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Chapter 19

Business Models for Power System Flexibility: New Actors, New Roles, New Rules

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1 INTRODUCTION

The significant increase in the share of renewables in the generation mix poses a number of planning and operational challenges to power systems, raising the need for flexibility more than ever. At the same time, the emergence of innovative solutions is catalyzing the development of new, flexibility-enabling business models; adding activities to the existing supply chain. New actors, sparking innovation in software, hardware, and market design, are defining new roles. For example, aggregators are linking small-scale suppliers of flexibility to electricity markets. Likewise, consumers are not passive anymore, but instead are evolving into active participants: *prosumers*, with an active role in the supply side.

The key element in the emergence of new business models for power system flexibility is, unequivocally, technological change. The context of this evolution is, in most cases, a post-liberalization power system, characterized by unbundling of activities, with transmission and distribution operating as regulated monopolies, and competition being promoted in generation and retail. After several years of experience with reforms throughout the world, market power has been mitigated, efficiency has increased, but many firms still retain a dominant position. On the other hand, market mechanisms are well established now and relied upon. Wholesale and intraday markets are generally used to allocate and price electric energy. Ancillary services and capacity are also competitively procured.

Sioshansi (in chapter: What future for electric power sector?) explored current trends in power systems, including the rapid uptake of distributed generation and renewables, microgrids, storage, and so on. With the increase in the cost efficiency and the competitiveness of renewable resources, they become a

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more serious alternative to traditional power plants. However, the operational challenges derived from power system operation with intermittent resources require planners to actively incentivize the adaptability of systems to the challenge posed by stochastic variability.[1] The IEA (2014), for example, claims that integrating a significant share of renewables is dependent on an overall transformation that increases system flexibility and advocates for further development of market-based, short-term balancing mechanisms that create reliable price signals for it.

In addition, the rapid progress of information systems, the declining cost of computing, and the swift evolution of software are creating the conditions for smart grid solutions to become feasible. Coupled with progress achieved in areas like electricity storage, home automation, and electric vehicle development, synergies among energy sectors, such as transportation and heating, are also becoming viable.

In light of recent developments, this chapter reviews the evolution of operational flexibility issues and its associated business models, with a particular focus on short-term flexibility services and the role of emerging players. Long-term issues of market based capacity arrangements have been discussed in the chapter by Woodhouse.

Section 2 discusses the concept of flexibility and reviews the resources that can enable flexible operation of the power system. Section 3 reviews the issue of trading flexibility as a commodity and describes some of the challenges associated with contracting for flexibility services. Section 4 is about the emerging business models for flexibility services and the role of new players, followed by the chapter's conclusions.

2 FLEXIBILITY IN THE POWER SYSTEM

In recent years, the technical literature has coined the term "flexibility" in relation to the requirements of power systems to integrate intermittent resources. However, its definition remains vague and implies different meanings depending on the context. In this chapter, flexibility refers to the ability of power systems to utilize its resources to manage net load variation and generation outage, over various time horizons. *Net load* is defined as load minus supply from intermittent resources, such as wind and solar. As a commodity, flexibility has several dimensions, including capacity, duration, and ramp rate or lead time, for demand-side resources. Boscán and Poudineh (2015) distinguish between short-term flexibility, associated to real-time balancing of the grid, and long-term flexibility, which relates to the adequacy of generation capacity and investment.

1. The technically oriented reader is referred to Morales et al. (2014), who devote an entire book to the analysis of operational problems associated to the integration of renewables into electricity markets. Chapter five of their book studies flexibility, originating from different sources in the power system, as an alternative to deal with the stochastic nature of renewable sources of generation.

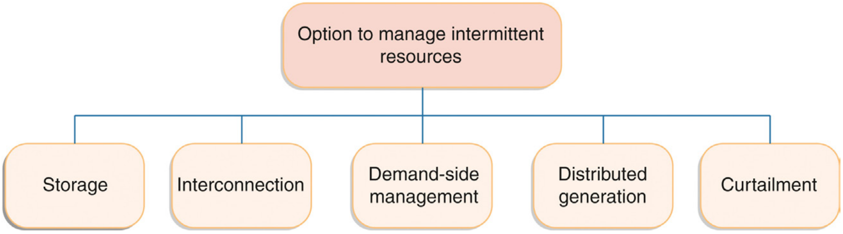

FIGURE 19.1 Options to manage variability of renewables.

It is also helpful to distinguish between *resource flexibility*, which refers to the built-in flexibility of a particular resource, such as demand response; and *system flexibility*, which comprehends transmission, network flexibility, and market design. The transmission network is not an additional source of flexibility per se, but the lack of an adequate transmission network severely affects power system flexibility.

2.1 Flexibility-Enabling Resources

There are various options available to manage the variability of intermittent resources. As shown in Fig. 19.1, these range from storage technologies, interconnections, demand-side management to distributed generation, and curtailment.

