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Smart grid and energy storage: Policy recommendations

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A R T I C L E I N F O

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A B S T R A C T

Traditional energy grid designs marginalize the value of information and energy storage, but a truly dynamic power grid requires both. The authors support defining energy storage as a distinct asset class within the electric grid system, supported with effective regulatory and financial policies for development and deployment within a storage-based smart grid system in which storage is placed in a central role. This would enhance load and market operations through realization of the full range and value of services from storage technologies. Energy storage technologies provide significant opportunities to further enhance the efficiency and operation of the grid. Its ability to provide application-specific energy services across different components of the grid make it uniquely suited to respond quickly and effectively to signals throughout the smart grid. Therefore, energy storage as a distinct asset class will increase the value of storage investments while enhancing the operation of the smart grid. To further this goal, storage requires policy support. Research, development and demonstration (RD & D) policies will increase operational experience and reduce costs; investment tax credits will accelerate investment in storage projects; and continued market deregulation will augment revenue streams, enhance competition, and provide more accurate prices for storage services.

1. Introduction

A shift to sustainable low carbon economy will require innovation and deployment of a range of low carbon technologies for providing energy and other services. Rapid developing literature on renewable energy and energy storage suggest electric power storage will facilitate the deployment of renewable energy and also facilitate the development of smart grids [1,2]. However, current conceptualization of the role of electrical energy storage in smart grids does not well position storage to realize its full potential in facilitating a smart grid holistically.

Advancing smart grid technology and design requires that energy system planning breaks from the business as usual understanding of energy storage to embrace a more efficient and sustainable framework. Energy storage systems (ESS) have been considered within the design of the energy grid but has had limited relevance because the high cost and inefficiency of many storage systems have undermined their value and functionality [3,4]. Additionally, existing perceptions of storage as little more than a bank to assist generators balance loads over time fails to capture the true potential of energy storage technologies [4]. Improvements in smart grid designs and storage technologies present unique opportunities to challenge the conventional model. To have a fully dynamic and optimized grid, while transitioning to a low carbon energy system, planners need to embrace more fully the benefits of renewable electricity generation and post-generation[1] energy storage.

Realizing the full benefit of storage and smart grid technologies requires establishing energy storage as a new asset class with a relevant set of regulatory and financial policies to support its development. Although, this concept has been mentioned in a number of publications [5–7], the specific role of electrical storage systems as a unique assert class in the structure of future electric gird value chain has not been sufficiently specified. This paper re-conceptualizes ESS as an asset class in a central role in the future structure of power markets and the grid; thereby enabling the realization of the full potential of ESS in facilitating a smart grid. In the sections that follow, we review the literature on electric grid system; review integration of renewables into the grid, differentiate between conventional and smart grid models, highlight the contributions or values of renewable energy to the electric grid. An overview of smart grid policy efforts is also provided. Next, we identify the limits to energy storage systems as a poorly defined asset class within the electric grid value chain, and demonstrate how creating a new asset class for storage will both enhance the value of storage and

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[1] Deal et al. defines energy storage as any technology, which is capable of storing energy after it has first been converted to electricity. For our purposes here, "post-generation" is used to make a distinction of the placement of energy storage in the energy value chain in contrast to "pre-generation" fuel storage [72].

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also provide significant benefits to the operation of the smart grid. Finally, policy mechanisms in support of the rapid deployment of energy storage systems are identified and discussed.

2. Related literature

2.1. The electric grid system

The first electric system in history was Thomas Edison's Manhattan Pearl Street Station in New York, which began operation in 1882. Edison's electrical system was essentially a microgrid [8] consisting of a 100 V coal-fed generator supplying electricity to power a few hundred lamps. Thus at its beginning, the electric grid was small and highly localized [9]. In the early years of electric systems, power plants were usually situated both close to their fuel sources and to the end-users of the power generated. However, with time, as more people began to demand for electricity smaller grids expanded into more complex systems, and the electric grid evolved into large interconnected networks as we have them now, connecting power generation stations, transmission lines, distribution networks and load centers (end users). The increasing complexity of power gird, coupled with growing electric demand, and the need for greater grid reliability and efficiency as well as environmental and energy sustainability concerns continue to highlight the need for a considerable leap in making the grid "smarter." The leap towards such a "smarter" grid is broadly referred to as "smart grid" [10,11]. Tuballa et al. (2016) noted that a smart grid does not have a one universal accepted definition, however, simply put, the smart grid is an intelligent grid. Whiles the traditional grid functions primarily by transmitting and distributing electricity, the smart grid on the other hand is able to store, communicate and make decisions, thereby functioning more cooperatively, responsibly and organically [11]. Differences between the traditional grid and the smart is well presented by a number of publications [11–13]. In Table 1, we present a compilation by Tuballa et al. (2016), of the general characteristics of the two grids.

2.2. Electric grid value chain: conventional vs. smart grid structures

Modern electric grid structures are often discussed through descriptive terminologies, such as "traditional" or "smart." Smart grid technologies and real-time access to user information improve the efficiency with which the production, transmission, and use of electricity occurs [7]. Through this improvement in efficiency, the roles and relationships of energy asset classes have begun to change. The inadequacy of the traditional energy grid becomes increasingly apparent as the transition away from stockpiled fuels (coal, natural gas, oil, and nuclear) continues towards more robust, renewable, and efficient processes of connecting end-users with energy services [14]. A disaggregated value chain [6] has created limits in the systematic efficiency of the traditional grid system. In contrast, a smart grid design allows for greater efficiencies by providing greater control of supply and immediate usage feedback, which limits waste.

