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Energy Flexibility For Dummies

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by Rich Hampshire

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Project Manager and Development Editor: Chad R. Sievers

Executive Editor: Katie Mohr

Editorial Manager: Rev Mengle

Business Development Representative: Felicity Whyte

Dummies Marketing: Jennifer Webb

Production Editor: Siddique Shaik

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Introduction

Welcome to *Energy Flexibility For Dummies*, your essential pocket (well if you have big pockets!) guide to flexibility in the electricity system, where it comes from today and where it's likely to come from in the future as the electricity system decarbonises between now and 2050. This book's focus is firmly on flexibility in the electricity system.

About This Book

If you've bothered to start reading this book, the chances are that you're already in the energy sector. More than likely, you've heard terms like smart power, energy flexibility, whole system and even transactive energy being increasingly used by people around the office and you want to understand more.

This book helps you understand where these terms have come from and why they're becoming increasingly important. As well as discussing what flexibility is, it looks at the associated commercial models and the major players.

Foolish Assumptions

I've made a few assumptions in writing this book that are worth stating up-front:

- You probably work in the British utilities sector or are associated with it in some way. That at least gives you a head start in deciphering the plethora of acronyms used in this industry, and you know the same acronym can be used for different things! If not, take a look at *GB Electricity Industry For Dummies,* CGI Special Edition.
- You're looking to improve your understanding of the background to why flexibility is important rather than definitive answers, because you won't find those here.

Anyone who tells you that he or she has the answer no doubt is giving you his or her opinion.

- Between drafting this book, it being printed and you finding time to read it, there haven't been any major changes to the political or regulatory environment in Britain, such as, say, a vote to leave the EU.

Icons Used in This Book

To make navigation to particular information easier, icons guide you to highlight key text. The icons used are as follows:

REMEMBER These are important points to keep in mind.

TIP This icon alerts you to information that can help you do or understand something.

TECHNICAL STUFF This icon flags some of the more advanced bits that can help you understand what something means in practice.

WARNING! Take head; you need to consider something risky with this icon.

Where to Go from Here

Like all *For Dummies* books, you can read sequentially from cover to cover, or you can jump in, out and around, depending on your preference. In an attempt to avoid repetition, some parts of the book reference other parts where there may be more detail on a particular area.

If the book piques your interest and you want to know more, feel free to visit `www.cgi-group.co.uk/utilities` (where you can also find access to the other *For Dummies* books that CGI has worked on).This book represents a position at a point in time, and flexibility is an area that's moving fast. To stay up to speed, keep an eye on some of the sources, especially those in Chapter 5.

Chapter 1

The Background to Energy Flexibility

In This Chapter

- Grasping why flexibility in the energy systems is essential
- Looking at capacity margins
- Comprehending energy storage

Flexibility in Britain's electricity system plays a vital role in helping to keep the lights on. It enables the system operator (more formally referred to as the National Electricity Transmission System Operator, NETSO, a division of National Grid) to keep Britain's electricity system in balance by ensuring that there's sufficient supply of electricity (from power stations, wind farms and other sources of electricity generation) to meet the demand from consumers. (For this book, I refer to the NETSO as the *system operator*.)

When big events such as football finals or the hyped climaxes of major story lines in people's favourite soap operas are on TV, the news often features reports from National Grid's control room. The news broadcast focuses on what happens to make sure that people's TVs, all the radio masts that transmit the digital broadcast signals, the kettles for that halftime cuppa, the fridges that are opened to get the milk out and then opened again to put it back, as well as all the other things that are consuming electricity at that time have sufficient energy!

For example, the system operator forecasted a 0.9GW increase in demand at full time of the England versus the Wales football match in the 2016 European Football Championship. The actual demand increase, often known as *TV Pick-Up,* was

1.1GW, which shows that, however good the system operator is at forecasting, it needs to be ready to respond to what actually happens.

This chapter examines on a closer level why energy flexibility is important and identifies where flexibility comes from.

Understanding the Importance of Energy Flexibility

When someone flicks a light switch, he or she has an expectation that the light will come on. But think about all the switches that are being flicked, either on or off, every day in 30 million homes and businesses across Britain. The energy to make those lights shine has to come from somewhere.

But it's not just about ensuring that there's sufficient electricity available – it's about making sure that it's the right quality and that it's at the right frequency. When demand starts to increase, the frequency starts to reduce (think about how your broadband speed drops at peak times and that annoying cycling thing comes up on your screen – it's a similar sort of thing), unless the supply of electricity increases too.

REMEMBER

Today, much of the flexibility used to ensure that supply and demand are in balance comes from the nature of the generation mix. The *generation mix* refers to the different types of power stations, wind farms, solar arrays and any other forms of electricity generation that are attached to the electricity transmission system and are either producing electricity, standing ready to produce electricity or not producing electricity when they were expected to be. (Refer to Chapter 2 for more information.) As demand grows, more generation is brought on line or taken off line as demand reduces.

Flexibility can also be provided through the opportunity to import energy from the European mainland via interconnectors – the big cables that link Britain to countries such as France, The Netherlands and the Republic of Ireland.

Although Britain's energy demand varies depending on the time of day, the time of year and the weather, to a large degree it's predictable within certain margins. The folks at the system operator spend a lot of time and effort in projecting what the demand is likely to be and ensuring that there is sufficient generation (also referred to as *supply capacity*) to meet that demand and ensure that some extra capacity is available (also known as the *capacity margin*), just in case.

Addressing Capacity Margins

The requirement for a capacity margin historically used to be 15 per cent, but in recent years that margin has reduced considerably, at times being forecast to be below 5 per cent.

By reducing the required capacity margin, the need to have lots of power stations sitting around not generating electricity for most of the year is also reduced. These extra power stations that are there *just in case* they're needed would make their cost of generation very high because the capital investment in these power stations still needs to be recovered – just over a much smaller amount of electricity produced.

REMEMBER

Over the last few winters, National Grid has issued an increasing number of *NISMs* (the utilities sector loves its acronyms – that's a *Notification of Insufficient Supply Margin*). The media love to portray the issuing of such notifications as being somewhere between an admission of failure and the end of the world. The truth is somewhat different. A NISM is a notification, not a warning, that the system operator issues when the demand for electricity has the potential to exceed the available supply capacity.

So, with reducing capacity margins available from the generation mix and *interconnection* (electricity interconnectors are the big, underwater wires that enable the transfer of electricity across borders and between markets; refer to Chapter 2 for more details), then where else can the system operator access the flexibility it needs to ensure the lights stay on?

The system operator has put in place contracts with a small number of major energy users to deal with these scenarios. The contracts enable the system operator to get these major energy users to reduce their demand for short periods, so enabling the system to be kept in balance. Chapter 3 discusses these options in greater detail.

So, the contracts to reduce demand provide a series of options for demand-side flexibility. The final option to provide flexibility is storage.

For the purpose of this book, I distinguish between grid-scale storage and demand-side storage. *Grid-scale storage* refers to storage connected to the transmission and distribution systems, whereas *demand-side storage* is part of demand-side flexibility because it's part of what happens beyond the meter.

Examining Energy Storage

For some reason, when storage is discussed, most people seem to start talking about batteries, but many other forms of energy storage are available. The use of battery technology is still nascent and the technologies are still maturing. Some other forms of energy storage are already well established.

For instance, Britain has been using the storage of potential energy through pumped storage schemes for many years, such as Dinorwig, Festiniog, Foyers and Cruachan, providing 2.8GW of generation when required, and using excess generation on the system to pump the water back to the reservoir when supply exceeds the demand. Refer to Chapter 2 for more detail on potential storage.

