Grid Benefits from Energy Storage

A Taxonomy for Smart Grid Benefits from Energy Storage

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***Abstract*—Grid reliability is one of the greatest challenges facing electric utilities. We argue that energy storage will play a significant role in meeting the challenges facing electric utilities by improving the grid's operating capabilities, lowering cost, ensuring high reliability, and deferring and reducing infrastructure investments. Several studies discuss the benefits of energy storage. This paper offers a taxonomy for smart-grid benefits from energy storage based on previous literature to illustrate four core classes of benefits for the grid. This work provides a solid foundation to equip researchers with the most pertinent information to advance future research in this domain.**

Keywords—peak shaving; load following; intermittent generation; battery; power quality.

I. Introduction

Thinking of electricity in our homes generally evokes the benefits it offers us. Consumers expect to have uninterrupted access to electricity and are consequently inconvenienced when provisioning is not possible. We like how inexpensive it is. We like that its cost is stable so we do not have to think about what time of day we turn on the dryer or take a shower, even though each of those actions may demand a hefty amount of energy from our power company. Finally, we really like the many life-simplifying gadgets it facilitates, whose numbers seem to increase every year: toaster ovens, hair dryers, computers, mobile computing and communication devices, super-efficient home heating systems, and zero-emission electric cars, to name a few.

In contrast, few of us think much about where the energy comes from or how it gets to our homes. As it turns out, supplying clean, high-quality, inexpensive electricity that is (nearly) always available to meet almost 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, utility-scale batteries, can help considerably.

Considering that energy storage is a critical component for the power network and considering the urgency of energy-storage deployment, this paper addresses the research question: "How will energy storage benefit the electric power network, and what services will it offer grid operators?" The objective of this research is to develop a taxonomy for smart-grid benefits from energy storage, to summarize the core concepts, and to offer a detailed typology for energy-storage types and their characteristics based on the current literature.

The remainder of this article is divided into three sections: Section 2 reviews the literature on utility-scale energy storage. Section 3 offers a taxonomy of energy-storage benefits and discusses those benefits in more detail. Section 4 concludes.

II. Literature Review

We conducted a literature review regarding the smart grid benefits from energy storage to highlight the knowledge base on the topic. One way to grasp the main core of a subject is to look at the references cited in current articles and highlight papers cited repeatedly. This step was particularly helpful in identifying the foundational papers. A literature review is a particularly influential tool in the hands of researchers because it allows scholars to gather and recap all the information about research in a specific field [1].

A. History of Energy Storage

Although it is not part of our collective consciousness, energy storage has been used by electric utilities for nearly their entire history. For example, the first major pumped hydroelectric storage plant was built by Connecticut Light and Power in 1929 [2]. The first battery-based utility-scale energy-storage plants were built in the 1980s, including Southern California Edison's Chino Battery Energy Storage Plant offering 10 MW of power and 40 MWh of storage [3].

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 [4]. Considering that energy storage is a critical component to be added to the power network and considering the urgency of energy storage deployment, several research studies have discussed the types of energy storage and the smart grid benefits associated with energy-storage technologies.

B. Types of Energy Storage

Reference [5] 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 and super capacitors 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 power (up to 3,000 MW at a single facility) and total energy stored (24 GWh) [6]. However, most of the 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 [5]. There is good

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reason for this: While a pumped hydroelectric system can store massive amounts of power and can deliver it at high power levels, like any mechanical system, it suffers from a relatively long response time, on the order of five minutes [7]. While this compares well with other spinning reserves (often idling natural gas or diesel power plants), which can take 10 minutes to produce their rated power [8], most battery system can produce their rated power in less than just a few seconds [9, 10]. In the remainder of this article, *energy storage systems* refers to systems with a response time of seconds or less.

C. *The Smart Grid*

Many of energy storage's benefit stem from enabling the smart grid. Reference [11] offered several definitions of the 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" [11, p. 712]. 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" [11, p. 712]. The use of distributed energy resources, such as renewable technologies and storages, would facilitate the transition to a smart grid because it can help meet regular power demand [11].

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. Grid reliability is a very important point that must be studied by researchers since it determines the grid's success in providing the needed services to the users [11, 12].

III. Benefits of Energy Storage

Several studies discuss the benefits of energy storage. Based on our literature review, We have built a taxonomy for smart grid benefits from energy storage that offers four classes of benefits for the grid: enabling the smart grid, facilitating renewable and intermittent generation, improving transmission and distribution, and increasing grid reliability and power quality. The taxonomy is shown graphically in Figure 1.

