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A research framework for grid benefits from energy storage

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ABSTRACT

Grid reliability is one of the greatest challenges facing electric utilities. Energy storage will play an important role in meeting these challenges by enhancing the grid's operating capabilities, lowering costs, ensuring high reliability, and deferring and reducing infrastructure investments. This paper offers a taxonomy of the advantages of energy storage to identify the main benefits offered to electrical utilities. In addition, it illustrates and discusses a detailed classification of energy-storage materials along with their characteristics. This paper provides a solid foundation to equip researchers with the most pertinent information to advance future research in the energy-informatics domain. The goal of creating this taxonomy and framework is to identify areas for future research endeavors and illustrate new research directions.

1. Introduction

When thinking of electricity in our homes, we generally think about the benefits it offers us. We like that it is (nearly) always available and sometimes complain bitterly when it is not. We like how inexpensive it is (EIA, 2011). We like that its cost is stable so we don't have to think about what time of day we turn on the dryer or take a shower, even though each of those actions may use a hefty amount of electrical energy from our power company. Finally, we really like the many life-simplifying gadgets it facilitates, whose numbers seem to increase faster and faster: toaster ovens, hairdryers, computers, mobile computing and communication devices, super-efficient home heating systems, and zero-emission electric cars, to name a few.

In contrast, most of us think very little about where the energy comes from or how it gets to our homes. As it turns out, making clean, high-quality, inexpensive electricity nearly always available to meet nearly any demand is no mean feat. Utility companies work hard at this, and, although they are getting better at it, they still encounter difficulties. Energy storage—essentially utility-scale batteries, but not necessarily what we think of when we use the term—can help considerably.

Several studies discuss the benefits of energy storage (Aneke and Wang, 2016; Cheng et al., 2012; Hou et al., 2016; Johnson et al., 2019; Roberts, 2010; Rodriguez, 2010; Šćekić et al., 2020; Sharma and Sankar, 2018; Such and Hill, 2012; Zakeri and Syri, 2015; Zame et al., 2018). This paper presents a taxonomy of the benefits from energy storage built by following the Nickerson et al. (2013) method to develop a taxonomy in information systems. This taxonomy is based on previous literature to illustrate four core dimensions of the benefits for the grid: enabling the smart grid, facilitating the renewable and intermittent generation, improving transmission and distribution, and increasing grid reliability and power quality. This paper also illustrates and discusses a detailed classification of energy-storage materials and their characteristics to help the utility companies' stakeholders achieve the full benefits of energy storage. The intent is to answer one research question: "How will energy storage benefit electric networks and what services does it offer grid operators?" The objective is to summarize the core concepts, offer a detailed typology for energy-storage types and their characteristics based on the current literature, identify areas for future research endeavors, and illustrate a new research direction via a research framework.

The remainder of this article is divided into four sections: Section 2 reviews the literature on utility-scale energy storage and illustrates a detailed

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classification of energy storage materials. Section 3 offers a taxonomy of energy-storage benefits and discusses those benefits in more detail. Section 4 illustrates and discusses a new framework for research to equip researchers with the most pertinent information to advance future research in the domain. Section 5 concludes.

2. Literature review

We conducted a literature review regarding the smart-grid benefits from energy storage to highlight the knowledge base on the topic. Looking at the references cited in the current articles and highlighting papers cited most frequently can help one grasp the main core of a subject. This step is particularly helpful in identifying the foundational papers.

2.1. History of energy storage

Although it is not part of the collective consciousness, energy storage has been used by electric utilities for nearly their entire history. For example, the first major pumped hydropower storage plant was built by Connecticut Light and Power in 1929 (OEERE, 2016). The first battery-based utility-scale energy storage plant was built in the 1980s, Southern California Edison's Chino Battery Energy Storage Plant offered 10 MW of power and 40 MWh of storage (Rodriguez, 2010).

"An August 2013 White House report, written in conjunction with the Office of Electricity Delivery and Energy Reliability, detailed the vital role that energy storage would play in improving grid resiliency and robustness related to weather outages and other potential disruptions" (EOPUS, 2013). Considering that energy storage is a critical component to be added to the power network and the urgency of energy-storage deployment, several research studies have discussed the types of energy storage and the benefits associated with energy storage.

2.2. Types of energy storage

Aneke and Wang (2016) offered an extensive introduction to the wide range of energy-storage technologies, from mechanical systems (flywheels, pumped hydroelectric, compressed air, liquid piston) to superconducting magnets to various chemical energy-storage systems. Pumped hydroelectric energy storage had a significant head start on the field and still retains the edge in both available powers (3,000 MW) and total energy stored (24 GWh) (Lewis, 2018). However, most new research and innovation is in chemical energy storage: hydrogen electrolysis, synthesized methane, and such liquid and dry battery systems as lithium-ion, sodium-sulfur, and iron-chromium (Aneke and Wang, 2016). Table 1 presents some of the many different types of energy storage systems that have been developed, studied, and used.

