	300 - 3,500	Distributed/off-grid storage; short-term storage
Thermochemical	S&D	Thermal	90 - 99%	1,000 - 3,000	Low, medium and high temperature applications
Chemical-hydrogen storage	S&D	Electrical	22 - 50%	500 - 750	Long-term storage
Flywheels	T&D	Electricity	90 - 95%	130 - 500	Short-term storage
Supercapacitors	T&D	Electricity	90 - 95%	130 - 515	Short-term storage
SMES	T&D	Electricity	90 - 95%	130 - 515	Short-term storage
Solid media storage	Demand	Thermal	50 - 90%	500 - 3,000	Medium temperature applications
Ice storage	Demand	Thermal	75 - 90%	6,000 - 15,000	Low temperature applications
Hot-water storage (residential)	Demand	Thermal	50 - 90%	Negligible[1]	Medium temperature applications
Cold-water storage	Demand	Thermal	50 - 90%	300 - 600	Low-temperature applications
Hydrogen	Supply	Electricity	30 – 50%	550 - 4,500	Long-term storage

[1] *Additional costs associated with adapting existing hot water storage tank systems to be utilised as energy storage devices are negligible; S&D: Supply and Demand; T&D: Transmission and Distribution*

In regards to the current commercial maturity of energy storage technologies, PSH, pit storage, cold water storage, UTES and residential hot water heaters with storage are the technologies which are currently in their commercialization phase, ranked on lowest capital requirement and technology risk. Of these technologies, PSH is the most mature technology. It is to be noted that CAES is still considered to be near the end of the demonstration and deployment phase, and thus near full commercialization [4].

2.2. Current Levelized Cost of Electricity of Energy Storage Technologies

The levelized cost of electricity (LCOE) is a parameter used to measure the overall competiveness of different electricity generating technologies [5]. It represents the per-kilowatt-hour cost (in real dollars) of building and operating a generating plant over an assumed financial life and duty cycle. The key parameters used in calculating the LCOE include capital costs, fuel costs, fixed and variable operations and maintenance (O&M) costs, and financing costs.

Table 2 presents the current levelized cost of electricity for selected energy storage technologies and other electricity generation technologies [6, 7]. From Table 2, it can be seen that CAES and PSH have the lowest median levelized cost of electricity among the energy storage technologies identified; at 0.17 USD/kWh and 0.19 USD/kWh, respectively.

In regards to the other electricity generation technologies, Table 2 shows that combined cycle natural gas currently has the lowest median levelized cost of electricity at approximately 0.055 USD/kWh, while onshore wind has the second lowest median levelized cost of electricity at 0.065 USD/kWh.

Furthermore, from Table 2, it can be seen that renewable energy-based electricity generation are competitive with fossil fuel-based electricity generation and with nuclear-based electricity generation. Secondly, while project costs of energy storage technologies are site dependent, energy storage technologies are close to being cost-competitive compared to other electricity generation technologies. However, their costs remain one of the main barriers to their large-scale deployment. Finally, in relation to improving grid flexibility, energy storage technologies are still considered the most expensive resource compared to other options available.

Table 2. Levelized Cost of Electricity for Selected Energy Storage Technologies and Other Electricity Generation Technologies [6, 7]

Technology	Levelized cost of electricity (LCOE) in USD/kWh
Energy storage technologies	
PSH	0.16 – 0.22
CAES	0.12 – 0.22
Batteries	0.09 – 0.80
Flywheels	0.30 – 0.38
Other electricity generation technologies	
Wind (onshore)	0.04 – 0.09
Solar PV	0.16 – 0.63
CSP	0.13 – 0.36
Hydro (large-scale)	0.04 – 0.12
Natural gas (combined cycle)	0.04 – 0.07
Natural gas (simple cycle)	0.06 – 0.12
Coal	0.05 – 0.10
Nuclear	0.06 – 0.10

3. Energy Storage Policy Options

It has been shown that the widespread deployment of energy storage technologies is highly dependent on achieving acceptable cost recovery [1]. Currently, market conditions and policy environments are unclear in regards to the costs of energy services rendered by energy storage technologies. Furthermore, since energy storage technologies provide value across different portions of the energy market (i.e. supply and demand sides, or transmission and distribution), they typically do not fit naturally into existing regulatory frameworks. To this end, policy options should seek to enable compensation for the multiple services performed by energy storage across the energy system in order to achieve widespread technology deployment. This would involve payments based on the value of energy reliability, power quality, energy security and efficiency gains.