Some innovative hydro storage schemes have been proposed for geographies that don't benefit from hilly and mountainous terrain associated with more conventional pumped storage schemes.

Furthermore, the use of thermal storage is also well established for the provision of demand-side flexibility. From hot water cylinders to cold stores to air conditioned buildings, this type of storage provides a level of thermal inertia that can enable the electricity supply to be curtailed for a few minutes without having a noticeable effect on the temperature inside these buildings. (Flip to Chapter 2 for more information on thermal storage.)

Innovation in other forms of storage is also taking place. These developments include *grid-connected thermal storage* (for example, utilising excess energy to produce hydrogen) and *kinetic storage* (by using hi-tech fly wheels or utilising compressed air). Check out Chapter 2 for more about the different storage methods.

Although much of this discussion relates to the way the current energy system makes use of flexibility, the energy system is changing fundamentally. In order for Britain to meet its climate change obligations, electricity production needs to be pretty much decarbonised by 2050. Figure 1-1 illustrates the scale of the challenge, and why achieving 1990 carbon dioxide levels leads to decarbonisation of electricity generation. Some sectors, such as aviation, will be hard to decarbonise, which means that others have to go further – electricity being one of them.

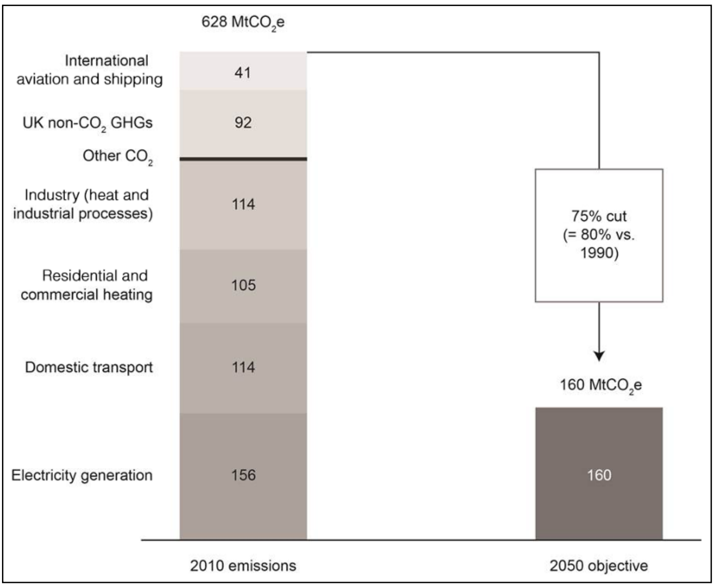


Figure 1-1: The Decarbonisation Challenge (based on Committee of Climate Change figures).

Doing so leads to a greater diversity of energy sources in the generation mix, many of which will change fundamentally the dynamics of the electricity system and the level of inertia in the system. But more than just the way that electricity demand is satisfied is changing, the nature of demand itself is changing too. Heat and transport are decarbonising through *electrification*. Then there's the growing adoption of demand-side generation and storage.

With both supply and demand changing, flexibility is projected to become increasingly important, with the significance of demand-side flexibility growing. The good news is that the progressive adoption of low carbon technologies on the demand side can provide the basis of demand-side flexibility. The many existing players in the electricity market, as well as innovative new players, have spotted the opportunity for new business models and new ways of designing and operating the energy system.

In an April 2016 survey, senior people from energy suppliers, from distribution network operators and from demand aggregators indicated that the level of flexibility in the electricity system needs to double by 2030.

Chapter 2

Recognising the Sources of Flexibility

In This Chapter

- Appreciating the different technologies that provide flexibility, today and in the future
- Considering storage options

Flexibility in the electricity system is crucial to keeping the system in balance. Why's that important? Simple, just like when you lose your balance, you fall over; when the electricity system goes out of balance, it also falls over – that is, the lights go out.

This chapter takes a look at the sources of flexibility, where flexibility will increasingly come from as the electricity system decarbonises and some of their associated pros and cons.

A diverse range of sources of flexibility is a good thing. No single source will provide the whole solution, but lots of sources provide resilience.

Generation Mix: The Dynamics of Power Stations

Britain has a lot of different types of power stations and generating plants connected to the transmission system (that's mainly the big metal transmission towers, which most people refer to as *pylons,* that you see when you're driving along most motorways). These different types of power station currently provide the main form of flexibility in the electricity system. Their characteristics, such as how quickly they can start generating or stop generating, enable the system operator to match supply to the consumers' demand.

Britain currently has around 70GW generation capacity connected to the transmission system in 2016. These power stations use fuels as varied as refined uranium, coal (mainly now imported), oil, gas, poo, wind and water. And these stations can run anywhere from constantly to just a few minutes per year to not at all. Those power stations that barely run still have to have their costs covered to ensure they are there if, or when, they're required to meet the demand for electricity. When they do run, the energy produced costs!

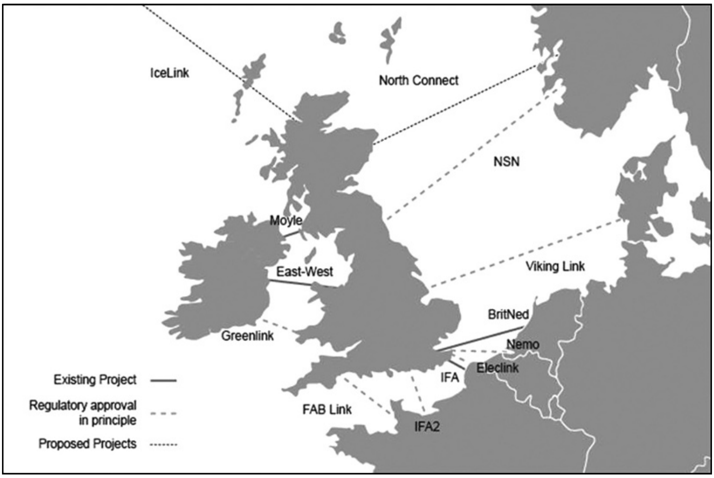
Interconnection: Trading Electricity between Markets

Interconnectors connect Britain's transmission system to the transmission systems of other countries. When demand for electricity in Britain is greater than the available supply capacity (or if electricity can be imported across an interconnector cheaper than running up another power station), then the interconnectors present an option for the system operator to keep the system in balance.

At the time that this book is being written, four electricity interconnectors serve Britain: France (2GW), the Netherlands (1.2GW), Northern Ireland (0.5GW) and the Republic of Ireland (0.5GW) provide around 5 per cent of Britain's supply capacity (see Figure 2-1). The combined capacity of the existing interconnectors is 3.75GW (the Moyle interconnector to Northern Ireland is currently only operating at half its capacity).

More interconnectors have been contracted, which could deliver a total of around 12.4GW, equivalent to more than 10 per cent of the supply capacity.

But interconnectors work in both directions, and when an excess of generation exists or when the price of energy on the European market is attractive, energy can be exported.



Source: www.gov.uk/government/uploads/system/uploads/attachment_data/file/505218/IC_Energy_Report_web.pdf

Figure 2-1: GB interconnection.