Electrical energy storage technologies are among the most effective ways of absorbing net load variability, and although there are various options available, not all of them are commercially viable. Fig. 19.2 (IEC, 2011) classifies existing technologies into five main categories: mechanical, electrochemical, chemical, electrical, and thermal. Of these, the most widely used form is mechanical: specifically, pumped hydro, which accounts for 99% of global energy

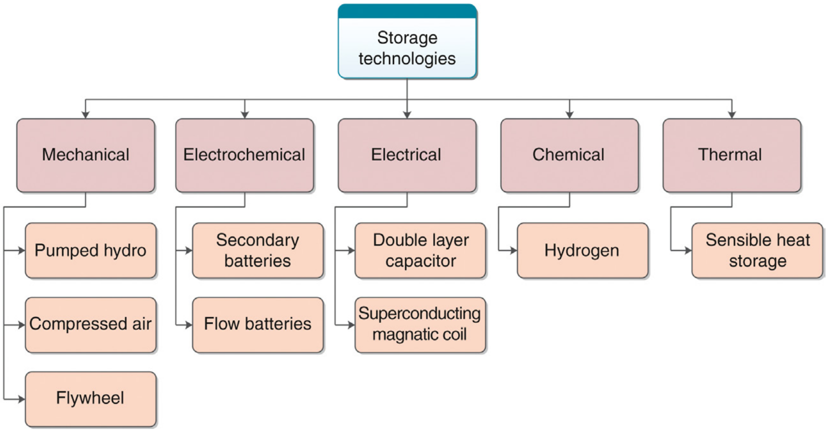

FIGURE 19.2 Storage technologies classification. *(Source: Authors, adapted from IEC (2011).)*

storage (127 GW of installed capacity). Given its unparalleled startup and ramp rate capability, it is a particularly attractive option to address variability from renewables. The second largest electrical energy storage in operation is compressed air but, compared to pumped hydro, it has a negligible global capacity (440 MW). Other means of storage, such as batteries, capacitors, or heat storage have very low penetration levels currently, but recent improvements in technology and cost of electrochemical batteries (particularly, lithium-ion) makes them a promising source of electrical storage, with various benefits to the power system, including flexibility. However, the key to the success of storage technologies is the viability of business models that allow the industry to move forward, beyond demonstration cases and toward massive penetration (Section 4.1.4).

The interconnectivity of power systems is a determinant factor in the extent to which power systems are flexible. In fact, not only interconnections have the potential to facilitate integration of variable generation, but also can contribute to energy security, decarbonization and affordability. In Europe, for example, where there is a strong interest to create an integrated, sustainable, and competitive energy market, there is a specific target to achieve 10% of interconnection (as a share of the installed production capacity) for each member state. Although the European interconnection capacity has increased considerably during the last decade, there remain member states that have less than the 10% goal, and are thus isolated from the internal electricity market (EC, 2015). Fig. 19.3 shows the countries with interconnection that is higher and lower than 10%. Countries such as the United Kingdom, Spain, Italy, and Ireland need to invest in their interconnection capacity. In contrast, Denmark, with a high penetration of wind power, has benefited significantly from the interconnection with countries such as Germany, besides the existing interconnections with Nord-Pool countries.[2] The EU third energy package clearly states the need for cross border interconnections, but for this to become a reality, it is required to design an efficient regulatory framework that incentivizes investment. The existing legal framework seems to favor a regulated business model for interconnection expansion, but it also allows for private merchant transmission initiatives.

Because of its suitability for relieving network congestion and providing ancillary services, such as fast and long-term reserve requirements, distributed generation, such as combined heat and power, is well positioned to increase power system flexibility (IEA, 2005). Traditionally, large conventional power plants served this purpose, and depending on their types, have been an effective source of flexibility. The most important requirements of flexible operation for conventional plants are startup time, ramp rate, and partial load efficiency (Boscán and Poudineh, 2015), but these are not fully available in all types of

2. Interestingly and widely cited by various media outlets, on Jul. 9, 2015, Denmark generated 140% of its electricity demand with wind power. However, Denmark managed the excess production by exporting to neighboring Norway, Sweden, and Germany. In relation to the relevance of interconnections, Green and Vasilakos (2012) perform an econometric analysis of Denmark's electricity exports and find that exporting on windy days is a cost-effective way to deal with intermittency.