Looking to Makansi (2007), the traditional grid is easily defined through five (5) asset classes: Source, Generation, Transmission, Distribution, and Delivery [6]. This classification of asset classes compartmentalizes the value chain and supports disaggregation as mentioned above. A depiction of Makansi's electricity value chain maintains the core components: Energy Source, Generation, Transmission, Distribution, and End User (Delivery), but to this the modified model (as shown in Fig. 1) adds various forms of energy storage and surplus (in the form of dump-loads). Notice the central feature of this grid structure: the mono-directional flow of energy and information.

There are no feedback loops – just supply. It is only by occasionally dumping excess loads that the energy is diverted from the end user. Since dump loads amplify revenue losses – in the sense of all costs and no revenue – there are strong incentives for grid operators to minimize these occurrences while simultaneously maintaining delivery expectations and the quality of energy services.

In contrast, a smart grid is often defined by the use of technology to relay time-sensitive energy data from end users back to the grid operator in an effort to optimize the grid's efficiency while also providing end users with real-time pricing from upstream generators. The same series of asset classes are considered, but now the flow of information is bi-directional, as depicted in Fig. 2. This representation of the smart grid design replaces dump loads with a more direct flow of information back to generation. The result is that the energy generator is provided with real-time demand, and supply can be matched more directly with consumer needs than by estimating the expected demand at any given time. The drawback associated with this design is that the feedback loop applies only with the generation of energy, creating inefficiencies in supply as generators ramp up and down in response to rapidly changing demand. Distributed generation technologies mitigate this problem to a degree, but the scale of capacity is comparatively small (i.e. residential solar use).

Differentiating the traditional energy grid from a smart grid design focuses on greater efficiency by increasing knowledge. Better information leads to more efficient operation, while more stable and responsive supply reduces consumer costs [15]. Note that energy storage enters this value chain in a supplementary rather than central role (see Fig. 2), limiting the value of energy storage services and complicating regulatory and operational considerations for storage ownership.

Table 1
Traditional electric grid versus the smart grid [11].

Traditional Grid	Smart Grid
Mechanization	Digitization
One-way communication	Two-way real-time communication
Centralized power generation	Distributed power generation
Radial network	Dispersed network
Less data involved	Large volumes of data involved
Small number of sensors	Many sensors and monitors
Less or no automatic monitoring	Great automatic monitors
Manual control and recovery	Automatic control and recovery
Less security and privacy concerns	Prone to security and privacy issues
Human attention to system disruptions	Adaptive protection
Simultaneous production and consumption of energy/electricity	Use of storage systems
Limited control	Extensive control system
Slow response to emergencies	Fast response to emergencies
Fewer user choices	Vast user choices

2.3. Smart grid policy overview

A number of existing published work have examined the social, regulatory, and institutional issues relating to sustainable energy development in general, and smart grid development in particular towards advancing the technological evolution of smart grids [1,16–18]. The introduction of various smart grid policies in many countries has stem from the need to formulate innovative policies to support competitive offerings and end-user pricing systems which in turn will contribute to improving allocative and productive efficiency within the operation of the grid while minimizing risk in the power market thereby incentivizing investors [19,20].

Various approaches to smart grid policy adoption in different countries and jurisdictions globally are linked to the state of the power industry and market in these countries/jurisdictions [21]. Lin et al. (2013) explains that the U.S.A, for instance, prefers an "environmental-side policy" approach which focuses on "scientific and technical development, financial, policy and public enterprise." While China, on the other hand, is focused on "supply-side policy" approach with

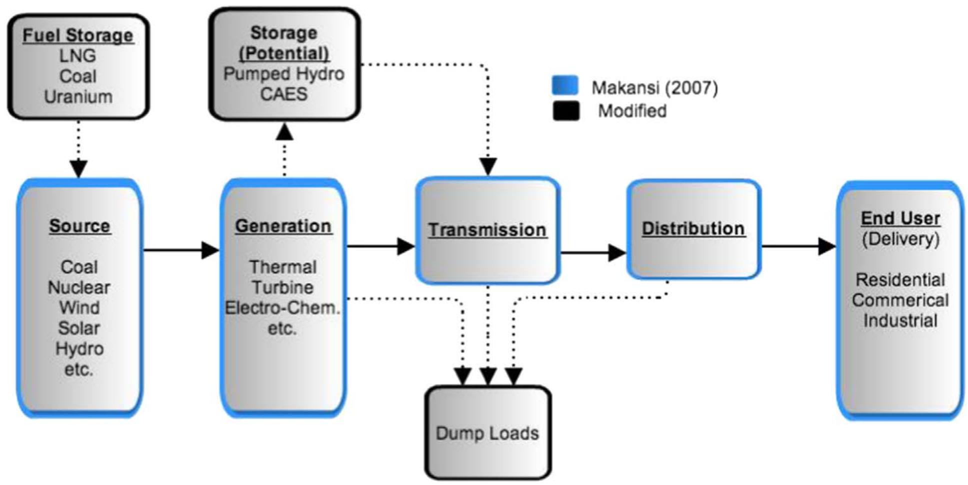

Fig. 1. Traditional Electricity Grid Value Chain.

emphasis on "public enterprise, scientific and technical development and legal regulations." To illustrate some of the smart-grid policies used in different places, the rest of this section presents a quick overview of smart-grid policies across a number of countries/jurisdictions.