2.3. The smart grid

Many energy-storage benefits stem from enabling the smart grid. Tuballa and Abundo (2016) offered several definitions of smart grid, where smart means neat, trim, or intelligent and grid means a network of electrical conductors that distribute electricity to definite points: "An electricity network that can intelligently integrate the actions of all users connected to it, generators, consumers and those that do both, in order to efficiently deliver sustainable, economic and secure electricity supplies" (Tuballa and Abundo, 2016). The National Institute of Standards and Technology defined smart grid as "a grid system that integrates many varieties of digital computing and communication technologies and services into the power system infrastructure" (Tuballa and Abundo, 2016). The use of distributed energy resources, such as renewable technologies and energy storage, would facilitate the transition to a smart grid because such a grid can help meet regular power demand from irregular sources (Tuballa and Abundo, 2016).

The smart grid would help optimize energy efficiency with a two-way exchange of real-time electricity information between consumers and suppliers. This technology can maximize availability, efficiency, reliability, security, economic and environmental performance, and power-distribution efficiency. Grid reliability is very important and must be studied by researchers since it determines the grid's success in providing users with what they need (Zame et al., 2018; Tuballa and Abundo, 2016).

3. Research method

Energy-storage technologies can enhance the grid's operation and efficiency by quickly responding to changes in demand signaled through the smart grid (Zame et al., 2018). Energy storage is any system that can store a definite amount of energy for the electric grid and provide the stored energy back to the grid. These storage systems must have a known calendar life in years and cycle life in kWh under identified conditions, maintenance standards with schedules, and round-trip efficiency. Finally, the design for these storage systems could be applied in one or more applications to optimize energy economics and grid operations (Zame et al., 2018). According to Moslehi and Kumar (2010), battery storage is a promising solution to economically improve grid reliability through technology. The advantages of specific energy-storage technologies include low self-discharge, high efficiency, high power, and fast response (Hesse et al., 2017).

In the following section, a taxonomy of the benefits from energy storage is developed following Nickerson et al. (2013) in information systems and based on previous literature.

Table 1: Energy storage technologies

Storage type	Materials	Characteristics	Work
Flow batteries	Two electrolyte reservoirs; electrochemical cell composed of a cathode, anode, and membrane separator	High power; long duration; power and energy ratings decoupled; electrolyte is easily replaced; fast response: from charge to discharge in about 1 ms; low efficiencies; electrolytes cannot react when stored separately; discharge time ups to 10 h; low energy density; limited operating-temperature range (10–35 °C); high capital costs; flexible discharge time, power rating, and energy capacity; long lifetime (13,000 cycles)	(Divya and Østergaard, 2009; Zakeri and Syri, 2015)
Metal air	Anode: such commonly available metals with high energy density as aluminum or zinc; cathode: a porous carbon structure or a metal mesh with proper catalysts; electrolyte: a good hydroxide (OH−) ion conductor	Low cost; high energy densities; very difficult to recharge	(Divya and Østergaard, 2009)
Lead-acid (flooded type)	Anode: lead dioxide; cathode: microporous sponge lead; electrolyte: sulfuric acid	Largest capacity: 10 MW/40 MWh; valve-regulated lead-acid batteries can reach 10-fold longer life compared to others	(Divya and Østergaard, 2009; Zakeri and Syri, 2015)
Sodium sulfur (NaS)	Anode: molten sulfur; cathode: molten sodium; electrolyte: solid beta alumina ceramic	High energy density (151–170 kWh/m^3); small and light; operates at 300 °C; largest capacity: 9.6 MW/64 MWh; high efficiency (> 85%); 2,500–4,500 life cycles at 90% depth of discharge; expected lifetime of 15 years; discharge time up to 7 hours; scalable power rating; promising utility-scale demonstrations; prompt, precise responses for applications in power-quality regulation	(Aneke and Wang, 2016; Divya and Østergaard, 2009; Zakeri and Syri, 2015)
Lithium-ion (Li-ion)	Cathode: lithiated metal oxide; anode: graphitic carbon with a layer structure; electrolyte: lithium salts dissolved in organic carbonates	High power density; potential for future development and optimization; highest energy density and storage efficiency close to 100%; well suited for portable devices; high cost	(Divya and Østergaard, 2009)
Sodium nickel chloride	$NaNiCl_2$	Built for electric vehicles and hybrid electric vehicle applications	(Aneke and Wang, 2016)
Vanadium redox battery (VRB)	A type of flow battery	Efficiency is about 85%; low maintenance; overcharge and deep-discharge tolerant	(Aneke and Wang, 2016)
Iron chromium (FeCr)	A type of flow battery	Low cost; high-performance uncertainty; high life-cycle uncertainty	(Aneke and Wang, 2016)
Zinc-air (ZnAir)	A type of metal-air battery	Low cost; low efficiency (50%)	(Aneke and Wang, 2016)
Sodium/nickel chloride	Molten table salt and nickel in combination with a ceramic electrolyte	High-temperature batteries (270–350 °C); successfully employed in several mobile applications	(Zakeri and Syri, 2015)
Nickel-cadmium battery (Ni-Cd)	Anode: nickel; cathode: cadmium; electrolyte: aqueous alkali solution KOH	High energy density (55–75 Wh/kg); low maintenance; 2,000 to 2,500 discharge cycles; high capital costs; high disposal costs; memory effect; susceptible to overcharging; low efficiency	(Johnson et al., 2019; Zakeri and Syri, 2015)
Superconducting magnetic energy storage (SMES)	Magnetic field	High energy-storage efficiency; Fast response; 100,000 cycles; high cost	(Zakeri and Syri, 2015)
Hydrogen storage	Ammonia (NH_3) liquefied in such materials as hydrogen storage alloys, inorganic chemical hydrides, carbon materials, and liquid hydrides, by compression at 1 MPa and 298 K	High energy density; low efficiency; high cost; highest volumetric hydrogen density of 10.7 kg H_2/100 L	(Kojima, 2019; Zakeri and Syri, 2015)
Power-to-gas energy storage	Hydrogen or synthesized methane	High density; long-term storage	(Aneke and Wang, 2016; Zakeri and Syri, 2015)
Flywheel energy storage (FES)	Composite flywheel; motor-generator; often magnetic bearings; low-pressure casing	Operates in charging and discharging mode; improves power quality; low maintenance; long life; high transfer efficiency; no depth-of-discharge effects; environmentally friendly; temperature and harsh-condition tolerant; not good for long-term energy storage; low storage efficiency	(Aneke and Wang, 2016)
Pumped hydroelectric energy storage (PHES)	Stores energy in gravitational potential energy	Reliable power within a short time (1 min); 65%–85% efficiency; incorporation into natural lakes, rivers, or reservoirs	(Aneke and Wang, 2016; Šćekić et al., 2020)
Compressed air energy storage (CAES)	Off-peak electricity compresses air and stores it in a reservoir	70% efficiency; 40-year expected lifetime	(Aneke and Wang, 2016)
Liquid-piston energy storage (LPES)	Compressed air forces a liquid from one chamber to another	Unlimited cycling ability; lower maintenance; storage capacity unaffected by age; full-discharge and overcharge tolerant; power unlinked to capacity; near-zero self-discharge; 3.2 to 5.55 Wh/kg; chances of leakage at the piping assembly; lower energy efficiency, around 73%	(Aneke and Wang, 2016)
Capacitive energy storage	Supercapacitors, electrochemical capacitors, ultracapacitors, electric double-layer capacitors	Large energy density; responds to any change in power demand; high cost	(Aneke and Wang, 2016)