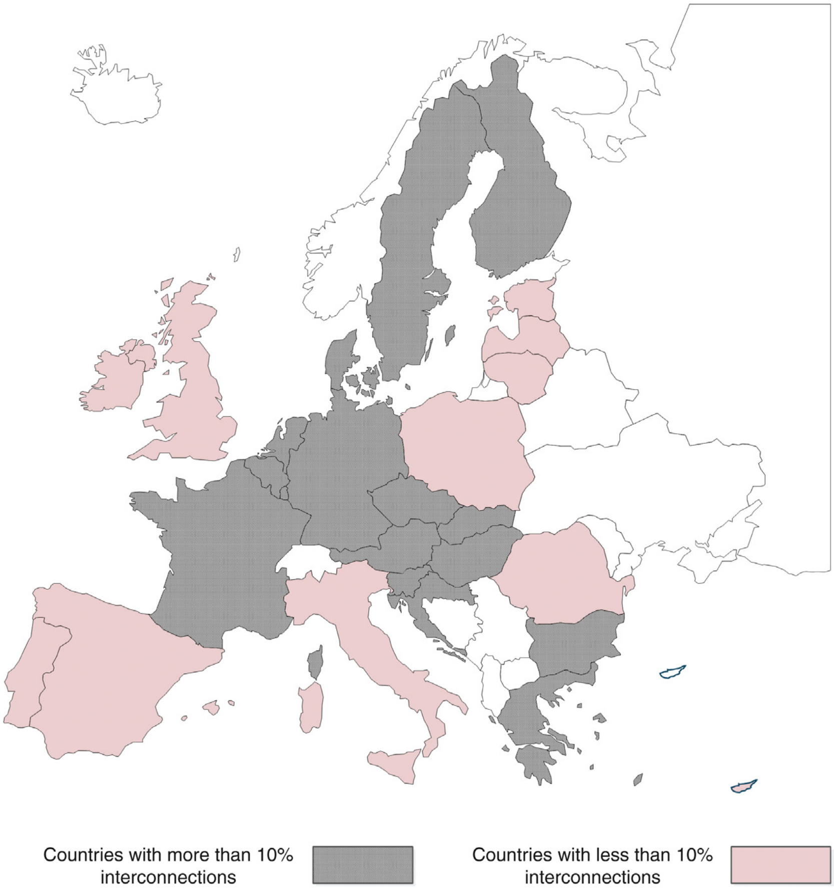

FIGURE 19.3 The European electricity interconnection as a share of total installed capacity in 2014. *(Source: Authors, based on the information from EC (2015).)*

conventional generation. For instance, cycling capability of most current coal power plants is limited and their ramp rate is generally low.[3] The same applies to nuclear power plants, with even more degrees of inflexibility. The most flexible types of thermal generation are gas fired power plants. However, cycling and ramping increase the wear and tear of plants, as well as their heat rate.

In recent years, the need for an efficient portfolio of flexibility resources has drawn attention to demand-side flexibility. In fact, with the advancement in information and communication technologies (ICT), many of the generation services can also be provided through demand response. In the United Kingdom, some forms of demand-side flexibility are currently being traded in the balancing market. For example, through National Grid's Frequency Control

3. Coal power plants, however, can be designed to operate flexibility.

Demand Management scheme, frequency response is provided through automatic interruption of contracted consumers, when the system frequency transgresses the low frequency relay setting on site. Furthermore, National Grid is utilizing slower responding demand response for load following services. Similar arrangements exist in other countries, as demand-side schemes gradually find their way into balancing markets.

Curtailment, a form of negative dispatch in which the system operator reduces the output of wind and solar generation to maintain stability, happens more frequently in the absence of sufficient flexibility. The issues that trigger curtailment are related to system balancing, system dynamics or grid constraints and, therefore the level of curtailment can be used as a negative metric for measuring power system flexibility. Although many countries with increasing shares of renewables have attempted to improve the flexibility of their systems, there remain some with high levels of curtailment. For example, China had an average curtailment rate of 18% in 2012 (Li, 2015), whereas this figure was 4% for the United States during the same period (NREL, 2014). As more renewables are integrated, these figures will rise, unless more flexibility is enabled. For example, the risk of overgeneration in the afternoon (low demand periods) is high in California, and this is likely to become even worse when the renewable portfolio requirement increases from 33% by 2020 to 50% by 2030, as currently proposed.

The use of flexibility services is not limited to addressing net load variation. Indeed, flexibility has three different functions in the power system, and three final users of flexibility services. An important role of flexibility is to ease the integration of intermittent resources. The transmission system operator (TSO), which is responsible for balancing the grid, is thus one of the main procurers of flexibility services. Another function of flexibility is to manage congestion in the electricity distribution network for which the distribution system operator (DSO) is the buyer of flexibility. The third usage of flexibility is for portfolio optimization. The market players (eg, aggregators, suppliers, balancing responsible parties) can obtain flexibility services to fulfill their energy obligations in a cost-efficient way by, for example, arbitraging between generation and demand response. Table 19.1 presents the parties involved in the procurement side of flexibility services in liberalized electricity markets. It is worth mentioning that although TSOs or DSOs procure flexibility services in a competitive manner, these companies recover their costs in a regulated fashion.

3 TRADING FLEXIBILITY SERVICES

The ability to trade flexibility services is important for the reliable operation of power systems. In the currently liberalized electricity sector, flexibility services are traded in intraday and day-ahead markets as an energy product, or in ancillary service markets, as control reserve products (Boscán and Poudineh, 2015). Market design has important implications for procuring flexibility in an efficient and reliable manner: even when there are sufficient resources available for managing

TABLE 19.1 Flexibility Service and Their Final Users

Party	Activity	Business model	Commodity	Use	Final objectives
TSO	Balancing the grid	Regulated business	System flexibility service	System-wide	Grid planning and operational efficiency maximization
DSO	Managing distribution grid	Regulated business	System flexibility service	Local, regional, or national	Grid planning and operational efficiency maximization
Market player	Trading electricity	Price set by market rules	Resource flexibility (portfolio optimization)	System-wide	Profit maximization

Source: Adapted from EDSO (2014).

variable generation, the market may not have been designed to incentivize efficient use of them. For example, in some US regions where there are no subhourly electricity markets, variations in the net load need to be met by regulation services, which have a high ramping rate, and thus are among the costliest flexibility services. This unnecessarily high cost results from the market design because it has been shown that variable generation requires does not require a faster ramping rate than the contingency reserves (Boscán and Poudineh, 2015).[4]