When energy costs via the interconnectors are low, it helps to keep energy bills lower by importing the cheaper energy. But when Britain's European neighbours' demand exceeds their supply capacity, prices rise. This price increase makes it attractive to reverse the direction of energy flow on the interconnectors, thus increasing the costs in Britain. At the time this book was published, Britain had just voted to leave the European Union (the so-called 'Brexit') and the negotiations about how the British energy market would be affected hadn't begun. Therefore, the future economics of using interconnection as a source of flexibility are unclear. However, it's a safe bet that if the price differentials are high enough and there's money to be made, then electricity will continue to flow across the interconnectors.

WARNING!

Energy supply capacity in Iceland is high through its wealth of natural resources, which makes electricity extremely cheap to produce. That low cost makes it attractive to build interconnectors to Europe and sell energy at a profit. The big concern is what that would do to energy prices in Iceland.

Demand-Side Flexibility: Matching Demand to Supply

Traditionally, the use of demand-side flexibility to ensure that supply and demand remain in balance on Britain's electricity system has been a last resort.

Demand-side flexibility is generally thought of as reduction in demand in response to a shortage of supply capacity, but it can also be an increase in demand in response to excess supply, a shifting of demand from one time period to another, the displacement of demand through firing up backup generators (often fuelled by diesel, which sort of defeats the object of decarbonising generation) or drawing down from electricity storage capacity.

The following sections break down the categories of demand-side flexibility.

Demand reduction

Demand reduction is the ability to lower the demand on the system when insufficient supply capacity is available. In the current system, demand reduction is achieved by establishing contracts with major electricity users to curtail their demand when required. In extreme situations, National Grid, in its capacity as the system operator, has the statutory powers to ask the distribution network operators to disconnect consumers for a period of time.

If you're old enough to remember the 1970s, then you may recall planned power outages to enable the system to remain in balance during a period of industrial action by power station workers, or maybe you've heard your parents reminiscing about the 'good old days' before the Internet.

Over the longer term, the increasing efficiency in the use of energy through reduced waste and increasingly efficient appliances will help to reduce demand.

Demand increase

The ability to *demand increase* (also referred to as *demand turn-up*) when an excess of supply capacity is available is a valuable tool to avoid wasting electricity that is produced.

You may be familiar with the Economy 7 or the Economy 10 tariffs enabled through radio teleswitches. These tariffs encouraged demand to be increased over night to make use of inflexible base-load generation that couldn't be reduced and for which there was insufficient demand.

REMEMBER

Today, with the growth in solar farms, the system is starting to see excess supply within the networks at certain times of day. Excess supply capacity will cause the wholesale price of energy to fall – which can help to address energy affordability if consumers can make use of the energy when the prices are low. Or, those consumers that have some form of energy storage can put this cheaper electricity into storage to use later.

Demand shifting

Demand shifting is the reduction of noncritical demand (things that you won't notice have been turned off for short periods, unlike the TV, which you'll release pretty quickly if it suddenly goes off halfway through your favourite programme) during periods of constrained supply and increasing it when supply capacity exceeds the demand on the system. It's often enabled by storage or the use of backup generation.

Demand-side storage

Demand-side storage is an enabler to increase demand when the supply capacity exceeds the demand on the system at any given time. Equally, it provides a means to reduce demand (by satisfying energy demand from the storage) when the supply capacity is insufficient to meet the demand on the system.

In the domestic setting, storage is likely to be some form of electrical battery storage. And, of course, with the growth in electric vehicles, the opportunity for significant off-grid storage is created.

In its 2016 Future Energy Scenarios, National Grid sees 200k to 700k electric vehicles on Britain's roads by 2020, each with a standard storage capacity of 24kWhs. Assuming that at any given time an average number of the electric vehicles will be half full, that's 2.4GWhs to 8.4GWhs of stored energy – or the equivalent of the output from Hinkley Point C for 45 minutes to 2.5 hours when it is commissioned.

Demand-side generation

Demand-side generation in the industrial and commercial markets is typically going to take the form of backup generation. It often ensures that essential services have electricity in case of a power cut or if National Grid has requested demand to be reduced. However, it can just as easily be used to reduce exposure to high energy costs associated to some types of wholesale market price tracker-type energy supply contracts.

In the domestic setting, the increasing adoption of *micro-generation* (that's small scale devices that produce electricity, such as photovoltaic solar panels) is helping to reduce the demand of a property during the day. When combined with storage solutions (which is typically electrical by a battery or thermal via a hot water cylinder), any excess energy that is produced can be saved and used during other periods.

Storage: Changing the Game

If Britain's electricity system is to embrace the use of the new sources of flexibility arising from the progressive adoption of low carbon technologies on the demand side and decarbonised generation on the supply side, then grid-connected storage will become an important component of the system.

Grid-connected storage helps to ensure that when supply capacity exceeds demand, the energy doesn't go to waste. It also helps to provide supply capacity when demand is high. These sections examine the four types of storage in greater detail.

Electrical storage

Grid-connected electrical storage is still in its infancy, and the technologies aren't yet commercialised. Nevertheless, they'll undoubtedly play an important role in helping to ensure that intermittent generation doesn't go to waste when supply capacity exceeds demand. Furthermore, they'll help meet demand when it exceeds the available generation.

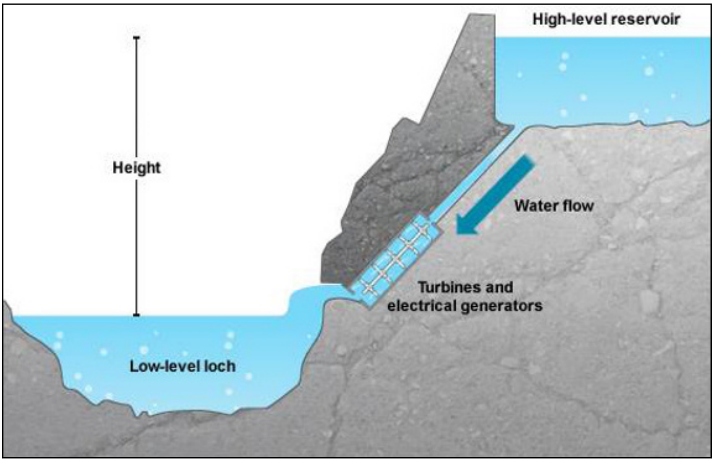
A number of battery storage schemes are currently being trialed by *Distribution Network Operators* (or *DNOs*) as part of the Ofgem-funded innovation programmes, the Network Innovation Competition and its predecessor the Low Carbon Networks Fund. The DNOs are the six companies responsible for the 14 licenced distribution areas in Britain that own the wires that connect the transmission network to the electricity meter in a premises.

Of note are the UK Power Networks' Smarter Network Storage programme, which is investigating the economics of electrical storage as a cost effective and flexible means of reinforcing networks. Also, Western Power Distribution's Project FALCON looked at the role electricity storage could play in managing network constraints that are expected to be created through the progressive deployment of low carbon technologies and embedded generation.

Potential storage

Let me give a quick reminder for those of you that haven't had need to make recent use of the physics you learned at school. *Potential energy* is the stored energy an object possesses by virtue of its position relative to other objects due to the forces that are acting on it, such as gravity.

Britain has long employed the storage of potential energy in pumped storage schemes. Currently there are four schemes in Britain: at Dinorwig and Festiniog in Wales and Foyers and Cruachan in Scotland. Between them they provide 2.828GW of installed supply capacity, with Dinorwig being by far the biggest at 1.728GW. Figure 2-2 illustrates the design of most pumped storage schemes.



Source: www.bbc.co.uk/bitesize/standard/physics/energy_matters/generation_of_electricity/revision/3

Figure 2-2: Schematic of a pumped storage scheme.