Further, policy options should address regulatory barriers in relation to the appropriate functional classification mechanism of energy storage technologies in order to allow them to provide multiple benefits to the energy system. In the U.S., the Federal Energy Regulatory Commission (FERC) has recently revised its market-based rate regulations, ancillary services requirements and accounting and reporting requirements. These revised regulations create new electric plant accounts specific to energy storage assets in the existing functional classifications of production, transmission and distribution. Depending on the function performed by the energy storage system, asset costs will be allocated across these accounts. It is believed that these regulatory revisions should address the complexity involved in their accounting and remove a significant barrier to their increased deployment in the U.S. market [8].

Examples of policy options that can be used to support an increasing deployment of energy storage technologies are presented in Table 3.

Table 3. Policy Options to Support Deployment of Energy Storage Technologies [1]

Policy options	Government examples
Direct financial support	
Capital assistance	-
Subsidies	Germany
Research, development and demonstration support	China, Germany, Japan, South Korea
Direct mandate of procurement	Ontario (Canada), California (USA)
Feed-in tariffs	Ontario (Canada)
Market evolution and regulatory revision	Ontario (Canada), Federal Energy Regulatory Commission, FERC, (USA)
Performance documentation	Japan, South Korea
Price distortion reduction	Federal Energy Regulatory Commission, FERC, (USA)

Specifically, it is to be noted that direct mandates for procurement are currently used, with great success, in the province of Ontario (Canada) and in the state of California (USA). In both of these jurisdictions, procurement mandates of 50 MW of new energy storage projects have recently been announced and have been met with many formal project proposals (e.g. over 500 formal project proposals in California). Furthermore, other governments are choosing to align their support of energy storage technologies with their support of renewable energy projects, such as in Germany, where the government is supporting small-scale energy storage projects in order to support the further development of distributed solar photovoltaic technologies. Such policy alignments can be useful in high renewable energy penetration markets or in jurisdictions having manufacturing capabilities of both technologies.

Finally, for jurisdictions having existing energy storage facilities, actions should be taken to increase their efficiencies and flexibilities, to improve their potential to support additional levels of renewable energy generation, and to facilitate and optimize energy exchanges between electricity and thermal grids. Also, governments should look at supporting the existing thermal distributed storage capacity (e.g. residential hot water heater systems) by inventorying and improving system performance feedback to users. Such actions could result in better matching of supply and demand curves, which could potentially result in significant savings in greenhouse gas (GHG) emissions.

Conclusion

This paper presents technology applications and policy options related to energy storage in energy systems or grids. Based on the analysis presented, while some energy storage technologies have not reached commercial maturity in their development phase, energy storage technologies in general can still provide near-term benefits in certain key areas or applications. Pumped storage hydropower (PSH), compressed air energy storage (CAES) and flywheels can provide near-term benefits in electricity grids that can easily accommodate centralized energy supply resources. For their parts, hot and cold-water heater-based thermal energy storage can provide near-term benefits for areas having high variability of energy demand. In terms of policy options, current market conditions and policy environments are unclear in regards to the costs of energy services rendered by energy storage technologies. Further, these technologies typically do not fit naturally into existing regulatory frameworks. In order to achieve widespread technology deployment, policy options should seek to enable compensation for the multiple services performed by energy storage across the energy system, including payments based on the value of energy reliability, power quality, energy security and efficiency gains.

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