As the current electricity markets in many countries were not originally designed to manage a large share of intermittent resources, further penetration of variable generation might lead to increased market power, reduced competition, and reliability degradation (Ela et al., 2014). Additionally, it is not clear whether the current market design can provide a sufficient level of flexibility when the need for it increases in the system. In the US electricity market, several mechanisms are in place to incentivize flexibility, for example, centralized scheduling and pricing, 5-min settlements, ancillary service markets, make-whole payments, and day-ahead profit guarantees (Ela et al., 2014). However, a different design might be required to incentivize the right amount of flexibility resources both in the short run and the long run. Nontraditional resources such as demand response, storage, and even variable generation itself can contribute to system flexibility when the incentives are provided. Evidence from Great Britain's electricity market shows that, with more uptake of variable generation, the real-time price volatility increases

4. On Nov. 1, 2014, California ISO has introduced an energy imbalance market (EIM), mostly to allow grid operators of adjacent areas to share and economically dispatch a broad array of resources for efficient renewable integration.

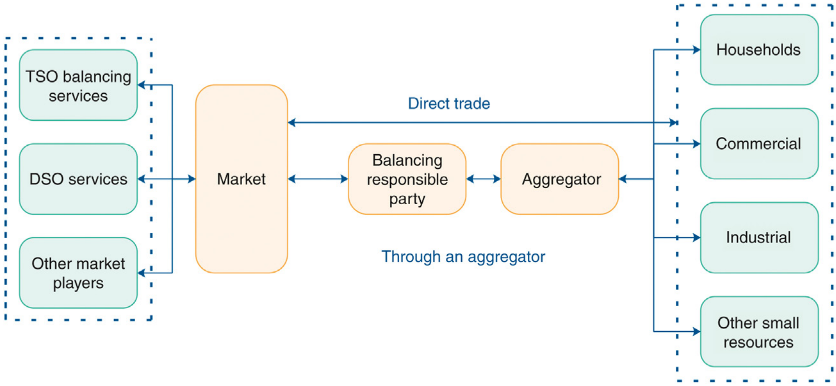

FIGURE 19.4 Trading demand-side flexibility services in the electricity market.

much faster than the day-ahead price volatility and flexible resources can take the advantages of this volatility (Pöyry, 2014).

Flexibility enabling contracts can be traded either directly between the final user and the resource provider or through an aggregator. The capacity of supply is an important factor for the way that trade can happen: transaction cost is an impediment for the small capacity resources to participate directly in the market. The small resource providers, such as households, can thus be aggregated and offered to the market through an intermediary. Fig. 19.4 presents the way that demand-side flexibility-enabling contracts can be traded in an electricity market.

3.1 Designing Contracts for Flexibility Services

Flexibility is a multidimensional commodity, and the marginal cost at each dimension is the private information of the resource provider. Therefore the procurer should design the contract in such a manner that informational rents are minimized, and the cost of integrating renewables is efficient. Designing optimal contracts for flexibility services under multidimensional information asymmetry is challenging, and becomes even more important when the cost of balancing services increases with an increased uptake of intermittent resources.

In bilateral contracts (between the resource providers and the final users or an aggregator), when the sellers differentiate themselves by concentrating on different dimensions, the procurer can design the contract in a way to extract all informational rents (Li et al., 2015). For example, consider a system operator who aims to control thermostats in two households' premises and for this she offers a contract based on two parameters of lead time and duration of load control.[5] Under the condition that the households are very similar, in terms of the disutility they experience at each dimension (lead time and duration of load control), there is no way for the system operator to design a truth-telling contract, which extracts

5. So the contract is in the form of a payment for specific lead time and duration.

all informational rents. In this case, the system operator needs to give up some rents by distorting downward the contract specifications (lead time and duration of load control) from the optimal level for one of the households. However, if the two households differ significantly at each dimension, the system operator can extract all the rents. This happens when, for example, the flexibility procurer knows that one household incurs a high disutility for the short lead time and the other for the long duration of load control. Naturally, the former household prefers a contract with higher lead time, but can sacrifice on load control duration, whereas the latter value more a contract which has a shorter load control duration. In this case, both households select a contract, which is optimal for them.

The previous results also hold when there are multiple flexibility resource providers. Therefore more differentiation across the dimensions of flexibility, by the resource providers, benefits the buyer, and vice versa. If the contract is designed (and offered) by flexibility resource provider rather than the system operator, the results are not necessarily symmetric to the previous case. For example, double marginalization[6] can happen although the supplier can change the specification of contract to avoid this. Additionally, when the resource provider enters into a contract with an aggregator who faces an uncertain demand for flexibility in the market, the optimal mechanism requires reducing the specification of contract at each dimensions, that is, it is optimal for the aggregator to buy less compared to the case of a deterministic demand.

An intermediary (for example, an aggregator) might face a demand for multiple flexibility products, with various specifications in terms of capacity, duration, response time, and ramp rate. This is because the impact of intermittent resources on the power system can be considered in four time frames: frequency regulation, load following, scheduling, and unit commitment (Boscán and Poudineh, 2015). Frequency regulation requires very speedy response and ramp rates, and thus is costly. The requirement for speed of response decreases, as the time frame moves toward load following and beyond. Therefore for each time frame a different flexibility service and, consequently, flexibility contracts are needed. In this case, the intermediary needs to make a decision between supplying all range of flexibility products, or only some of them. Theoretically, there is a fundamental trade-off in the intermediary's product selection decision in this case. This trade-off results from the market share of slower responding flexibility resources, versus the revenue obtained from more expensive flexibility services (eg, regulation services).