Pumped storage has many advantages, including the following:

- It can be brought on line, when required, in seconds.
- It can be used to store electricity that is produced when there is insufficient demand by converting the excess electrical energy into potential energy through pumping water to a higher altitude.
- It's one of the oldest forms of large-scale energy storage. It consists of two reservoirs at different heights. When the water is released from the upper reservoir, it flows under gravity (so the potential energy of the water stored in the reservoir is being converted into kinetic energy) through a turbine and generator to create electricity and into the lower reservoir. When supply capacity exceeds demand, typically overnight, the water is pumped back to the upper reservoir.

The downside to pumped storage is that it uses more energy to pump the water back to the upper reservoir than is generated when the water is released to flow through the turbines.

You probably noticed that all four of Britain's pumped storage schemes are situated in Britain's hillier and more mountainous regions – making use of the natural geography of the landscape to create the reservoirs and height differential.

For flatter terrain, underground caverns with lakes or aboveground reservoirs can be used, which is sometimes referred to as Flat-land, Large-scale, Electricity Storage (FLES). Another innovation proposes creating an underground reservoir by cutting out a large slug of land, which would be used to provide the downward force to drive the water through the turbine and generator, as illustrated in Figure 2-3.

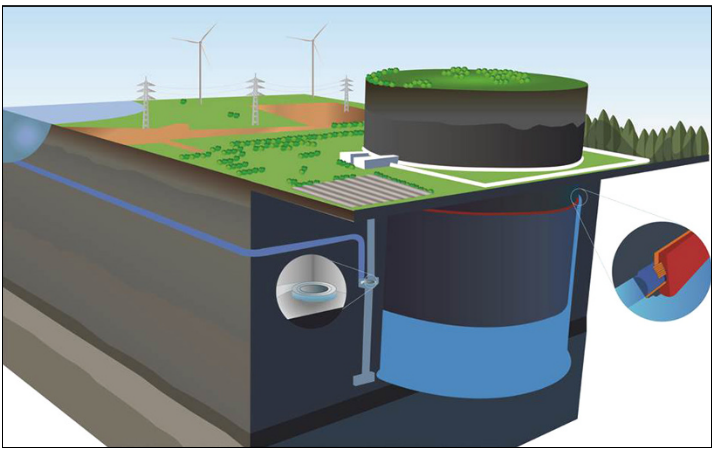


Figure 2-3: A different form of pumped storage.

Compressed Air Energy Storage (CAES) is similar, but instead of pumping water from a lower to a higher reservoir when there is an excess of supply capacity, ambient air is compressed and stored under high pressure (around 70 Bar – about 70 times atmospheric pressure) in an underground cavern. When demand exceeds the generation capacity, the compressed air is released to flow through an expansion turbine, which drives a generator and produces electricity.

If you studied physics, you may recall that compressing a gas creates heat and expanding the gas cools it. Air compressors normally cool the air, but the compressor discharge temperatures are still in excess of 150°C and needs to be cooled to less than 50°C for storage. That presents an opportunity to recover the heat energy and use it. Or it can be stored, because when the air at 70 Bar is released, it needs to be heated, or else it becomes very cold.

CAES systems are equivalent to pumped hydro power plants in terms of their capability, storage capacity and output.

Kinetic storage

Rotational *kinetic energy* has been stored in flywheels since before the Industrial Revolution and is often used to provide continuous energy in systems where the energy source isn't continuous. So flywheels are widely used to ensure that power supply is uninterrupted to critical applications in the event of a power cut or unplanned outage.

TECHNICAL STUFF

In essence, a flywheel is a rotating (hence *wheel*) mass. The heavier it is and the faster it rotates, the more energy it stores. When demand exceeds the available supply capacity, the flywheel is connected to a turbine-like device to convert the kinetic energy into electricity, which slows the rate of rotation as the energy stored is depleted. When the supply capacity exceeds the demand again, electrical motors increase the speed of rotation of the flywheel and increase the stored energy.

Flywheels are able to respond near instantly, providing an invaluable tool in maintaining the frequency of the system and the quality of electricity supply. They also have the advantages of being highly reliable with low maintenance and long service lives. Furthermore, the inertia of a flywheel has additional potential benefits to the energy system because the changing energy mix tends to reduce the inertia of the energy system. (You can thank Newton's First Law of Motion, the one that says an object in motion tends to remain in motion unless acted upon by an external force.)

Thermal storage

Thermal storage is another energy storage method, and it can be categorised in two ways: demand-side thermal storage and grid-connected thermal storage.

Demand-side thermal storage

You may be familiar with the Economy 7 tariff and its association with electric night storage heaters. Night storage heaters were a popular means of providing electric heating to properties where there was no gas supply.

The storage heater consists of bricks of high thermal density material (that's stuff that, for its size, requires a lot of energy to raise its temperature). These bricks would be heated overnight when the supply capacity from base-load generation exceeded the demand and would otherwise have gone to waste, so had a low cost. The stored energy would be used through the day to provide space heating as either radiators or to provide warm air, thus avoiding the need for electricity during the day when demand exceeded base load generation.

A lot of thermal storage capacity can be employed to provide flexibility in the energy system, enabling demand to be shifted from periods when it exceeds the available supply capacity.

Cold stores, such as refrigerated warehouses, have a high level of thermal inertia. After they achieve a temperature, that temperature tends to remain pretty stable unless things are being moved in and out of the store. Hence, the refrigeration units can be isolated for short periods without affecting the temperature of the stored products.

Similarly, the same is true of air-conditioning systems, which can be cycled off for a few minutes without noticeably affecting the office or home environment. This type of cycling of commercial air conditioning to help balance demand against constrained supply capacity has become well established in California, following the blackouts there in the early 2000s.

Grid-connected thermal storage

A range of grid-connected thermal energy storage technologies currently in use or in development is as follows:

- **Pumped heat electrical storage (PHES)** uses excess supply capacity when demand is low to drive a heat pump (commonly found in refrigerators and air-conditioning plants), which pumps heat from the cold store to the hot store. To recover the energy, the heat pump is reversed to become a heat engine. The engine takes heat from the hot store and uses it to drive a generator, delivering waste heat to the cold store.

PHES is currently in the developmental stage, but commercial units are expected to be in the 2MW to 5MW range.

- **Hydrogen storage** involves using excess supply capacity to power electrolysers that produce hydrogen. The hydrogen can then be stored and used either to power combined cycle gas turbine power plants or hydrogen fuel cells in order to produce electricity when required.

  Hydrogen fuel cells may, of course, become standard in hybrid electric vehicles in the future, aiding the decarbonisation of transport as well as helping to reduce the demand placed on the electricity infrastructure by the growing adoption of electric vehicles.

- **Liquid air energy storage (LAES)**, also known as cryogenic energy storage (CES), stores energy through the liquefaction of air (rather than its compression). Excess supply capacity is used to cool air to the point where it liquefies and is stored. When required, the liquid air is allowed to evaporate. In doing so, it's used to drive a turbine and generate electricity.

  The application of LAES to the energy system remains relatively novel, but it's based on mature technologies, so it carries relatively low technology risks with proven long service lives associated with the electricity sector. Unit sizes could range from 5MW to the hundreds of megawatts. Its characteristics from a system perspective are similar to those of compressed air storage and the established pumped hydro schemes.