It is to illustrate four core classes of benefits for the grid: Enabling the smart grid, facilitating the renewable and intermittent generation, improving transmission and distribution, and increasing grid reliability and power quality. Section 3.2 illustrates the framework of energy-storage grid benefits that are grounded and developed based on the previous literature.

3.1. Developing the energy-storage grid benefit taxonomy

The purpose of our taxonomy is to identify the main benefits offered to the grid by energy storage to help utility companies around the world fully understand those benefits. This taxonomy will help researchers and decision-makers in the field of energy informatics identify whether other benefits could be added as these technologies emerge and evolve. The taxonomy is shown graphically in Fig. 1.

Development of the grid-benefits taxonomy followed Nickerson et al. (2013): (1) determine meta characteristics, (2) determine ending conditions (objective, subjective), (3) determine the approach to follow (empirical to conceptual, conceptual to empirical), and (4) meet the ending condition. After demonstrating this method, we started to develop the taxonomy by first determining the meta characteristics, the benefits to the grid from energy storage. Second, the objective and subjective conditions are (1) no dimensions or characteristics were merged or split in the last iteration (objective), and (2) new dimensions are easily added (subjective). Third, we chose to use the empirical-to-conceptual approach because we discovered some benefits for the grid from previous research articles. This step consists of three substeps: (3a) conceptualize new characteristics and dimensions of objects, (3b) study objects for these characteristics and dimensions, and (3c) create or revise the taxonomy (Nickerson et al., 2013). These substeps are used and implemented in each of the following iterations.