With a call by the European Union (EU) for the installation of smart meters in 80% of EU households by 2020, majority of member states of the EU have instituted electricity smart metering [22,23]. Though smart meter programs in many European countries are a core part of their energy policies, these policies are not exclusively designed to only facilitate balancing of supply and demand within the electric grid. These policies serve to support other sustainable energy or climate change policies [19,23,24]. In the United States for instance, the country's Energy Policy Act of 2005 promotes the development of smart meters and for that matter smart grid, as the Act directs all utilities in the country to consider time-based rate schedule and time-based metering upon the request of customers [25]. Also in the U.S, the American Recovery Act of 2009 stipulates for the development of smart grid technologies and provides smart grid investment grants towards this purpose [26].

Japan has a goal of reducing its emissions by 30% by 2030. To achieve this goal, the country plans to transform its energy system by building "the world's most advanced next generation interactive grid network." Japan's objective is towards the realization of smart grids and smart communities by the year 2020, and this plan is documented in the country's Strategic Energy Plan of 2014 [27]. China's amended Renewable Energy Law of 2009, which specifies the development and deployment of smart grid technologies and energy storage to improve grid operation and management, and facilitation of the integration of renewables is one of the country's piece of legislation that indicates China's commitment to smart grid development [23,28]. China's "Special Planning of 12th Five-Year Plan on Smart Grid Science and Technology Industrialization Projects" is one other policy that shows the country's commitment to smart grid development. This plan identifies the following as the key drivers for China's smart grid deployment: large scale grid-connected intermittent renewable energy technology; large scale energy storage systems; intelligent distribution technology; intelligent transmission technology and equipment; grid information and communication technologies; flexible power transmission technology and equipment; and comprehensive smart grid integration demonstrations [23,29].

While a number of countries recognize the need for policy reform towards the development of smart grid, the implementation of such policies usually face challenges or difficulties such as institutional rigidity and inertia. Such institutional barriers are sometimes as a result of financial constraints and/or security and privacy risks concerns regarding smart grids. However, a country like Denmark has demonstrated that effective implementation of changes in complex country-specific social, economic, and political factors that impede the implementation of smart grid policies are relevant towards transforming a traditional grid into a smart one.

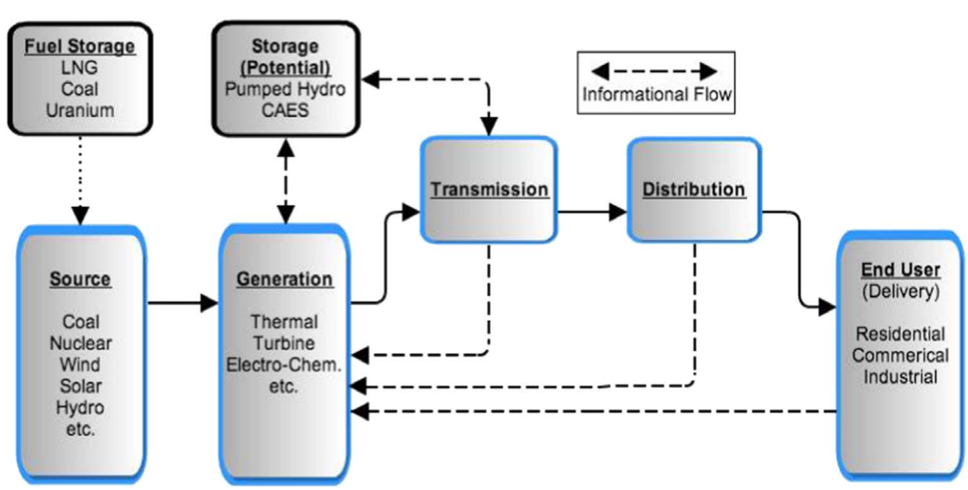

Fig. 2. Smart Grid Value Chain.

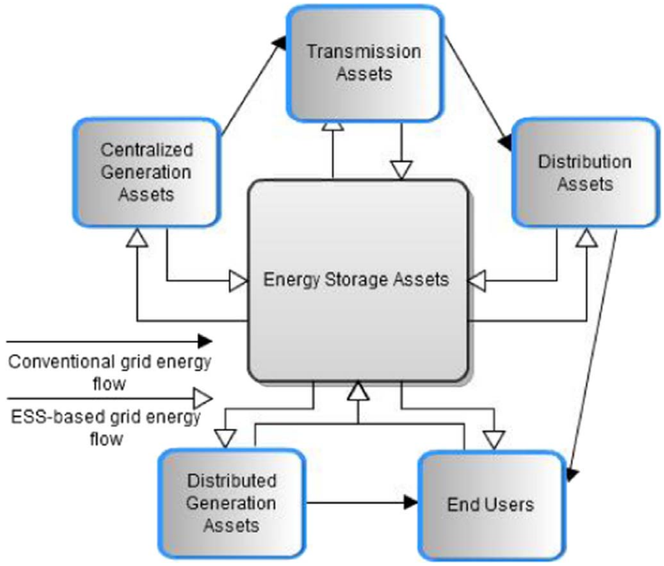

Fig. 3. Energy Flow in a Storage-based Grid.