Chapter 3

Examining the Current Market Arrangements for Energy Flexibility

In This Chapter

- Uncovering the role of regulation
- Recognising the stakeholders and their roles and responsibilities
- Eyeing the commercial arrangements

This chapter takes a peak at the current shape of the market for flexibility in the electricity system. From the role of the Ofgem in regulating the market to the players in the market, you can find them here.

I also provide an overview of the current way in which the system operator works out how much flexibility it needs to make sure that you can have that cuppa during the advert break, how it communicates with the market and how it currently contracts for flexibility.

Uncovering the Role of Regulation

Britain's energy market is one of the most unbundled and consistently competitive energy markets anywhere in the world. For it to operate as effectively as it does, the role of regulation is crucial in defining what is expected of current and potential participants in the market and what they should expect of each other.

In Britain, the Office of Gas and Electricity Markets (Ofgem) regulates the energy markets and the participants in those markets.

In the context of European Union Directives, Ofgem acts as an independent National Regulatory Authority and, in the British context, is a non-ministerial department that works independently of the government and specifically the Department of Business Energy and Industrial Strategy (DBEIS). The DBEIS is responsible for setting energy policy and drafting or amending the associated legislation.

REMEMBER

Ofgem's primary role is to protect the interests of electricity and gas consumers, which means it's responsible for developing and supervising competition in the energy market, promoting security of supply in a sustainable way and encouraging value for money for all consumers. It achieves this by working the energy market participants, government and other stakeholders.

In order to become a market participant in pretty much any market role, you have to have a licence from Ofgem. Ofgem issues licences to companies that want to become a market participant in any of the market roles it regulates. There are licences for generators, interconnectors, the transmission system, the distribution networks, electricity suppliers to consumers and for the provision of data and communication services for smart metering (although there is only one of those licences). These licences set out the obligations on the market participants. These obligations often include the need to become signatories to the relevant industry codes.

The industry codes define in detail how the market participants will operate so that, for instance, electricity suppliers and distributors know what to expect of each other. For more information, check out *GB Electricity Industry For Dummies*, CGI Special Edition, by Chris Beard.

Naming the Different Market Roles

To fully comprehend flexibility in the electricity system, you need a little understanding around the different market participant roles and their respective obligations and interests in enabling flexibility. These sections break down the different players and their responsibilities.

System operator (SO)

National Grid fulfills the role of National Electricity Transmission System Operator (NETSO) for the National Electricity Transmission System (NETS) across Great Britain. The NETS is made up of three main licensed transmission network operators, who are

- National Grid Electricity Transmission (NGET)
- Scottish Hydro Electricity Transmission (SHE)
- Scottish Power Transmission (SPT)

There are a number of other offshore transmission licencees.

In its capacity as system operator (SO), National Grid is responsible for the following:

- Balancing generation supply capacity and consumer demand by coordinating electricity flows onto and across the transmission system.
- Acting as SO for the offshore electricity transmission system.
- Forecasting the demands on the system over the long term and ensuring that the system remains in balance over the short term. The SO achieves this by contracting for sources of supply and demand to increase or decrease their generation or consumption respectively.

Refer to the later section 'Focusing on Balancing Services' for discussion on the types of balancing services for which the SO contracts.

Generators

Ofgem regulates generators through the issuing of generation licences. As of May 2016, 150 companies held generation licences. Licenced *generators* produce electricity and export it onto the transmission and distribution networks. The electricity that they produce can come from traditional fossil fuel sources, such as coal and gas, from nuclear, from hydro schemes and from renewable sources such as onshore or offshore wind and photovoltaic solar arrays, as well as renewable thermal sources such as poo and anaerobic digestion.

Britain's generation capacity is currently around 70GW, and the peak demand during the 2015–16 winter was 52.3GW. Although that number looks like there's a healthy capacity margin available, remember that at any given time some of the generating capacity is unavailable due to maintenance. Also, with the increasing level of supply capacity being provided by intermittent, inflexible solar and wind generation, the availability of that capacity isn't necessarily coincident with when it's needed to meet the demand.

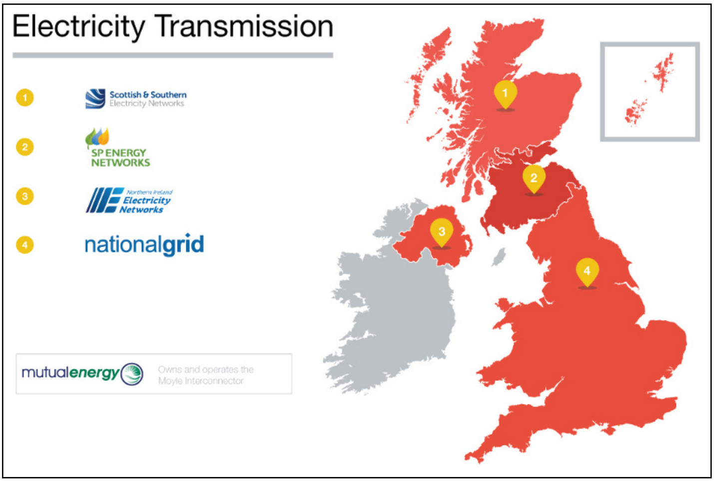
TECHNICAL STUFF

Even though the 2015–16 winter was one of the mildest winters in almost 60 years and increasing output from generation embedded on the distribution networks reduced the peak demands below those projected, the SO needed to make use of Demand-Side Balancing Reserve to balance the system. (Check out the later section on DSBR.)

Transmission network owners

Britain has three main electricity transmission network operators with a further 14 transmission network licensees, mainly operating offshore transmission networks. Figure 3-1 shows the geographic footprints and ownership of the three onshore transmission networks.

The role of the transmission networks is to connect generation and interconnectors to the distribution networks. Transmission networks consist of overhead lines, underground cables and substations, operating at 400kV and 275kV. In Scotland, the 132kV networks are also operated as part of the transmission system. The transmission networks can be considered as the motorways of the electricity system.



Source: www.energynetworks.org/info/faqs/electricity-transmission-map.html

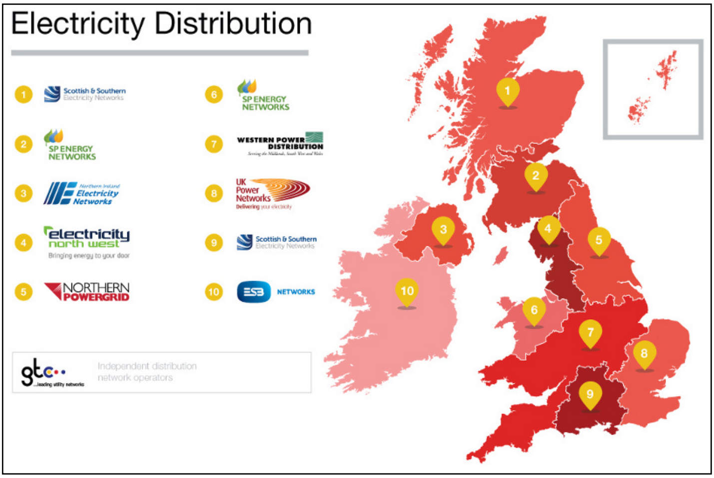
Figure 3-1: Onshore transmission network ownership.

Distribution network operators (DNOs)

Britain has 14 licenced electricity distribution networks, which are owned by six companies, each being responsible for between one and four licences.

The role of the distribution network operators (DNOs) is to distribute electricity from the transmission network to consumers, most of whom are connected to the low voltage secondary distribution networks. Figure 3-2 shows the geographic footprints and ownership of the 14 licenced distribution networks by the six owners. Spot the eight areas shown on the map, and then look closely to see that Scottish & Southern Electricity Networks and SP Energy Networks both have network areas that aren't contiguous.