Energy storage technologies can enhance the grid's operation and efficiency by quickly responding to changes in demand through the smart grid [12]. Energy storage can be defined as storage with the ability to store a definite amount of energy for the electric grid and to 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 [12]. According to [13], battery storage is a promising solution to economically improve grid reliability through technology. Other advantages include low self-discharge, high efficiency, and fast response [14].

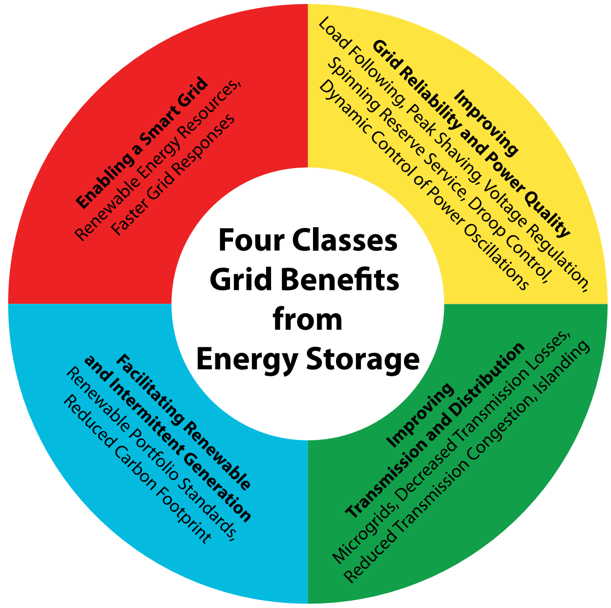

Figure 1. Taxonomy of the grid benefits of energy storage.

A. *Enabling the Smart Grid*

The smart grid is an umbrella term for technologies that are expected to help dramatically increase local and national electricity grid resilience to extreme events, reliability, efficiency, and quality, while reducing their environmental and financial costs. Energy storage can facilitate 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 [12]. See Figure 2.

B. *Facilitating Renewable and Intermittent Generation*

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

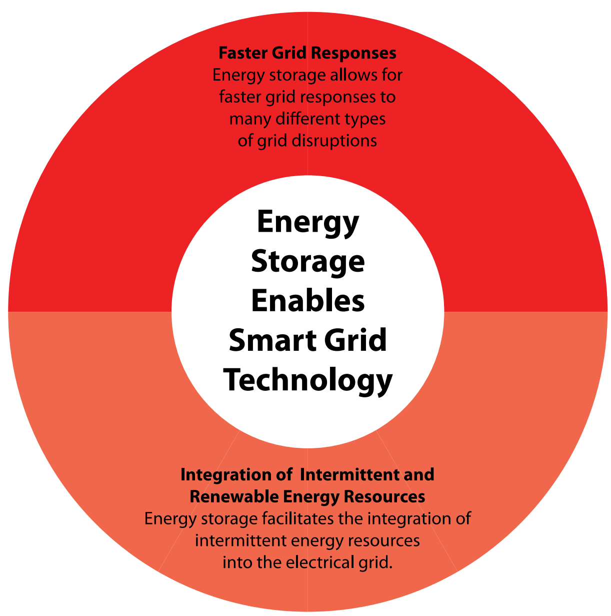

Figure 2. Enabling the smart grid.

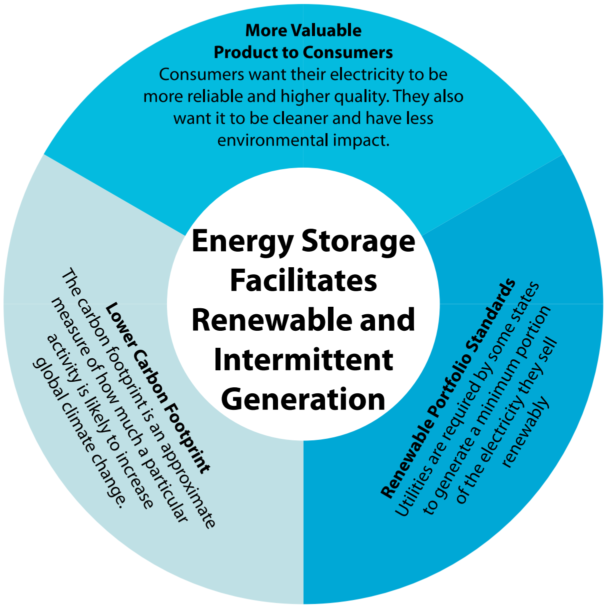

Figure 3. Facilitating renewable and intermittent generation.