2.4. Integrating renewables into the grid

Integration of renewable sources of electricity into the grid enables the efficient use of renewable energies which is a key challenge for now. Due to the availability and environmentally friendly nature of renewables, as well as the application of smart grid in renewable energy, integration of renewables is viewed as valuable [30,31]. However, the fluctuating nature of generation from renewable energy sources like solar and wind into distribution grids complicates the balancing of demand and supply, which in turn gives rise to the risk of grid instabilities [32].

Many recent studies have examined high penetrations of renewable generation; especially from wind, and investigated approaches to dealing with the increase in net-load variability and uncertainty that this brings into reliability management of the electric grid. Increasing demand elasticity or storing surplus power are considered general approaches to addressing the challenge of fluctuating feed-in of renewable energy resources into the distribution grid [33–37]. Matching fluctuating renewable electricity generation with electricity demand in an economically efficient manner that is sustainable with low losses and high levels of quality is enabled by smart grid technologies [32,38].

A number of studies confirm that hydropower resources contribute significantly to the operation of the grid. Most hydropower facilities have the capability to cycle to help manage net load variability and uncertainty which in turn enables high wind and solar power grid integration [39,40]. With increased development and expansion in integration of renewables into the grid, interest in coupling and coordinating renewables with pumped storage hydropower is growing; enhancing the integration of renewables; particularly wind and solar [34–36,41]. In this way, pumped storage hydropower projects are used by utilities to flexibly pick up or shed load very rapidly to ensure the stability and power quality of the electric grid.

Although geothermal electricity generation is usually operated as a source of baseload power, the advancement of power plant and control technology allow geothermal power plants to work in several variable modes [42]. Such variable modes or ancillary services include grid support, regulation, load following, spinning reserve, non-spinning reserve, and replacement or supplemental reserve. Puna Geothermal Venture plant in Hawaii which generates 38 MW, and contracted 16 MW of flexible capacity is one such geothermal power project that provides ancillary services for grid support, and these services are identical to those of existing oil-fired peak generating resources on the Big Island [42]. The ability of geothermal power to serve as a form of baseload power and also to perform such ancillary services in the grid make it suitable to support the increased grid integration of other forms of renewable electricity like wind and solar PV.

Literature on renewable power generation indicates that the integration of renewable electricity into the electric grid is not only already happening now, but renewable power's share in the grid is sure to continue to increase [33,43–45]. International Energy Agency's (IEA's) "Sustainable Energy Future" scenario projects 57% of the world's electricity to be generated from renewables by 2050 [43]. In developing a low carbon scenario for Europe, the European Climate Foundation (ECF) found that a 50% renewable electricity by 2030 is achievable at a cost comparable to that of a business-as-usual scenario [46]. Denmark, for instance, plans to increase its wind energy penetration to 50% by 2025. A study in 2010 by the Danish Energy Association and Energinet.dk (Denmark's largest utility) compared the cost of using smart grid technologies to the cost of traditional grid upgrades to accommodate this goal. Results from this study showed that the net cost of the necessary smart grid upgrades would be DKK 1.6 billion, versus DKK 7.7 billion for traditional grid upgrades [44]. The study's assertion is that an intelligent power system – smart grid – is the most effective strategy for developing the power system [44]. In 2015, electricity generated by Denmark from wind turbines corresponded to about 42% of the country's electricity consumption. Denmark is able to sustain increasing levels in wind power deployment over the years by adopting several smart grid technologies to effectively integrate wind energy forecasting into its grid operations, and to efficiently supply electricity to users in Denmark and surrounding countries [45]. In a Dutch smart grid pilot project called "PowerMatching City," a domestic virtual power plant was used to demonstrate that the flexibility in virtual power plants can be used to dampen the intermittent behavior of wind and solar energy [37].

The significance of renewable sources and other forms of decentralized generation in providing additional grid support services is enhanced via electrical storage systems (ESS). Centralized power plants (originally to the traditional power grid) supply large quantities of electricity for transmission and distribution (as depicted by the "conventional grid energy flow" arrow in Fig. 3); however, this model of operation of the power grid does not adequately meet the needs of the electricity industry. Economically, the cost of transmission and distribution facilities associated with centralized generation no longer offer efficiency gains through economies of scale associated with increased generation capacities. Decentralized generation creates gains accruing from the aggregation of energy from many sources as a result of economies of scale [47]. For instance, appropriately sized and customer-targeted distributed generation assets such as solar photovoltaic systems are proving to be more commercially viable. Additionally, distributed generation is able to offer end users (who could simultaneously be distributed generators) and utilities peak management, emergency power and other capabilities via energy storage [48,49].

As illustrated in Fig. 3; an ESS-based grid system facilitates energy flow interactions among distributed generation, end users and other grid elements via storage. The integration of distributed energy generation assets and storage is expected to become increasingly important in the future for implementing the smart grid concept and balancing the growing production and grid deployment of decentralized renewable energy sources. Energy storage at the core of the power grid does not mean a single large facility, as this can jeopardize grid reliability. The idea of "the energy bank"[2] that combines various storage systems to an "energy storage cloud" would ensure efficient power distribution with a high share of distributed solar PV and wind

[2] The "energy bank" concept of creating an "energy storage cloud" is inspired by the concept of cloud computing and financial banking [50].

energy [50]. A well-defined energy storage asset class at the core of the power grid would best facilitate this. This not only promotes the smart grid but also advances a shift away from conventional sources of energy such as coal and nuclear energy.