In extreme situations where the market mechanisms are failing to deliver an increase in supply or a reduction in demand, the DNOs play a crucial role in enabling the system to remain in balance. In this situation the SO issues a Demand Control Imminent (DCI) to the DNOs. See more about DCIs in the 'Forecasting and communicating to the market' section later in this chapter.



Source: www.energynetworks.org/info/faqs/electricity-distribution-map.html

Figure 3-2: Ownership of the licensed distribution areas.

Electricity suppliers

Ofgem has issued 190 current electricity supply licences, but not all of these licensees are currently active in the supply of energy.

A lot more is involved with being an electricity supplier than simply producing a bill once a month. Electricity suppliers in Britain are responsible for contracting with consumers for the supply of electricity. As well as setting the prices for the customers and billing them for the energy they use, the electricity suppliers have to pay for the following:

- The meters
- The meter reading
- The use of the electricity distribution and transmission networks
- The generators for the energy they have used
- Any imbalance charges if they incorrectly have forecasted their electricity demand

Implicit in the last bullet is that suppliers need to accurately forecast their customers' consumption and have purchased sufficient electricity from the wholesale market to meet that demand (or sell excess electricity if they find they are *long*, which means that many larger suppliers also have trading operations).

Aggregators

Aggregators aren't licenced, regulated market participants, but they're fulfilling an increasingly important role. *Aggregators* contract with customers to manage their demand and contract with National Grid to make control of that demand available as part of the demand response service that the SO contacts for.

Aggregators can reduce their customers' demand in a range of ways, from reducing voltage within acceptable parameters to firing up backup generation to taking demand off the system.

Consumers

Britain has around 30 million electricity-metered premises, most of which expect to be able to consume electricity whenever they want to.

To this point, only a few thousand major energy users have benefited from being able to manage their demand against price signals and participate in system balancing. However, with the progressive adoption of low carbon technologies on the demand side, things are changing.

Flexibility operator

You probably haven't come across the term *flexibility operator* as a market role before, but it's one that you should expect to read more about as access to new forms of flexibility, particularly on the demand side and from electricity storage, increase in the coming years. The role of the *flexibility operator* will be the co-ordination of access to sources of flexibility by market participants and resolution of conflicts between participants in the use of that flexibility.

As the significance of flexibility in the electricity system grows and the sources of flexibility increase – particularly on the demand side – the use of flexibility needs to be more co-ordinated. The benefits to the SO of flexibility are well understood and managed; however, DNOs are identifying benefits from flexibility on their networks, enabling them to better manage their networks and defer the need to reinforce networks as demand grows. Furthermore, suppliers are eyeing the opportunity to use their customers' flexibility, enabling them to balance better their wholesale portfolio by avoiding purchasing energy when supply is constrained and prices are high, or taking the opportunity to buy when energy supply is abundant and prices are low.

A flexibility operator could play a key role in enabling new business models to develop (or as Ofgem refers to them, *non-traditional business models*).

Focusing on Balancing Services

National Grid, in its capacity as the SO, procures balancing services to enable it to balance supply and demand across the *NETS* in order to make sure that electricity isn't just there when needed, but that electricity is at the right voltage and frequency. These sections look at the current market arrangements employed by the SO to ensure that the energy system remains in balance.

Forecasting and communicating to the market

National Grid, in its capacity as NETSO, publishes a series of forecasts about how Britain's electricity demand will be met. These forecasts cover different time frames, which shouldn't be surprising given the length of time it takes to contract for, build and commission a generating plant that is connected to the transmission networks. The following sections examine these documents.

Electricity Ten-Year Statement (ETYS)

The yearly *Electricity Ten-Year Statement (ETYS)* forms part of the annual electricity transmission planning cycle and forecasts the projected future transmission requirements for the bulk power transfer capability of NETS. The ETYS is informed by the Future Energy Scenarios (FES), which helps the understanding of the factors affecting future energy needs.

Future Energy Scenarios

The report covering Future Energy Scenarios is reviewed and published annually. It's intended to provide a reference point for a range of modeling activities and aid understanding of what the likely demand will be under certain scenarios and the factors or decisions that determine which scenarios become reality.

Winter and Summer Outlook reports

The Winter and Summer Outlook reports are published each year, one for each period. They outline the SO's view of the electricity system for the period ahead. They're intended to inform and enable the energy industry to prepare for the forthcoming period and for the SO to contract for the appropriate level of balancing services (refer to the later 'Balancing services' section for more details).

Winter and Summer reviews

The annual Winter and Summer reviews report on the accuracy of the forecasts from the outlook reports for the preceding periods and analyse the variations from the forecasts to help refine the forecasts for the outlook report for the forthcoming period.

In the shorter term, the SO can issue more critical notifications to the market. These include the following:

Notice of Insufficient System Margin (NISM)

The *Notice of Insufficient System Margin (NISM)* is a formal communication to market participants that the *capacity margin,* the expected level of available generation compared to the forecasted level of demand, is predicted to be tighter than is acceptable at a particular time of the day that it's issued. NISMs typically are issued up to a day ahead of when demand is forecast to be close to the level of available supply.

The issuing of a NISM is a rare occurrence. When a NISM was issued in November 2015, it made the news, perhaps because it was the first one to be issued since February 2012, although another NISM was issued on 9 May 2016 (the first to be issued in a summer period since 2008!) when the supply margin was lower than forecasted due to a series of unplanned power station shutdowns and the capacity available from wind generation was lower than expected.

The purpose of issuing a NISM is that generators will make additional supply capacity available for the critical time periods. The NISMs had the desired effect, and the necessary additional supply capacity was available in November 2015. Some large energy users, in response to a NISM, may also take a commercial decision to reduce their demand during the peak periods in order to avoid higher charges for using the system at these times. It may be an opportunity for them to run up their backup generation and check that it's in working order for when they really need it.

High Risk of Demand Reduction (HRDR)

This communication is issued when there isn't much time to notify the market of a sudden shortfall, such as an unexpected loss of generating capacity.

Demand Control Imminent (DCI)

If the market doesn't respond to the HRDR, then a DCI notice is issued to electricity distribution network operators asking them to reduce demand across their networks. The DNOs can generally achieve the necessary curtailment of demand by reducing, within acceptable bounds, the voltage at which electricity is supplied. Most electrical equipment continues to operate normally, and consumers are unlikely to notice that their kettle takes a few seconds longer to boil. However, if the disruption to supply is very severe, the DNOs may need to instigate controlled power cuts to homes and businesses.

The fact that these events are so rare is an indication of the effectiveness of the measures to ensure that the system remains in balance.

If you're old enough to remember the industrial action in the 1970s, you may well recall planned power outages for an hour or so. The rarity of these events in Britain is a testament to how effectively the electricity system is operated.