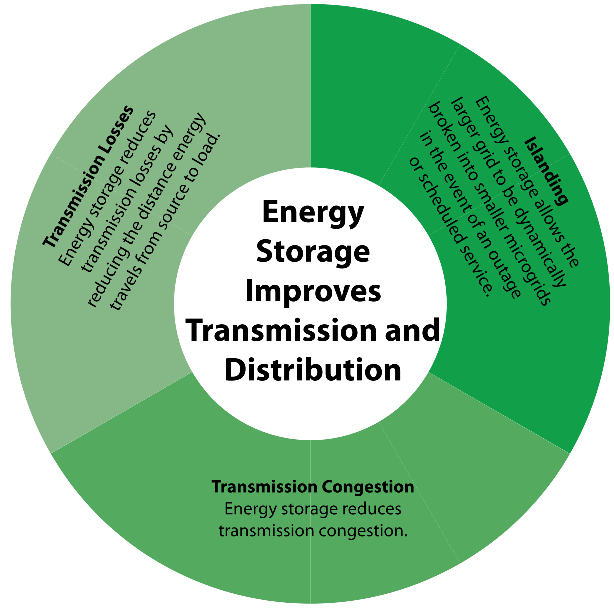

Figure 5. Improving transmission and distribution.

photovoltaics, wind turbines, and run-of-the-river hydro turbines) because it will help reduce climate change and improve local air quality [15]. However, many people believe that these cleaner energy sources' intermittent nature strains the electricity grid's aging technologies ([16–18]. By accepting energy whenever it is available and providing energy when it is needed, energy storage breaks 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. See Figure 3.

C. *Improving Transmission and Distribution*

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 [19]. Additionally, energy storage system 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 [19]. See Figure 4.

D. *Improving Grid Reliability and Power Quality*

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, 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 reserve service and dynamic control of power oscillations [3]. See Figure 5.

Load following means quickly increasing or decreasing the output of an energy source in response to changes in demand. This increase and decrease is important to the grid because it ensures that the right amount of power is available at all times. 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. In either case, the results can be damage to sensitive electronics or loss of 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 [3].

Peak shaving means reducing the highest demand levels at the powerplant. This is important because power produced by peaking plants, those power plants than can quickly ramp up to meet a quick spike in demand, is the most expensive.

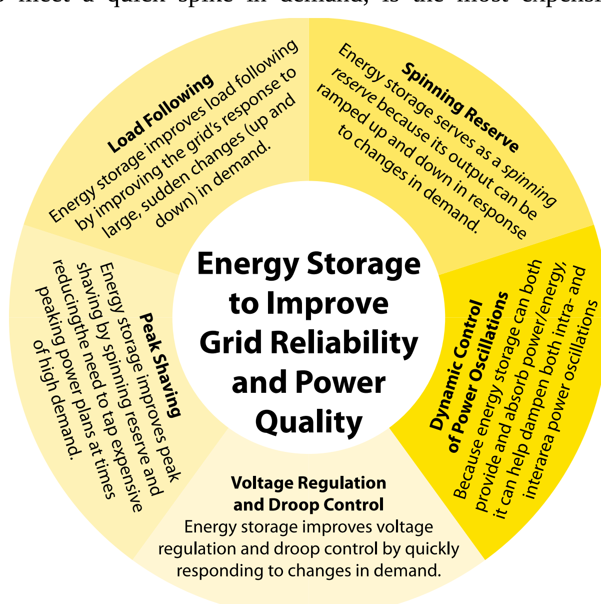

Figure 4. Improving grid reliability and power quality.

Because energy storage systems respond quickly to changes in demand, they provide a spinning reserve service and can dramatically reduce the need to use expensive peaking plants, a savings that utilities can pass on to their customers in the form of lower energy costs [3].

Finally, mismatches between the supply and demand of power can lead to oscillations in the voltage, phase angle, and frequency of the power. 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 [20].

IV. CONCLUSION

This study aimed to address an important question: "How will energy storage benefit the electric power network and what services will if offer to grid operators?" To answer the research question, we have searched the background literature to develop a taxonomy for smart-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 endeavors.

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.

The literature review and taxonomy offered in this paper provide a solid foundation to equip researchers with the most pertinent information. From this taxonomy, a research framework can be developed to provide direction for future research in this domain.

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