3. Energy storage: an asset class within the electric value chain

3.1. Energy storage: the missing link in electric value chain

Energy storage is pinpointed as a key technological component that can transform the current structure and operation of the power grid [51–53]. However, regulatory and economic barriers limit its feasibility and deployment on the grid. This, in turn, limits the applications and sources of revenue of energy storage systems. The source of these limits originates in the poorly defined status of energy storage. Creating a new asset class for energy storage systems will open storage technologies to provide multiple services and generate greater value. Currently, energy storage operators are forced to "choose between two dichotomous regulatory structures, both of which may result in inefficient storage use and investment" [54, p. 8]. Existing regulatory structures lead to energy storage being undervalued in both traditional, vertically integrated electricity models and restructured markets. A rate based system inhibits the deployment of energy storage toward its full value because it limits the revenue from multiple market services such as those for ancillary services. A purely market-based system does not provide price signals for the full range of energy storage services such as transmission and distribution relief, and it currently is incapable of pricing all energy services [54].

The problem with narrowly defining the role or form of energy storage is that it limits the full value of storage services. Energy management, bridging power, and power stability [15] are key market roles, which are at present provided less effectively by other asset classes. Energy storage is capable of providing a "shock absorber" for the overall grid system [15]. The traditional consideration of the role of energy storage as supplementary largely creates regulatory uncertainties. Regulators are uncertain how energy storage costs and benefits should be allocated among the main components of the grid, as energy storage can provide multiple services for generation, transmission, and distribution [55].

With grid assets classified as generation, transmission and distribution, services offered by storage facilities only fall under one of these three asset classes. Narrowly classifying energy storage as supplementary to existing asset class of the grid stymies its pivotal role in facilitating a smart grid and makes it difficult for energy storage to find a suitable place in regulation as currently there is no defined energy storage-pricing policy and no specific tariff-regulation for storage. As an inexplicitly defined or even non-asset class in the electric grid system, energy storage cannot derive full valuation in the marketplace as markets are not structured and regulated to recognize services that do not fit in the current value-chain. The economic argument against energy storage of not being able to fully recover cost stems from the fact that energy storage facilities are not offered distinct asset status and accorded the appropriate regulations to harness multiple revenue streams.

It is quite obvious that, in order to extract the full value of energy storage applications, energy storage must be defined as a distinct asset class from those that currently exist in the grid value chain. The problem at this point is building a definition that sufficiently distinguishes energy storage from other asset classes, especially generation. DNV KEMA,[3] an energy and environmental consulting firm, provides an excellent starting point by proposing the following definition for an energy storage asset class [56]:

1. Has the ability to store (receive and supply back) a definable amount of energy (joules or gigajoules) to an electrical network or electrical grid
2. Has a definable rate of both storing and providing the stored energy (watts and watt-hours respectively)
3. Has a definable calendar life (years) under specified conditions
4. Has a definable cycle life (total kWh transferred) under specified conditions
5. Has definable maintenance criteria and schedule
6. Has a definable round trip efficiency (including parasitic losses) to be used for economic analysis
7. Can be designed for use in one or more specific applications to optimize grid operation and energy economics.

Of particular importance is the seventh and final characteristic of the energy storage asset class. If energy storage is to be viable it is vital that we consider its viability in relation to its intended use. Howard & Kamath (2007) argue in support of this point by saying: *"The real challenge for energy storage is not whether it is possible, but how it will be used. There is no question that storage represents an opportunity; it will take strategy and understanding of this opportunity to make sure it is exploited to its full potential"* [57]. If that potential is to be directed towards each of the various asset classes and stakeholders, the framework for using energy storage needs to change. Because energy storage systems store electricity in a form and for a duration determined by the technology itself, they can be designed for multiple applications as needed by the grid. This is the source of its value, and defining storage as a new asset class would allow owners and operators to provide the highest-valued services across components of the grid.

The benefits of energy storage depend on the flexibility in application inherent in system design and operation. A growing body of literature details the numerous benefits of storage with new technologies expanding the range of potential applications [4,58–62]. Storage services are generally classified based on applications for grid support (market), generation, transmission/distribution, and customer/end-user applications [58,60]. Apart from the aforementioned benefits of storage through peak-shaving capabilities, which may be considered either a generation or transmission benefit, storage is also effective for power quality and regulation, integration of distributed and intermittent power resources, reserve capacity supply, local, regional and grid-level power back-up, and demand or supply management, amongst others. The following table (Table 2) summarizes a number of the services provided at each point of the traditionally defined electricity grid value chain [58,60].

Each of the above services represents potential market opportunities for generators, utilities, end-users, and other interests. Traditionally, many of these services have been provided through more conventional technologies, principally through generation-based technology [63]. Recent approaches include demand-side management and energy efficiency strategies, but these approaches, too, have limitations in terms of matching technology or strategy to service desired. For example, demand-side management strategies limit options to load leveling or peak shaving (by contracting consumers who agree to limit energy consumption during specific periods), but this option cannot also provide additional grid support services such as back-up power, transmission congestion relief, and system upgrade deferrals. Energy storage options provide applications and services that match technologies to needs. Already, several reports indicate the technical and economic benefits that storage has over conventional technologies, particularly in ancillary service markets [61,63].