3.2 Next Generation Utilities and System Flexibility

As the traditional utility model is evolving, next generation utility concepts emerge as a result of rapid advancement in ICT. Demand response, electric vehicles, energy efficiency, and intelligent grid management, will have an evolved

6. Double marginalization happens when the two actors across the supply chain apply their own markups over the price, which results in higher deadweight losses.

TABLE 19.2 Next Generation Utility Concepts

	Traditional approach	Conventional wisdom now	Next generation concepts
Demand response	Emergency curtailment	Peak shaving	Resource for capacity and balancing service
Plug-in electric vehicles	R&D only	Flexible load	Vehicle-to-grid storage resource
Intermittent resources	Marginal fuel saving, no capacity value	Some capacity value with gas fired firming	Resource for capacity and balancing service
Grid automation and intelligence	Unidirectional from source to load	Some intelligence to automate loads	Omnidirectional web of sources and loads
Energy efficiency	Up to the customer	Component-based utility programs	Breakthrough-level system efficiencies

Source: Adapted from Hansen and Levine (2008).

function, as described in Table 19.2 (Hansen and Levine, 2008). For example, demand response, traditionally used for emergency curtailment to protect grid frequency under an emergency condition (load shedding), gradually enters the electricity markets as a capacity resource, as well as balancing service at all time frames. In the current electricity markets, the need for system flexibility may not be critical yet, but it is not clear that this will remain the case in the future, as long as renewables gain a greater share in the generation mix. Access to various sources of flexibility services, both on the supply and demand side, along with appropriate market design, provide an opportunity to profit from short-term spikes in spot prices, balancing markets and specific contracts with grid operators.

It is likely that next generation utilities will be more reliant on ICT, and they are already storming the industry with "smart," programmable, communicable gadgets, and "Internet of Things" (see the chapter by Cooper). Although ICT has always been important in the power sector, especially for system protection, with the need for more flexibility and a reliable real-time operation, the role of ICT becomes even more critical. Smart grid, smart meters, intelligent home management systems, and various forms of advanced technologies, will enable utilities to profit from trading flexibility services.

4 NEW BUSINESS MODELS

The electricity sector landscape is changing rapidly with the integration of renewables, technological advancement in ICT, and the emergence of various new players. Amidst this environment, entrants are coming to participate in electricity markets, but in completely novel ways. Decentralized generation units are beginning to compete with traditional generators. Aggregators, acting as intermediaries, acquire the right to modify energy consumption from end users, and sell it in the form of available capacity. Software and technology developers offer energy management solutions, intelligent devices, and storage capability. Ventures among these new players, teaming up to offer new services, are becoming more frequent, and the sum of it all depicts a creatively chaotic picture. Yet, these entrants share some common features: relative to incumbents that rely on traditional, large scale industrial assets, entrants have considerably lower fixed costs, and depend on nontraditional, knowledge-based assets.[7]

Taken together, they constitute a *layer of innovation* that is being added to the existing structure of power systems and challenges the traditional business model in which utilities enjoy a relatively undisputed position, and consumers act as the passive end of the supply chain. All of this contests the status quo, motivates incumbents to reconsider their roles and, potentially, adopt new ones in accordance with the changing environment. Regulators, in consequence, are being led to consider new, previously unforeseen sources of involvement and potential dispute among entrants and incumbents.

4.1 Partial Taxonomy of New Actors, New Roles, and New Business Models

The rapidly evolving nature of innovation and frequent function overlap prevents an exhaustive enumeration, and mutually exclusive categorization of agents involved.[8] To contribute in the understanding of business models leading to increased levels of power system flexibility, a simple, yet partial, categorization is proposed as follows:

1. *New actors* are the constituents of the innovation layer, composed of entrants sparking innovation through new software, technology, and market design proposals. Firms, researchers and, to a lesser extent, regulators can also be identified here.
2. *New roles* are defined by new actors, and are assumed by existing market participants and new actors alike. Aggregators and prosumers are two good examples of this category.
3. *Business models* are the commercial outcome of innovation brought about by the new actors. In a well-defined business model, the sources of revenue,

7. Rodgers (2003) identifies three categories of knowledge-based assets, namely *human assets*: attitudes, perceptions, and abilities of employees; *organizational*: intellectual property such as brands, copyrights, patents, and trademarks; *relational*: knowledge of and acquaintance with communities, competitors, customers, governments, and suppliers in which the company operates.

8. In a recent discussion paper by Ofgem (2015) on the topic of nontraditional, business models, they find the same difficulty.

cost and, therefore profitability, are unambiguously defined. Furthermore, business models are subject to evolution and depend on the overall economic environment: some will appear, consolidate, and evolve into new areas of action, while others will disappear, given their lack of viability (for more on this, see the chapter by Nillesen and Pollitt).