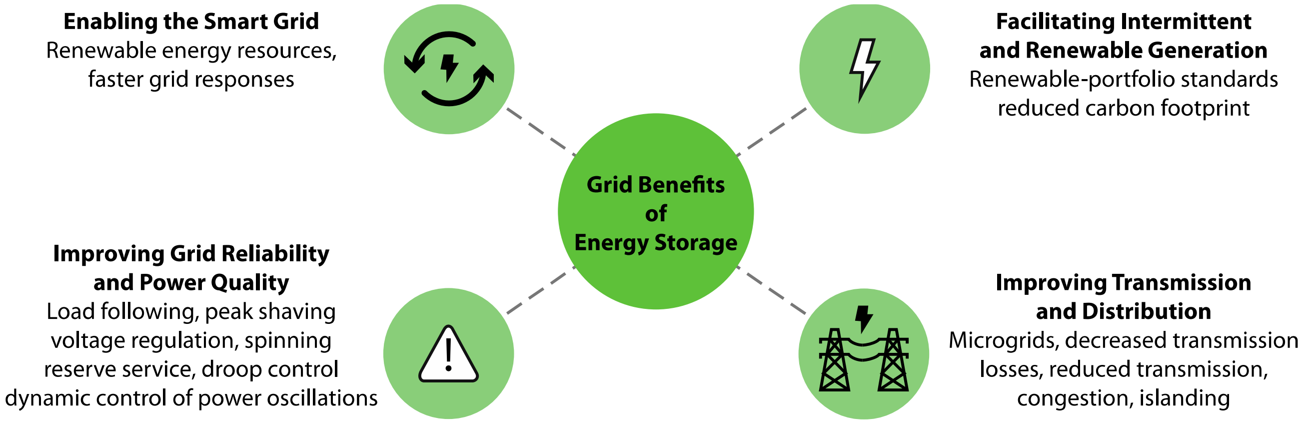

Fig. 1: Energy storage grid benefit taxonomy

3.1.1. Iteration 1

According to Moslehi and Kumar (2010), a smart grid is an umbrella term for several technologies expected to help dramatically increase reliability, efficiency, quality, and local and national electricity-grid resilience to extreme events while reducing environmental and financial costs. Energy storage can help enable the smart grid in two ways, by increasing the use of renewable energy resources and by allowing the grid to react more quickly to changes in the operating environment. In this iteration, one dimension has evolved: Enabling the smart grid now includes two characteristics as shown in Table 2 and Fig. 2.

Finally, we end this iteration here since the ending conditions are met: There are no more dimensions to merge, and there is still a chance to add more dimensions from other published research articles.

Table 2: Dimension 1 enabling the smart grid

	Benefit from energy storage	
Dimension	Enabling the smart grid	
Characteristics	Increasing the use of renewable energy resources	Allowing the grid to react more quickly to changes in the operating environment

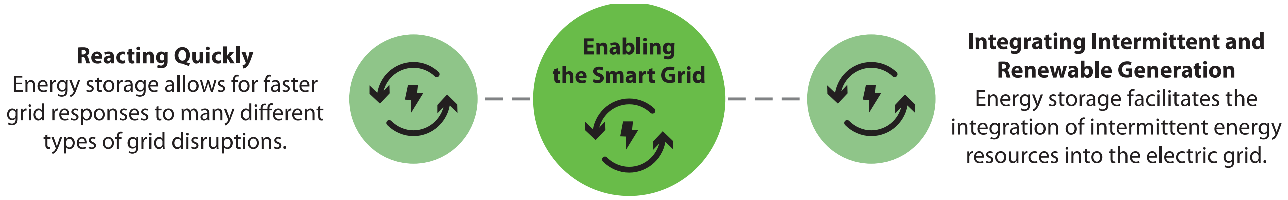

Fig. 2: Enabling the smart grid

3.1.2. Iteration 2

As reported by Tyson and Kennedy (2020), most consumers support moving from carbon-polluting energy sources (such as coal-, diesel-, and natural-gas-fired power plants) to carbon-neutral energy sources (such as solar photovoltaics, wind turbines, and run-of-the-river hydro turbines) because it will help reduce climate change and improve local air quality. However, many people believe that these cleaner energy sources often produce power intermittently, straining the electricity grid's aging technologies. By accepting energy whenever it is available and providing energy when it is needed, energy storage softens the necessary connection between supply and demand, greatly improving the value of renewable energy resources to the grid. Properly designed energy-storage systems can help utilities meet states' renewable-portfolio standards and reduce their carbon footprints by relying more on carbon-neutral energy sources and less on carbon-polluting sources. These three characteristics are grouped under one new dimension in this taxonomy, facilitating the renewable and intermittent generation, as shown in Table 3 and Fig. 3.

Table 3: Dimension 2 facilitating the renewable and intermittent generation

	Benefit from energy storage		
Dimension	Enabling the smart grid		
Characteristics	Increasing the use of renewable energy resources	Allowing the grid to react more quickly to changes in the operating environment	
Dimension	Facilitating the renewable and intermittent generation		
Characteristics	Lower carbon footprint	More valuable product to consumers	Renewable-portfolio standards

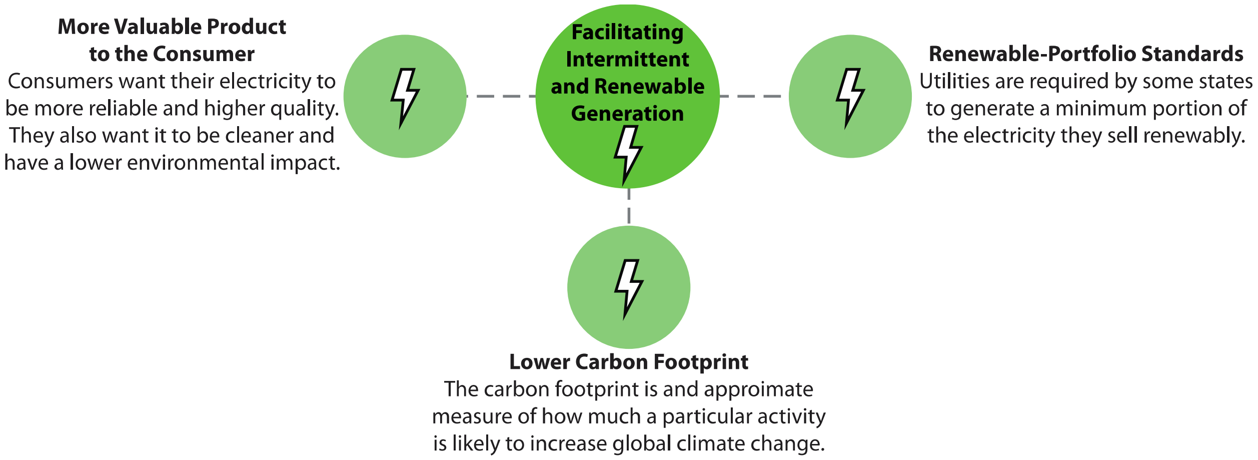

Fig. 3: Facilitating renewable and intermittent generation dimension

We stopped this iteration and moved to the third iteration because the ending conditions were met: There is a chance to create a new dimension from other research articles and no more dimensions emerge from this iteration.