Balancing services

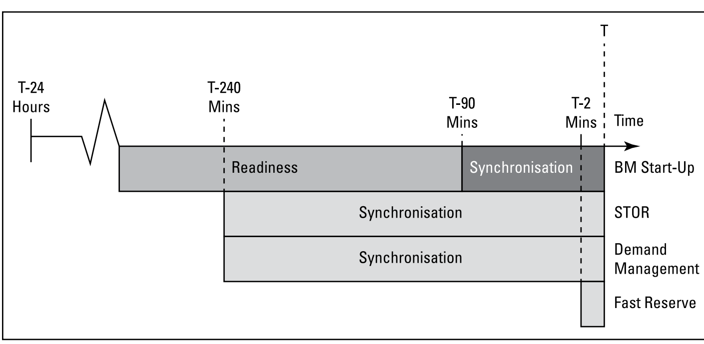
In order to enable it to economically balance demand and supply capacity, the SO procures *balancing services.* These services are employed to ensure both the security (making sure the lights stay on) and quality (a bit more technical, but making sure the voltage and frequency are at the right levels for things to work correctly) of electricity supply across the NETS.

These sections examine the different balancing services.

Reserve services

The SO contracts for additional capacity that it holds in reserve to deal with demand being higher than forecast (perhaps due to weather being colder than expected) or supply being lower than expected (perhaps due to unplanned generation outages). The level of reserve contracted is based on the forecast demand on the electricity system. This reserve capacity can take the form of additional generation or demand reduction, and it provides a sort of insurance cover to keep the lights on.

Figure 3-3 illustrates the notification and response times for the different forms of balancing services for which the SO contracts.



Source: Based on National Grid data

Figure 3-3: Level of notification for different forms of balancing reserve.

Balancing Mechanism (BM) Start-Up

BM Start-Up enables the SO to access generation capacity that, due to its technical characteristics, can't meet the timescales required by the Balancing Mechanism. Generating plant covered by BM Start-Up takes longer than the notification period in the Balancing Mechanism to begin generating, so it's of no use in the timescales required to balance the system if the plant wasn't planned to be operational anyway.

The SO is able to establish contracts with generators that operate plants with these characteristics so that they can, on request, get the plant ready to generate ahead of time if required.

The SO is able to do this as it acts as *residual balancer* (the party responsible for ensuring that the system remains in balance if the suppliers and generators have forecasted incorrectly) to ensure that there is sufficient *operating margin* (the available generation capacity to meet forecast demand) on a day-ahead basis.

BM Start-Up has two elements:

- The request to begin readying plant
- The actual operation of the plant on *hot stand-by,* which means that can be synchronised within 90 minutes if called by the SO

Short-Term Operating Reserve (STOR)

Contracts for STOR are put in place well ahead of when they're likely to be used. STOR contracts provide the SO with reserve supply capacity in the form of either generation or demand reduction, enabling the SO to respond to situations where the actual demand for electricity is greater than the forecasted demand and/or to compensate for plant unavailability.

Provision of STOR is open to both balancing mechanism and non-balancing mechanism parties. In order to participate in STOR, a party must be able to provide at least 3MW of capacity, on an aggregate basis, within four hours of notification and for a minimum period of two hours.

STOR contracts are structured with both an availability payment and an utilisation payment for the energy delivered.

The SO is trialing alternate contracting mechanisms for access to STOR through the STOR Runway and Enhanced Optional STOR.

Demand Turn Up

Demand Turn Up has been introduced to address the situation when there is excess supply capacity, typically from renewable generation such as solar and wind. It encourages demand-side providers to increase demand (through reducing generation embedded in the distribution networks or through increasing demand).

Providers of Demand Turn Up typically are notified by email several hours ahead of when the increased demand is expected to be required. The actual notification period depends on when the SO identifies the requirement.

Demand-side response

Through the Power Responsive initiative, the SO is looking at how to develop services that enable businesses and consumers to turn up, turn down or shift demand in real-time.

Of course, many of the balancing services can benefit from demand being increased, reduced or shifted. However there are practical constraints to accessing DSR, such as current commercial arrangements and its treatment within the *capacity market* (refer to Chapter 5 for more details).

Fast Reserve

Fast Reserve is the reserve service with the quickest response. Providers of Fast Reserve must have a minimum of 50MW of generation capacity or the ability to reduce demand within two minutes following receipt of an electronic dispatch instruction from the SO. This reserve generation capacity or reduction in demand must be sustainable for a minimum of 15 minutes.

Unexpected or sudden changes in generation or demand (such as a generator failing or a major power outage due to a network fault) can affect the frequency at which the system is operating as well as causing imbalance. Fast Reserve is used, in addition to other energy balancing services, to manage such frequency changes.

Contingency Balancing Reserve

Contingency Balancing Reserve is used only in exceptional circumstances, such as insufficient capacity being available in the market to meet demand. In effect, it provides a safety net in case other measures are unable to deliver as intended.

Here are the two forms of contingency balancing reserve.

Demand Side Balancing Reserve (DSBR)

Demand Side Balancing Reserve (DSBR) is a commercial service targeted at large energy users that contract to reduce, when required, their demand during winter weekday evenings between 1600 and 2000. Because DSBR is a commercial contract, the energy users who sign it get paid for reducing their demand when required to do so.

Ofgem approved the introduction of DSBR as a balancing service in December 2013. DSBR was used to balance the system for the first time in November 2015.

Supplemental Balancing Reserve (SBR)

Supplemental Balancing Reserve (SBR) is a means by which the SO can contract with power stations that would otherwise be closed or mothballed to keep them in reserve for the eventuality that extra supply capacity is required. Ofgem first approved SBR in December 2013.

Frequency response services

Maintaining the frequency of the system at 50.00 Hz (that's cycles per second if physics wasn't your thing at school) plus or minus one percent (so in the range of 49.50Hz to 50.50Hz) and is an obligation on National Grid in its licence.

REMEMBER

When demand exceeds the available generation, the frequency falls; when generation exceeds demand, then frequency rises, which explains why balancing supply capacity and demand in near real time is so important.

Frequency response services are catagorised as one of these two:

- **Dynamic:** Dynamic frequency response is a continuously provided service used to manage the normal second-by-second changes on the system.
- **Non-Dynamic:** Non-dynamic frequency response is triggered at a defined frequency deviation.

Mandatory frequency response

All generators connected to the NETS are, as a condition of their connection, required to be capable of providing *mandatory frequency response*.

Generating equipment is required to monitor frequency and automatically adjust the active power output (that's measured in kW rather than the total power, which is measured in kVA) in order to maintain the frequency within operational limits (49.8Hz to 50.2Hz), which helps the SO meet its licence obligation of maintaining the system frequency within statutory limits (49.5Hz to 50.5Hz).

Frequency Control by Demand Management (FCDM)

As its name suggests, this mechanism is intended to ensure that system frequency remains within operational and statutory limits by employing reduction in the demand of major energy users.

Given that *Frequency Control by Demand Management (FCDM)* employs demand reduction, it addresses low system frequency. Participating consumers have frequency-sensing relays onsite that automatically interrupt supply when the system frequency falls below the low frequency threshold on the relay.

Participating consumers are prepared to accept their supply from the grid being interrupted for periods of up to 30 minutes on typically between 10 to 30 occasions per year. These consumers may have taken the precaution of investing in backup generation or some form of storage capability to cover their electricity needs during such and event.

FCDM addresses sudden, large deviations in frequency. These deviations are most likely caused by, for example, the loss of significantly large generation capacity.

Firm Frequency Response (FFR)

Firm Frequency Response (FFR) is the contracted provision of dynamic or non-dynamic response to changes in frequency.

The SO contracts for the provision of FFR through a competitive procurement. The procurement is open to existing providers of mandatory frequency response, to generators within the balancing mechanism and to non-balancing mechanism generators (increasing the number of potential providers of response capability). Bidders can tender to address low frequency events, high frequency events or both.

FFR compliments other sources of frequency response by delivering firm availability.