4.1.1 Aggregation for Demand-Side Management

Aggregation for demand-side management is one of the most consolidated existing business models for power system flexibility.[9] The role of aggregator, fulfilled by energy management software developers and other traditional retailers with real-time metering, is to bundle "negawatts" (unused capacity)[10] offered by commercial and industrial (C&I), and residential consumers of electricity. In exchange for capacity and energy usage payments or rebates in their electricity bill, consumers adjust consumption at times of peak demand, or when required by grid operators. Aggregators sell negawatts in different outlets, including capacity, balancing, and ancillary services markets, or as part of demand response programs carried out by utilities.

This business model has grown in several countries, including Europe and Asia, but has shown particular strength in the United States. As an example of its relevance, consider the 2014 capacity auction results for PJM, the largest wholesale electricity market in the United States: 10.9 GW of demand response capacity were procured, the equivalent to more than 6% of the total. Nevertheless, in the latest episode of a legal battle between power companies and aggregators, demand response in the United States has recently received a regulatory setback. The federal order that set demand response and generation on equal footing regarding payment received by grid operators was vacated last year, on the grounds that demand response is being overcompensated, inducing inefficient prices that discriminate against generators.[11] The final say, though, has not been declared yet: at the time of writing, the US Supreme Court of Justice has decided to reconsider the case.

From a more general perspective, though, the role of aggregation for demand-side management goes beyond conventional demand response. Aggregators typically rely on software solutions and other hardware to realize efficiency gains and, therefore they are shifting to developing integrated energy management solutions. As a result, some of them are rebranding themselves

9. The term "demand-side management" is used to encompass both participation of demand as a resource in markets, such in capacity markets; and in the conventional demand response sense, which includes interruptible loads, load management, peak shaving, and so on.

10. The term "negawatts" has been attributed to Amory Lovins, cofounder and Chief Scientist of the Rocky Mountain Institute, by a number of publications, including The Economist's special report on energy and technology (2015) and Maurer and Barroso (2011).

11. Order 745 issued by FERC (Mar. 15, 2011) on the topic of "Demand Response Compensation in Organized Wholesale Electricity Markets."

as software developers, while others are emphasizing the role of hardware as a tool for demand-side management, while retaining their role as aggregators. They are also entering agreements with utilities and grid operators to manage intermittency from renewables with demand-side resources, an element that emphasizes their growing role as a supplier of flexibility. For example, EnerNOC—a US-based aggregator known for its demand response operations who is refocusing its business toward software development—ran a pilot project with the Bonneville Power Administration to show the capabilities of demand response to deliver short-term balancing. Such new services from demand response are especially valuable, as the likelihood of overgeneration increases in places such as California. Also, as the role of distributed assets increases, aggregators will not only manage demand, but will make a transition into virtual power plant managers.

4.1.2 Thermostats as a Demand-Side Management Tool

Although thermostats are key for controlling energy consumption in residential and C&I buildings, they have rarely been a particularly interesting object of attention for retail consumers. With the majority of sales channeled through dealers offering service contracts, well-established products developed by long-standing incumbents have taken the lead.

Nevertheless, the usually undisrupted retail market for thermostats became invigorated once Nest Labs transformed this typically uninteresting device into an appealing gadget for tech-savvy consumers, through the development of user-adaptive technology, and a well-designed marketing strategy.

While the argument for significant product differentiation and technological breakthrough by the Nest thermostat is not easily argued for,[12] more significantly, their contribution has been to introduce innovative business models for flexibility, in which smart thermostats are the key element to enable demand-side management.

According to these business models, smart thermostat users are given the choice to surrender control of their load at peak demand hours or when there are seasonal weather variations, and allow the utility to adjust consumption, following user-defined comfort levels. In exchange, utilities compensate consumers with rebates on their final bill, or through direct payments. Not only have other smart thermostat developers followed suit, but utilities have also created *bring-your-own-thermostat* demand-side management programs. Moreover, nontraditional demand response services (increasing consumption as opposed to reduce demand) are also becoming increasingly important. These forms of demand-side management can be particularly relevant for places with overgeneration, like California, Texas, Denmark, and Germany.

12. Ecobee, a Canadian competitor to Google-owned Nest Labs, introduced the first WiFi connected thermostat at least 2 years before the Nest thermostat hit the market.

Looking forward, there is ample room for these business models to develop further, as the penetration of programmable thermostats still remains very low.[13] The upfront cost of deployment, though, is a barrier for many customers. As a solution, and in a similar vein to business models in the telecommunications industry where service carriers and hardware providers team up, utility companies are subsidizing the deployment of smart thermostats. In summary, thermostat-based demand-side management is setting new standards in the adoption of new technology and in the development of demand-side management models that could easily extend to other devices.

4.1.3 Software Developers

The emerging business models for power system flexibility are closely intertwined to smart grid development. Coupled with hardware, software is pervasive across processes and solutions. Remotely controlling devices, smart metering, and identifying consumption patterns to reduce demand charges, are just some of the many examples that highlight the role of software (for more details, see the chapter by Cooper).

In some models, software is bundled with hardware as part of the complete solution. For example, on-site energy storage vendor Stem describes its system as composed of three elements: software, batteries and a real-time meter. Others focus on software development and work with any kind of hardware. Such is the case of software vendor BuildingIQ, specializing on demand-side management for heating, ventilation, and air conditioning systems in C&I buildings.