3.1.3. Iteration 3

As demonstrated by Elliott et al. (2019), even the mundane field of transmission and distribution can be shaken up by energy storage. Long considered a fact of life, transmission losses and congestion can be dramatically improved by the microgrids, and islanding enabled by energy storage. Additionally, energy-storage systems distributed strategically around the grid would allow it to be broken into multiple independent grids during short outages, serving more customers while repairs are in progress. These characteristics are grouped under a new dimension, improving transmission and distribution as displayed in Table 4 and Fig. 4.

This iteration was ended because the objective and subjective ending conditions have been met. We moved to the next iteration to identify more dimensions to be added.

3.1.4. Iteration 4

Grid reliability and power quality are the heart of electric utilities' customer satisfaction, the most obvious aspects of the service provided. Reliability refers to how often the power goes out completely. A perfectly reliable gird, where the power never goes out, is a lofty goal, but it is never attained. In addition to staying on, high-quality power meets customers' expectations in a range of metrics for voltage, frequency, and wave-form regulation. Energy storage helps increase grid reliability and power quality by improving load following, peak shaving, voltage regulation, and droop control, and by offering spinning reserves and dynamic power-oscillation control.

Table 4: Dimension 3 improving transmission and distribution

	Benefit from energy storage		
Dimension	Enabling the smart grid		
Characteristics	Increasing the use of renewable energy resources	Allowing the grid to react more quickly to changes in the operating environment	
Dimension	Facilitating the renewable and intermittent generation		
Characteristics	Lower carbon footprint	More valuable product to consumers	Renewable-portfolio standards
Dimension	Improving transmission and distribution		
Characteristics	Transmission losses	Islanding	Transmission congestion

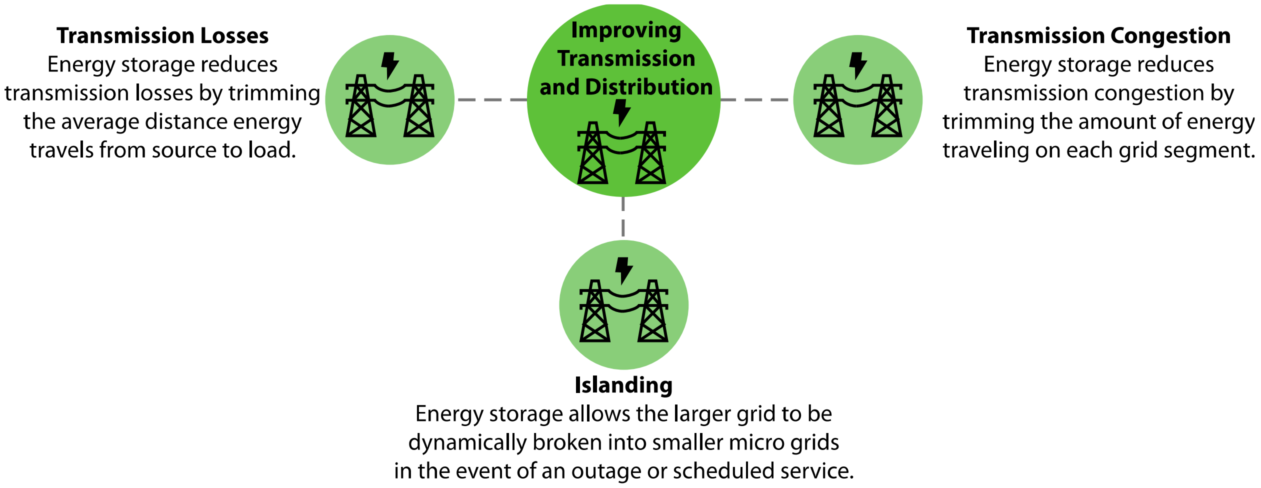

Fig. 4: Improving transmission and distribution dimension

Load following means quickly increasing or decreasing the output of an energy source in response to changes in demand. This increase and decrease are important to the grid because it ensures that the right amount of power is always available. If too little power is available, the voltage or frequency of the electricity supplied will drop. If too much power is available, at least one of them will increase. Either case can damage sensitive electronics or cut service in some areas. Most energy-storage systems are easily ramped up and down in response to the load on the system, improving voltage regulation and droop control.

Peak shaving means reducing the highest demand levels at the power plant. This is important because power produced by peaking plants, those power plants that can quickly ramp up to meet a quick spike in demand, is often the most expensive, economically and environmentally. Because energy-storage systems respond quickly to changes in demand, they provide a spinning reserve and can dramatically reduce the need to use expensive peaking plants, savings that utilities can pass on to their customers in the form of lower energy costs.