Another key benefit of the new storage asset class is that more revenue leads to more investment. Because energy storage is no longer

[3] DNV KEMA Energy & Sustainability is a global, leading authority in business and technical consultancy, testing, inspections & certification, risk management, and verification, along the energy value-chain (⟨http://www.dnvkema.com/about/⟩).

Table 2
Storage Services by Application.

Generation	Transmission & Generation	End-User	Grid Support
Peak-shaving	Peak Capacity Support	Back-up Power	Voltage Support
Capacity Deferral	Peak-shaving	Demand Management	Frequency Regulation
Reserve Capacity	Congestion Relief	Price Arbitrage	Energy Balancing
Distributed & Intermittent Source Integration	Upgrade Deferral		Resource Adequacy

restricted to supplementing other asset classes, it can derive revenue from the services it provides to each. Furthermore, storage operators are free to dispatch their systems according to the highest-valued use, thus generating a higher return on their systems than they would as a supplementary asset. Storage derives its greatest returns through its ability to provide multiple services for all currently existing asset classifications [56]. This creates a natural (rather than subsidy-based) incentive for additional investment in storage. Of course, such investments require appropriate market and regulatory guidelines to be in place, and operators would need access to accurate, real-time price and demand information to dispatch their systems in the most efficient manner.

Regulatory, economic and other challenges that inhibit further development and deployment of energy storage in the power grid can best be surmounted through the classification of storage as a distinct asset. The marketplace would be sufficiently receptive and responsive for storage to realize its most efficient value. The support for appropriate regulations and incentives for storage would also attract investments in energy storage systems.

3.2. Asset class position and role of energy storage within the smart grid

As utility networks are transformed into smart grids, interest in energy storage systems is increasing within the context of aging generation assets, heightening renewable energy penetration, and more distributed sources of generation [64]. Along with this growing interest, smart grids are developing to effectively and intelligently integrate the functions of various asset classes to more efficiently deliver sustainable, secure, and economic electricity supplies [65]. These systems become mutually beneficial. For example, storage systems require the information advantages of the smart grid to realize their full potential. Smart meters and real-time access to demand, supply, power quality, and price levels provide the signals that incentivize the use of storage across various points of the power supply chain.

Therefore, placing the energy storage asset class at the nexus of the electricity value chain would emphasize the role that energy storage technologies are able to play in the implementation of smart grid systems. The conceptualization of placing an explicitly defined energy storage as a distinct asset class in a central role to generation, transmission, distribution and end-user segments of the electric grid system is illustrated in Fig. 4. The bi-directional arrows indicate a bi-directional flow of information. With energy and information flow directly to the energy storage asset class, storage can respond more effectively to the needs of the grid.

The following sections provide examples of how the classification of energy storage as a separate asset class within the smart grid improves the performance of both.

3.3. Benefits of energy storage in the smart grid

Just as smart grids are essential in increasing the implementation of ESS, so is ESS complementary in meeting the goals of an efficient smart grid. The proposed benefits of smart grids to utility companies and the electricity system as a whole include improved reliability with less costly interruptions, deferred capital spending on costly transmission and generation assets, and increased efficiency of power delivery due to lower distribution losses [59]. Energy storage meets these benefits by negating the need for extra peaking generation through load leveling, deferring the transmission and distribution upgrades needed to meet load growth with a smaller sized energy storage investment, reducing transmission congestion fees in deregulated markets by adding energy storage to distribution substations, and providing the load following capabilities that will help improve the intermittency of renewable energy sources [66]. Electric energy storage as a key enabler and enhancer of dispatchability of renewables; provides options to offset the mismatch between demand and supply and to operate the distribution system in a more efficient, economic, and environmentally sound manner [11,32,38,52,67]. Lastly, with smart grid technologies and energy storage in place, benefits to residential consumers will include cost savings from peak load management, energy efficiency, and increasingly affordable distributed renewable energy systems [59]. On the other hand, smart grid in turn also provides opportunities for load control and dispatch of storage units making renewable sources such as solar PV and wind more valuable to the grid.

3.4. Benefits of the smart grid to energy storage

The availability of utility information through the smart grid facilitates achieving the maximum benefit in the operation of an ESS [64]. Heightened visibility enhances price forecasting techniques, ultimately optimizing gains in short term energy markets through arbitrage [67]. Currently, grid operators would use strategies, such as back-casting (using historical data to predict economically desirable deployment schedules) to apply energy storage. This strategy does not completely capture arbitrage value due to near time weather and usage variations (only 85%) [67]. Real time information exchanges allows for a more responsive grid, achieving near perfect forecasting. Maximizing these gains increases both return on investment for ESS and competitiveness with other energy systems. [67]

One of the advantages of the smart grid is that it allows for a wider array of technologies. Fast response storage technology, such as flywheels, can respond to intermittency issues, improving the overall reliability and power quality of the grid. Additional information can also lead to increasing storage deployment, ultimately reducing the standby efficiency losses.

Likewise, as the proportion of low voltage, feed-in renewable energy generators grow, grid complications in supply and demand will increase, potentially damaging electronic equipment and causing power outages [32]. Smart grid coupled with energy storage systems increases demand elasticity while also disconnecting the simultaneity of production and consumption. Together, these services balance supply and demand while allowing a continual increase of renewables on the grid. [32]

Although ESS can provide these various grid services along with others noted in Table 2, it is unrealistic that ESS can deliver every potential benefit at all times. The smart grid, however, can facilitate the delivery of the most needed technical benefit to the grid, co-optimizing between revenue streams such as arbitrage and ancillary markets [67]. Ultimately, the integration of ESS into a smart grid expands the exchange of both information and services between asset classes, ultimately optimizing usage and value of ESS.