More generally, and as part of an emerging trend, many agents currently developing new business models for power system flexibility are expanding their role into *software-as-a-service* suppliers. This licensing and delivery model has consolidated in recent years among software developers, because it allows end users to reduce hardware, upfront, and maintenance costs, and has enabled scalable usage and payment. On the other hand, vendors obtain a recurring revenue stream from subscription payments. Firms like EnerNOC, a leading aggregator, are following this trend as a growth strategy, and are also creating interactions with other existing business models. In summary, software is already playing a central role in the new business models for power system flexibility, and its relevance will only continue to grow.

4.1.4 Storage Providers

Location within the supply chain largely defines the scale, response time, size and, therefore suitability of different storage solutions to increase flexibility

13. Consider, for example, the American market, where (according to the US Energy Information), 85% of American homes with central heating own thermostats, but less than half of these are programmable. Similarly, 60% of those with central cooling own them, but approximately a half of these are programmable.

in the power system. Although not fully consolidated,[14] recent years have witnessed a considerable expansion of electricity storage business models, with greater emphasis on *behind-the-meter* (distributed) than in *front-of-the-meter* (grid-level) solutions. A report by the firm GTM Research (2015), sponsored by the US Energy Storage Association, reveals that distributed storage deployments increased more than threefold between 2013 and 2014 in the United States, and the nonresidential sector accounted for the lion's share of this amount. They expect the distributed storage segment to continue growing in years to come, outpacing grid-level storage, until it reaches 45% of the total market share by 2019.

Distributed storage targeted at C&I, large residential, and institutional consumers is one of these models. In most markets, these clients pay for the energy they consume, plus a share of their peak demand within a billing period. Coupled with software analytics and real-time metering to analyze *peak-shaving* opportunities, suppliers offer on-site storage systems to go off-grid when demand is high. Typical agreements between storage suppliers and their customers are based on revenue sharing, but initial investments, operational and price risk are assumed by suppliers.

The economic case for residential energy storage is different and, given current conditions in most retail markets, difficult to make. To begin with, most residential customers have fixed price retail contracts and, therefore price arbitrage and peak shaving become mostly irrelevant. Furthermore, in markets where residential solar PV systems are becoming widely adopted, it is sensible to acquire storage if customers wish to become entirely independent of the grid. Yet not only are such green energy oriented customers a well-off minority, but net metering—an incentive that is particularly relevant in many US states—is at odds with it: being completely off grid would imply cutting off a source of revenue that helps to pay the cost of the solar facility investment. Unless the cost of residential storage is competitive enough, or there is an economic incentive to install it, this business model is not viable.

However, distributed energy storage is one of the most effective resources to enable power system flexibility, as it can balance power supply and demand instantaneously. The aggregated deployment of storage capability creates virtual power plants that, depending on market design innovations at the distribution level, may create sources of revenue for owners of this kind of resources. Grid operators interested in the procurement of capacity, reactive power, and voltage management might well provide the necessary source of revenue to further boost the adoption of distributed storage, including residential applications. In fact, following the recent introduction of Tesla Motor's batteries for C&I and residential applications, at an approximate price of $500/kWh, its partner company Solar City clarified that the 10-year lease agreements for solar and storage systems, with which they typically operate, contemplated revenue sharing of grid service income.

14. Energy storage, mostly pumped hydro, accounts for 2% of total US generation capacity.

4.1.5 Market Design Innovation

Driven by technology, the new business models are already transforming the way in which power systems operate. However, given the crucial role of incentives, market design and regulation can either hinder or help their consolidation and evolution as a tool to increase flexibility.

Regulators and system operators in areas where renewables are on the way to playing a more relevant role are considering different market design innovations. Many of these, though, still appear to have a piecemeal and tentative approach. Some of them prioritize the role of short-term balancing, whereas others emphasize the role of demand-side management, and long-term resource adequacy. While there is no one-size-fits-all solution, restructuring existing electricity market designs to enable flexibility requires a holistic approach. Hogan (2014) argues that adapting existing markets to renewables requires, first, recognizing the value of energy efficiency, including demand-side management; second, upgrading grid operations to increase short-term flexibility; and third, incentivizing long-term flexibility investments, that is, adopting flexible resources.

An interesting example comes from the California Independent System Operator (CAISO) which is currently developing a *flexible ramping product,* aimed at minimizing short-term (5-min to 5-min) load variations. In contrast to conventional ancillary services, this product focuses on addressing net load changes between time intervals, and not on standby capacity aimed at meeting demand deviations within a time period. In addition, an innovative feature of this proposal is that it is continuously procured and dispatched.

Another interesting experience is Southern California Edison's recent capacity procurement of 2.2 GW of behind-the-meter solar PV generation, storage, and demand-side management to alleviate congestion in particular zones of the grid. Besides being a complex process because of the necessary cross-comparisons between technologies, location of assets, and the diverse nature of contracts with suppliers, it reveals emerging business models in which generation and distributed energy resources are treated on a par with conventional generation. Of particular interest is the agreement with distributed solar generation company Sun-Power which assumes and enhances the role of aggregator. Upon requirement of the utility, the aggregator commits to achieving savings through solar power, which it procures at specific sites from generation facilities scattered throughout different grid locations—a Virtual Power Plant—without exporting it to the grid.