Finally, mismatches between power supply and demand can lead to oscillations in the supplied voltage, phase angle, and frequency. These oscillations degrade power quality, possibly damaging sensitive electronic equipment. If that equipment is in the consumer's home or place of business, the consumer is inconvenienced. If that equipment is part of the grid infrastructure, the result can be much worse, possibly leading to a blackout. These characteristics are grouped under the final dimension, improving grid reliability and power quality (Table 5, Fig. 5).

Table 5: Dimension 4 improving grid reliability and power quality dimension

	Benefit from energy storage				
Dimension	Enabling the smart grid				
Characteristics	Increasing the use of renewable energy resources	Allowing the grid to react more quickly to changes in the operating environment			
Dimension	Facilitating the renewable and intermittent generation				
Characteristics	Lower carbon footprint	More valuable product to consumers	Renewable-portfolio standards		
Dimension	Improving transmission and distribution				
Characteristics	Transmission losses	Islanding	Transmission congestion		
Dimension	Improving grid reliability and power quality				
Characteristics	Load following	Spinning reserve	Dynamic control of power oscillations	Voltage regulation and droop control	Peak shaving

We have added one new dimension with this iteration and have covered most of the newly added research articles in this field. Therefore, the objective and subjective ending conditions are met. The taxonomy is extendible, explanatory, concise, and robust. Fig. 1 merges all four dimensions of this taxonomy.

3.2. Energy-storage grid-benefits research framework

Part of the paper's aim is to develop a framework that illustrates the energy-storage grid benefits that can be used by the targeted stakeholders to get the full benefits of energy storage. Fig. 6 shows a framework of energy-storage grid benefits grounded in the previous literature. The main focus, energy-storage grid benefits, can be categorized into four components: Facilitating intermittent and renewable generation, enabling a smart grid, improving grid reliability and power quality, and improving transmission and distribution.

These components are each further divided into research topics that need further attention by the researchers in those areas. The various topics in the framework would enhance the energy-storage benefits and can be further discussed by researchers. Table 6 presents some possible use cases for future research. Lastly, the framework identifies the possible relevant stakeholders: Utilities and renewable-energy traders, institutional hedge funds and investment banks, renewable-energy and battery-storage developers, engineering–procurement–construction and integrated-energy firms, and oil producers.