Placing the energy storage asset class at the nexus of the value chain emphasizes the role that energy storage technologies are able to play in the implementation of smart grid systems and vice versa. However, the

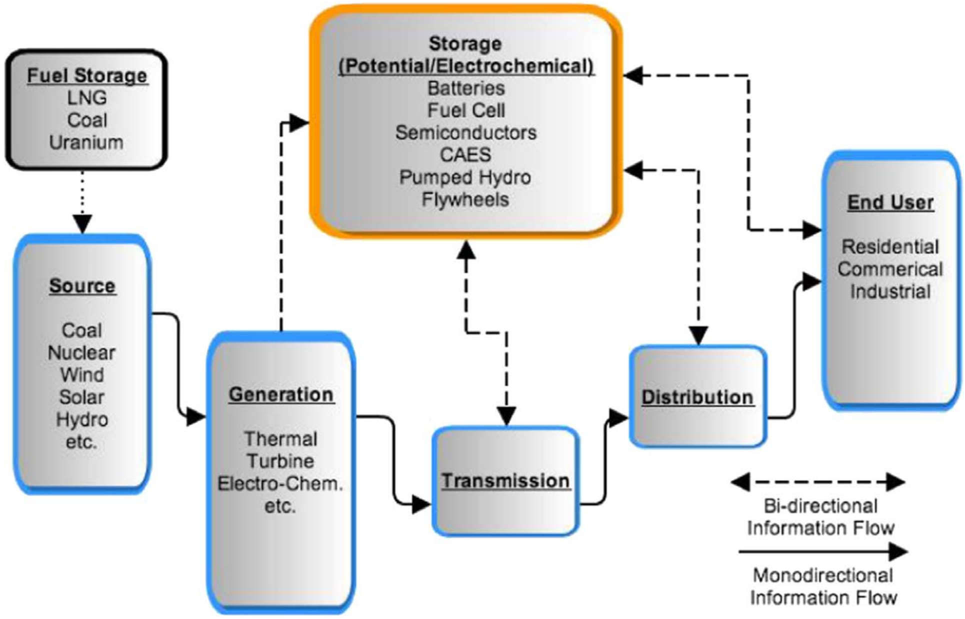

Fig. 4. Information Flow in an Energy Storage-based Smart Grid.

current capacity of energy storage on the grid is wholly inadequate. In order for it to reach sufficient capacity to support smart grid operation, energy storage systems require policies that will enhance their deployment in the near term. We therefore explore and recommend policies with the most potential at facilitating the transition to a storage-based smart grid.

4. Policy recommendations

4.1. Research, development and demonstration (RD & D)

Continued research and development of new energy storage technologies, as well as larger scale applications of existing energy storage technologies, is crucial for promoting the increased development of energy storage within a smart grid framework. Many advanced energy storage technologies are in a pre-commercialized stage, and thus the costs of energy storage devices are expected to decrease in the future [68]. RD & D reduces the relatively high capital costs of energy storage technologies, enhances the possible revenue streams of energy storage technologies through increased applications in ancillary services markets, and helps to show the viability of advanced and next-generation energy storage technologies. Research and development funding for energy storage includes such diverse areas as the pilot projects for emerging energy storage technologies, for the continued scale up in physical storage capacity of existing energy storage technologies, and improving technical capabilities of existing technologies with new designs and materials.

Technology risks are a critical barrier to the deployment of energy storage technologies, and numerous technically feasible energy storage technologies have seen delayed deployment because developers are reluctant to be the first to undertake projects with new systems [54]. Pilot and demonstration projects are especially critical in order to show the viability of newer technologies, and successful demonstrations reduce the risk of investing in these technologies and help in securing private investor funding for large-scale energy storage systems. Examples of technologies that have shown to be technologically feasible through small-scale demonstration projects include compressed air energy storage (CAES), flywheels, and battery technologies such as sodium-sulfur (NaS) batteries, lithium ion batteries, and liquid electrolyte low batteries such as vanadium redox batteries [54]. Typically, energy storage technologies tend to follow this pattern of deployment beginning with government-backed demonstration projects followed by utility and independent investment in larger installations should the pilot prove successful [54]. Although many emerging energy storage technologies exhibit this progressively scaled schedule, there are current existing limits to their physical storage capacity that prevent their application for larger scale energy management operations that are typically reserved for technologies such as pumped hydro storage and single-cycle natural gas-fired power plants.

On the technical side, the most immediate requirements are financing research to improve performance of the most market-ready or highest-valued storage systems. According to a United States Department of Energy (DOE) report that conducted an electricity market analysis for emerging energy storage applications such as flywheels and NaS batteries, current RD & D efforts for energy storage should focus on improving round-trip efficiency and reducing capital costs [62]. For instance, the current energy-limited nature of flywheels, or short dispatch time, limits the amount of time they can provide ancillary services such as regulation services and receive regulation revenues [62]. Increased research and development into improving the technical characteristics of existing and emerging technologies will allow them to play a greater role when improved ancillary service markets are created.