Also, in the context of a comprehensive review of their power system, the single electricity market for Ireland has decided on a number of measures aimed at adapting it to the 2020 goal of 40% of renewables in Irish electricity demand. On the market design front, relying on a hybrid regulated tariff/auction mechanism to procure contracts with maturities from 1 to 15 years, it has been agreed to increase the number of ancillary services procured from 7 to 14, including specific ramping products with horizons of up to 8 h.

To sum up, market design innovation is already playing a key role and it will have a substantial impact on the consolidation of emerging business models.

4.2 New Business Models and the Future of Utilities

The absence of large-scale economically viable storage, and an entirely passive demand-side have justified the existence of the traditional power system business model, but technological breakthrough has begun to challenge this approach. From this follows a central question for the future, namely: *what is the impact of new business models on existing utilities?*

The immediate consequence is that the business-as-usual operation of utilities is challenged, but the extent of the impact depends on the strategic decisions that both incumbents and entrants make. Incumbents can choose a confrontational approach to deter consolidation of the emerging business models, or can accommodate to entry (see the chapter by Burger and Weinmann).

Evidence shows that confrontation is already happening. The extended legal battle between power producers and aggregators in the US over Federal Order 745 mandating equal treatment between demand response and conventional generators in wholesale markets is an example of this. In France, a similar conflict over imbalance mechanisms arose between retailers and aggregator Voltalis.

Nonetheless, the line between confrontation and adaptation is not clearly delineated, because several incumbents are extending their activities into new business models. Big players, including large vertically integrated energy holdings, are entering the aggregation business, and are acquiring stakes in energy management developments, effectively extending their scope. For example, NRG, which owns 50 GW of fossil-fuel dominated generation assets in the United States, acquired Energy Curtailment Specialists in 2013, a leading US aggregator with a portfolio of 2 GW. In France, Schneider Electric acquired leading European aggregator Energy Pool in 2010, which controls more than 1.5 GW in demand response assets. Also, Swiss generator Alpiq, which owns a generation portfolio of 6 GW including hydro, fossil, and nuclear, acquired British aggregator Flexitricity in 2014.

Entrants, on the other hand, are partnering in their offers, bundling products in markets that show potential first-mover advantages. For example, Tesla and Advanced Microgrid Solutions (AMS) have recently announced a sales deal to install up to 500 MWh in battery capacity, as part of a grid-scale storage project. EnerNOC and Tesla have also announced a partnership to bundle batteries with software solutions to enable demand-side management. Google's acquisition of Nest Labs in 2014 for US$3.2 billion is yet another indication of the rapidly changing face of the new business models.

The future will depend, mostly, on these strategic interactions, and while it is impossible to predict the future, one thing is certain: utilities as we know them today will definitely change. Table 19.3 summarizes the emerging players and associated new business models for the flexible power systems of future.

TABLE 19.3 Summary of New Business Models for Power System Flexibility

Business model	Characteristics of the agreements
Aggregation for demand-side management	• Consumers obtain capacity and/or energy usage payments • Negawatts are sold in organized markets or as part of bilateral agreements with utilities
Thermostats as a demand-side management tool	• Consumers acquire the device with a subsidy from utility • Consumers enter direct-load control agreements, allowing load to be adjusted to predefined comfort settings • Consumers are given rebates or paid for energy not consumed • Utility manages peak load with higher cost efficiency • Hardware sales increase
Storage (C&I clients)	• Consumers pay no upfront cost for software or hardware deployment. Alternatively, supplier delays deployment costs until first revenue streams are realized • Revenue from demand charge reduction is shared between consumer and supplier
Storage (residential)	• Upfront deployment cost is borne by households • Consumers benefit from going off-grid, price arbitrage, or grid service payments
Market design innovation	• Utilities procuring services through a number of bilateral contracts with suppliers of flexibility • New ancillary services • New short-term services focused on short-term balancing
Software	• Software-as-a-service • Vendors collect subscription fees • End users reduce hardware, upfront and maintenance costs

5 CONCLUSIONS

Integrating renewables efficiently requires increasing flexibility and technological progress is facilitating this process. Over the last few decades, technology has pushed the operational boundary of utilities away from a traditional paradigm, but the changes happening now are paving the way for a next generation of utilities. According to this emerging paradigm, new actors sparking innovation are defining new roles and, as a result, interconnectors, distributed generators, storage providers, and suppliers of demand response are competing with incumbents, while relying on the novelty of their business models to provide flexibility services. Meanwhile, the interaction of regulation, technological innovation, and business model evolution are shaping the strategic interaction among players, who have several pieces of private information. Markets, contracts, and regulatory frameworks will have to change to become more compatible with the requirements of the new environment.

These trends provide a sense of the forces shaping the emergence of a completely new state of affairs in which existing utilities will have evolved, and will coexist with new players in the provision of flexibility. The final shape of power systems will not be unique, as it is path-dependent due to the effects of technological, financial, and institutional legacies. What is certain is that the change is inevitable, and utilities as are known today will definitely change. In the new environment, the opportunities for utilizing competition among the suppliers of flexibility increase. In conclusion, as flexibility becomes scarce in the system, innovative flexibility-enabling business models initiated by new actors will be highly valuable and critical for the efficient provision of flexibility services.

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