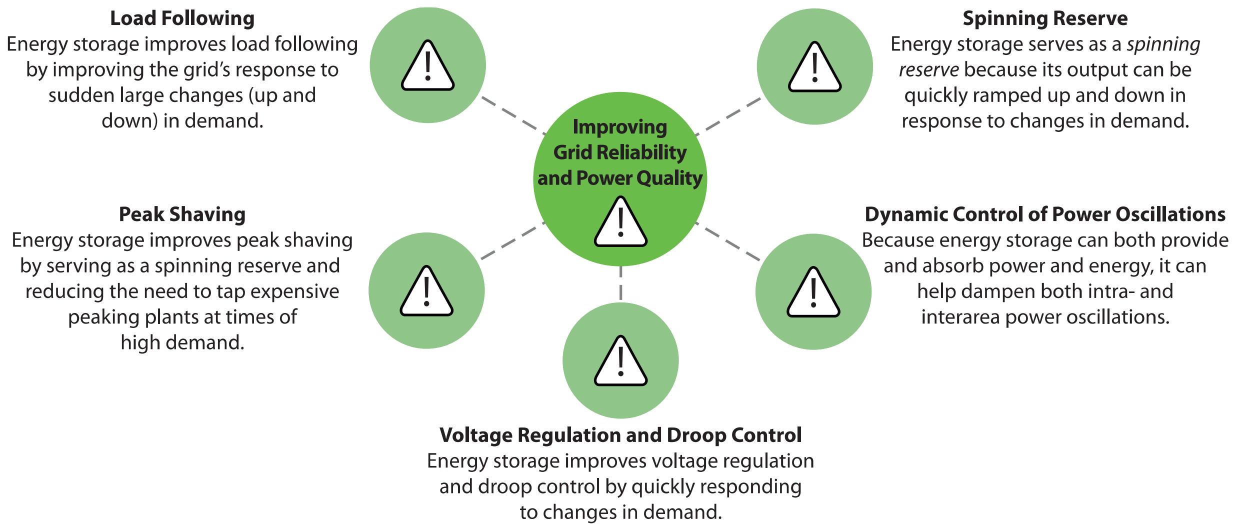

Fig. 5: Improving grid reliability and power quality dimension

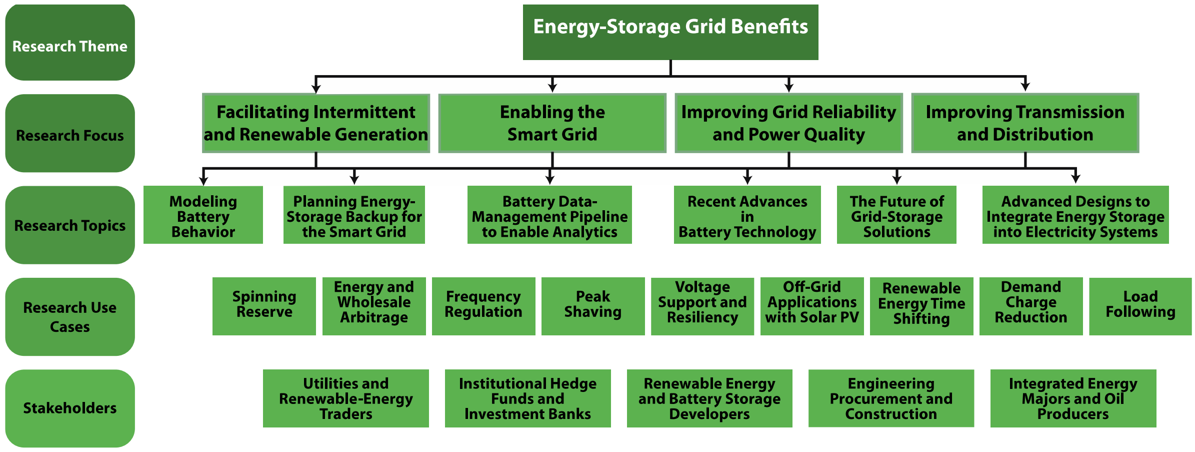

Fig. 6: The energy-storage grid-benefits research framework

Table 6: Use cases

Use case	Description	Works
Spinning reserve	Balancing long-term imbalances in both demand and supply	(Malhotra et al., 2016; Byrne et al., 2017)
Energy and wholesale arbitrage	Storing energy when grid prices are low and selling energy when prices are high (depending on the real-time hourly market)	(McLaren, 2016)
Frequency regulation	Stabilizing frequency on a moment-to-moment basis	(McLaren, 2016)
Peak shaving	Reducing the highest demand levels at the powerplant	(Elliott et al., 2019)
Voltage support and resiliency	Balancing generation and consumption to prevent the frequency and voltage deviation	(Malhotra et al., 2016; USDE, 2020)
Off-grid application and solar PV	Sustaining critical loads during outages	(Elliott et al., 2019)
Renewable energy time-shifting	Shifting renewable generation from off-peak to peak hours	(Malhotra et al., 2016; Byrne et al, 2017)
Demand charge reduction	Reducing sudden spikes in demand to reduce electricity bills	(Malhotra et al., 2016; Byrne et al, 2017)
Load following	Maintaining the balance among electric supply and demand while permitting conventional generation units to operate at peak efficiency.	(Malhotra et al., 2016; USDE, 2020)

4. Results and discussion

This study aimed to address an important question: "How will energy storage benefit electric networks and what services does it offer grid operators?" To answer the research question, we searched the background literature to develop a taxonomy of the grid benefits from energy storage. The taxonomy offered in this paper is the first to address the research question and is intended to help researchers identify areas for future research. From this research, we conclude that all four classes of grid benefits are important, but they are too broad to cover in any depth in a single research project.

Prospective authors in this space could examine topics such as modeling battery behavior, planning energy-storage backup for the smart grid, battery-data management and pipeline to enable analytics, recent advances in battery technology, the future of grid-storage solutions, and advanced designs to integrate energy storage into the electricity systems. Following the literature review and the development of the taxonomy, we also designed and developed a research framework of grid benefits from energy storage to answer the research question, as well as to help stakeholders get the full benefits of energy storage. This paper provides a solid foundation to equip researchers with the most pertinent information. From this taxonomy and with the research framework, a new direction for future research in this domain can emerge.

5. Future works, and conclusion

In the future, we expect to conduct a systematic review focusing on one or two top journal(s) in the field of energy informatics to illustrate the most popular energy storage systems, which may enhance the developed taxonomy and research framework. Moreover, other researchers may add more dimensions in the taxonomy, as well as more levels in the research framework to have a comprehensive framework in this research domain.

Several challenges currently face electric utilities. Focusing on energy storage may help solve some of these challenges. The energy-storage grid-benefits taxonomy and the energy-storage grid-benefits research framework are promising starts for other researchers to understand and fully bring the benefits of energy storage to the future smart grid.

Compliance with ethical standards

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

References

Aneke M and Wang M (2016). Energy storage technologies and real life applications–A state of the art review. Applied Energy, 179: 350-377. https://doi.org/10.1016/j.apenergy.2016.06.097

Byrne RH, Nguyen TA, Copp DA, Chalamala BR, and Gyuk I (2017). Energy management and optimization methods for grid energy storage systems. IEEE Access, 6: 13231-13260. https://doi.org/10.1109/ACCESS.2017.2741578

Cheng F, Willard S, Hawkins J, Arellano B, Lavrova O, and Mammoli A (2012). Applying battery energy storage to enhance the benefits of photovoltaics. In the 2012 IEEE Energytech, IEEE, Cleveland, USA: 1-5. https://doi.org/10.1109/EnergyTech.2012.6304684

Divya KC and Østergaard J (2009). Battery energy storage technology for power systems-An overview. Electric Power Systems Research, 79(4): 511-520. https://doi.org/10.1016/j.epsr.2008.09.017

EIA (2011). Annual energy review 2011. U.S. Energy Information Administration, Washington, USA.