4.2. Investment tax credit

Implementing short-term policies addresses the high cost of capital associated with many energy storage options. Investment tax credits (ITCs) are an extremely effective method of reducing capital costs and limiting exposure to technological and capital risk. ITCs promote a more rapid increase in storage capacity for services such as frequency regulation. ITCs also enhance wide-spread deployment of technology by bolstering market demand and promote the cost-competitiveness of new technologies against conventional or established ones. Research has shown that with a possible 20% federal ITC for storage in the United States over a ten-year period, total capacity could triple compared to a scenario without the ITC [69]. In the same analysis, it was shown that within seven years nearly 2500 MW of new compressed air energy storage capacity is possible with 20% ITC as compared with only 700 MW without any ITC [69]. Furthermore, renewable energy markets have demonstrated the effectiveness of tax break incentives, including ITC regimes over the past years [70].

An effective ITC program promotes energy storage expansion in the short run while accelerating long-run capital cost reductions. A dynamic energy storage market characterized by stable supply and low costs is essential to reach the full potential of an effective smart grid as envisioned in this paper. Several aspects are important in designing an ITC program [70,71]. Among the most important design aspects are that ITCs have a long-term program horizon to prevent cyclical market volatility, are simple and clear for market investors, and have a predictable, gradual phase-out schedule. In addition, ensuring that high-quality and reliable equipment is deployed, ITC-eligibility should be predicated on a set of performance standards. An effective set of standards will reinforce technical reliability, bolster consumer confidence and smooth out supply volatility by ensuring manufacturing quality.

Production incentives are preferred from a policy standpoint because there are fewer opportunities for misuse of the credits, but, because energy storage does not produce power but rather energy services, such a policy tool is impractical. A different policy approach is therefore required to ensure energy storage has adequate influence in power markets.

4.3. Market formation and support for energy storage

As was previously discussed, a key barrier to widespread deployment of energy storage results from its traditional role in the conventional grid system. When deployed as a one-dimensional means of load balancing and peak shaving, the value of grid-level and distributed storage systems is limited to energy arbitrage: transferring energy produced during low-price, off-peak hours to hours of high demand and prices. This severely circumscribes the full value of the services that different types of energy storage technologies provide. With the rise of deregulated markets, significant opportunities exist to expand markets to more fully and efficiently exploit energy storage services on the grid. This should further incentivize national regulatory entities or agencies such as the Federal Regulatory Commission (FERC) in the U.S. that regulates the transmission in the nation's interconnection regions to work towards developing and supporting new and existing markets that promote energy storage.

Deregulated electricity markets offer the best potential for developing storage services. For instance, in the U.S., a number of interconnection regions and independent service operators such as PJM (a regional transmission organization (RTO) that coordinates the movement of wholesale electricity in 13 States and the District of Columbia), and the New York Independent System Operator (NYISO) have already established vibrant ancillary services markets for services such as frequency regulation and voltage support [61,62]. For example, markets for frequency regulation in NYISO generated nearly $100 million in service payments, and as the price for regulation services has steadily risen so have incentives for growth in investments and increased deployment of storage technologies. Enhancing the value-generating potential of energy storage through expanding access to ancillary and other markets is a powerful mechanism for building a storage-based smart grid network.

In order to further this effort, agencies such the FERC should continue supporting the process of deregulation in energy and power markets. Furthermore, regulatory agencies, interconnection administrators, and utilities should take the necessary steps to ensure stable market development. Regulatory agencies can develop rules and protocol to monitor storage operations and evaluate cost-of-service rates that will enable owners of storage assets to secure revenue streams and access to capital for provision of ancillary storage services [63]. RTOs and utilities that participate in wholesale markets can enhance market participation and access to independent interests such as storage owners by creating interconnection standards and compensation schemes for distributed or small-scale storage units. This, in turn, furthers market competition.

Storing electricity is expensive, especially when compared against the cost of generating power with coal, gas, or other conventional resources. Deploying storage one-dimensionally – for peak-shaving and load balancing – limits its value and viability as a technology. Expanding markets for energy services that match energy storage applications is an appropriate mechanism to realize storage technologies' full value. The deregulation of utilities and energy markets and support for greater regulatory and market structure will enhance participation by storage owners and allow greater third-party and independent access to energy markets. Energy markets, too, will become more diversified in terms of the services available for exchange and eligible participants. Allowing storage to capture its full value in competitive markets may be among the most effective tools in promoting the development and deployment of storage technologies.

5. Conclusion

In conclusion, we reaffirm the proposition for the re-conceptualization of the traditional power grid model. The conventional model relies on upstream generators to forecast demand and operates based on these forecasts. This results in inefficient operation of the grid, with surplus loads being dumped while insufficient energy scenarios result in expensive courses of action to prevent more serious grid problems. This model is one of unidirectional energy and informational flows, with limited feedback systems to enhance operation. The emergence of smart grid technologies provides ample opportunity to improve grid operation by increasing the bi-directional flow of information between upstream and downstream parties. However, there are still limitations to this model, as all energy services rely primarily upon generation assets.

Energy storage technologies provide significant opportunities to further enhance the efficiency and operation of the grid. Its ability to provide application-specific energy services across different components of the grid make it uniquely suited to respond quickly and effectively to signals throughout the smart grid. Therefore, energy storage as a distinct asset class in a central role will increase the value of storage investments while enhancing the operation of the smart grid. To further this goal, storage requires policy support. RD & D policies would increase operational experience and reduce costs; investment tax credits will accelerate investment in storage projects; and continued market deregulation will augment revenue streams, enhances competition, and more accurately price storage services.

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