Elliott RT, Fernández-Blanco R, Kozdras K, Kaplan J, Lockyear B, Zyskowski J, and Kirschen DS (2019). Sharing energy storage between transmission and distribution. IEEE Transactions on Power Systems, 34(1): 152-162. https://doi.org/10.1109/TPWRS.2018.2866420

EOPUS (2013). Economic benefits of increasing electric grid resilience to weather outages. Executive Office of the President of the United States (White House), Washington, USA.

Hesse HC, Schimpe M, Kucevic D, and Jossen A (2017). Lithium-ion battery storage for the grid-A review of stationary battery storage system design tailored for applications in modern power grids. Energies, 10(12). https://doi.org/10.3390/en10122107

Hou T, Cui Y, Zhou X, Zhang W, and Ruan B (2016). Charge-discharge strategy for battery energy storage to smooth power fluctuations from wind farms. In the China International Conference on Electricity Distribution, IEEE, Xi'an, China: 1-5. https://doi.org/10.1109/CICED.2016.7576001

Johnson SC, Davidson FT, Rhodes JD, Coleman JL, Bragg-Sitton SM, Dufek EJ, and Webber ME (2019). Selecting favorable energy storage technologies for nuclear power. In: Bindra H and Revankar S (Eds.), Storage and hybridization of nuclear energy: Techno-economic integration of renewable and nuclear energy: 119-175. Academic Press, Cambridge, USA. https://doi.org/10.1016/B978-0-12-813975-2.00005-3

Kojima Y (2019). Hydrogen storage materials for hydrogen and energy carriers. International Journal of Hydrogen Energy, 44(33): 18179-18192. https://doi.org/10.1016/j.ijhydene.2019.05.119

Lewis S (2018). The 10 largest pumped-storage hydropower plants in the world. Available online at: https://www.enr.com/articles/44302-the-10-largest-pumped-storage-hydropower-plants-in-the-world

Malhotra A, Battke B, Beuse M, Stephan A, and Schmidt T (2016). Use cases for stationary battery technologies: A review of the literature and existing projects. Renewable and Sustainable Energy Reviews, 56: 705-721. https://doi.org/10.1016/j.rser.2015.11.085

McLaren J (2016). Batteries 101 series: Use cases and value streams for energy storage. Available online at: https://www.nrel.gov/state-local-tribal/blog/posts/batteries-101-series-use-cases-and-value-streams-for-energy-storage.html

Moslehi K and Kumar R (2010). Smart grid-A reliability perspective. In the Innovative Smart Grid Technologies, IEEE, Gaithersburg, USA: 1-8. https://doi.org/10.1109/ISGT.2010.5434765

Nickerson RC, Varshney U, and Muntermann J (2013). A method for taxonomy development and its application in information systems. European Journal of Information Systems, 22(3): 336-359. https://doi.org/10.1057/ejis.2012.26

OEERE (2016). History of hydropower. Office of Energy Efficiency and Renewable Energy, Washington, USA.

Roberts BP (2010). Deploying battery energy storage in the utility distribution grid. In the IEEE PES General Meeting, IEEE, Minneapolis, USA: 1-2. https://doi.org/10.1109/PES.2010.5589571

Rodriguez GD (2010). A utility perspective of the role of energy storage in the smart grid. In the IEEE PES general meeting, IEEE, Minneapolis, USA: 1-2. https://doi.org/10.1109/PES.2010.5589870

Šćekić L, Mujović S, and Radulović V (2020). Pumped hydroelectric energy storage as a facilitator of renewable energy in liberalized electricity market. Energies, 13(22): 6076. https://doi.org/10.3390/en13226076

Sharma N and Sankar S (2018). Modeling and control of battery energy storage system for providing grid support services. In the Clemson University Power Systems Conference, IEEE, Charleston, USA: 1-5. https://doi.org/10.1109/PSC.2018.8664018

Such MC and Hill C (2012). Battery energy storage and wind energy integrated into the smart grid. In the 2012 IEEE PES Innovative Smart Grid Technologies, IEEE, Washington, USA: 1-4. https://doi.org/10.1109/ISGT.2012.6175772 **PMid:21538063**

Tuballa ML and Abundo ML (2016). A review of the development of smart grid technologies. Renewable and Sustainable Energy Reviews, 59: 710-725. https://doi.org/10.1016/j.rser.2016.01.011

Tyson A and Kennedy B (2020). Two-thirds of Americans think government should do more on climate: Bipartisan backing for carbon capture tax credits, extensive tree-planting efforts. Pew Research Center, Washington, USA.

USDE (2020). Energy storage grand challenge (ESGC) use cases. U.S. Department of Energy, Washington, USA.

Zakeri B and Syri S (2015). Electrical energy storage systems: A comparative life cycle cost analysis. Renewable and Sustainable Energy Reviews, 42: 569-596. https://doi.org/10.1016/j.rser.2014.10.011

Zame KK, Brehm CA, Nitica AT, Richard CL, and Schweitzer III GD (2018). Smart grid and energy storage: Policy recommendations. Renewable and Sustainable Energy Reviews, 82: 1646-1654. https://doi.org/10.1016/j.rser.2017.07.011