Chapter 4

New World, New Opportunities

In This Chapter

- Understanding the *trilemma*
- Grasping how the energy system is changing
- Looking at new technologies and how they affect flexibility

This chapter looks at what is driving change in the energy system and how these changes are likely to affect the energy system. From the so-called *trilemma* and legally binding climate change goals to how that's changing the dynamics of the way the electricity system has to operate, this chapter looks at the reality of the new technologies and how they impact on the need for new ways of accessing flexibility.

Identifying the Trilemma That's Driving Change

This section examines the three pillars that have formed the basis of Britain's energy policy for the last decade or so. Balancing these three pillars of energy security, affordability and sustainability has become known as the *trilemma.* Figure 4-1 shows an illustration of the trilemma.

"The what? That's a made-up word!" And, to be fair, you may have a point because trilemma certainly hasn't made it into the Cambridge or the Oxford dictionaries, yet! In case you haven't worked it out, a *trilemma* is analogous to a dilemma, but with three choices instead of two.

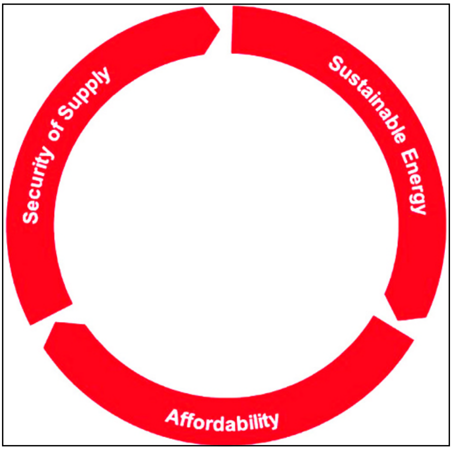


Figure 4-1: The trilemma – the pillars of energy policy.

In the following sections, I set out to help you understand both what is changing and why. The three pillars of energy policy are inextricably interrelated. The pillar you choose to prioritise depends on what you do and, to some degree, your values.

Energy security

International Energy Agency (IEA) defines *energy security* as 'the uninterrupted availability of energy sources at an affordable price'. So you already start to see in the IEA's definition the inter-relationship between energy security and affordability!

REMEMBER

Delivering energy security is complex with many dimensions, but understanding the short-term and the long-term factors is helpful. Energy security covers the availability of all the forms of energy required for the economy to function. This book focuses only on energy security in the context of the electricity system.

Chapter 3 highlights the short-term role that flexibility in the electricity system plays in helping to keep the lights on by balancing supply and demand and by enabling sudden or unexpected changes to be responded to effectively.

A discussion about keeping electricity affordable

Most people have come to take the reliable availability of electricity for granted (when you throw that light switch, you expect the light to come on!). Regular power outages are a distant memory. The affordability of energy has become the main issue for most consumers and seems to be the focus of newspaper headlines. For those people charged with meeting consumers' expectation that electricity is available on demand, then security is probably their main focus. But the Secretary of State, with his (well it was a 'he' at the time of writing this book) legally binding goal and the Climate Change Act in the inbox, will undoubtedly be keeping at least half an eye on the sustainability pillar. He'll no doubt be ensuring that the policies are in place to enable that goal to be achieved. In turn, those policies will be driving decisions around how Britain maintains its energy security while keeping it affordable.

The use of that made-up word *trilemma* implies trade-offs between the three policy pillars. However, across the electricity sector recognition appears to be growing that flexibility in the electricity system, when combined with a *whole-system approach* that incorporates the demand side could well create a *virtuous circle* – a cycle where the decarbonisation of heat and transport through electrification offers increased demand-side flexibility that can help to address the capacity-margin issues created by decarbonisation of generation and help to keep electricity affordable.

Delivering energy security also has an important long-term aspect. It's about understanding the likely changes to demand for electricity over the time horizon from consenting, through securing the necessary investment, to planning and building, to commissioning new generating capacity. Don't forget that the transmission and distribution infrastructure also needs to be in place to get electricity from where it is produced to where it is needed.

Forecasting the changes in demand is an iterative process supported by National Grid's annual publication of its Future Energy Scenarios (see Chapter 3). Factors such as economic growth (which tends to increase demand) or downturn, improvements to energy efficiency (tending to reduce demand), population growth (which tends to increase demand) and migration (which tends to shift demand from one area to another), transfer of demand from other fuels to electricity (increasing demand), as well as technological innovation (which means more stuff that consumes electricity, but hopefully it's more energy efficient than the gizmos it replaces) all need to be considered in the development of the scenarios.

You may wonder why I'm explaining energy security in a book about flexibility in the electricity system. The answer is simple: flexibility is today and will become increasingly an important tool for, within reasonable bounds, delivering uninterrupted electricity supply. The reason this will become more important is because electricity will increasingly be the fuel of choice to meet energy needs at the point of consumption. More miles travelled will be powered by electricity and more heat in homes and manufacturing will be provided by electricity from decarbonised generation (which generally is less flexible) in order to meet climate change goals (refer to the later 'Sustainability' section for more discussion).

REMEMBER

Electricity is produced from a range of sources, some of which are finite and have to be sourced in a global market, including fossil fuels and uranium.

Affordability

The IEA's definition of energy security recognises the importance of *affordability*. But what determines affordability?

REMEMBER

Chapter 1 discusses *capacity margin*, the amount of generating capacity that is available in excess of the expected peak demand at a given time. How that capacity margin is delivered and the investment required to provide sufficient generating capacity drives affordability. The investors need to be able to see a return, or the required investment can't be secured, and the electricity supply becomes less secure.

The challenge is to deliver sufficient capacity margin while also meeting Britain's legally binding climate change goal of reducing carbon emissions by 80 per cent by 2050, which requires electricity production to be virtually decarbonised by 2050, if not before! Why is that a challenge? Well, generation from wind turbines is intermittent, and photovoltaic solar arrays only generate when there is light, so electricity produced from both of these sources can't be guaranteed to be available when it is needed. That means additional investment in extra capacity. This investment could be in the form of more generating capacity, more interconnectors or more storage. But all of that additional investment has to be ultimately paid for by consumers in the price they pay for the electricity they consume.

Or, the role of demand-side flexibility and the use of demand management in balancing services could grow. Demand-side flexibility has the potential to play a significant role keeping electricity affordable. The growth in demand because of the adoption of low carbon technologies that will decarbonise other sectors, such as through the electrification of heat and transport, is demand that is flexible and can be controlled to match available supply. Both the 'Value of Flexibility in a Decarbonised Grid and System Externalities of Low-Carbon Generation Technologies' (a report by Imperial College London and NERA in support of the Committee on Climate Change's Fifth Carbon Budget in November 2015) and 'Delivering Future-Proof Energy Infrastructure' (a report by Cambridge University and Imperial College London in support of the National Infrastructure Commission's 'Smart Power' report from March 2016) quantify the value of flexibility in the energy system and its role in keeping energy affordable.

REMEMBER

The figure that the National Infrastructure Commission places on a more flexible energy system, or *smart power* as it's referred to, is a saving of £8bn annually by 2030. So worth taking seriously!

Sustainability

The third pillar of Britain's energy policy, or trilemma, is *sustainability*. The significance of this pillar would be clear in two words: climate change.

REMEMBER

In 2008, the UK government at the time passed into law the Climate Change Act. It placed a legal obligation on the Secretary of State at the Department of Energy and Climate Change (or its successors, so that's the Department of Business, Energy and Industrial Strategy today) to ensure that the net UK carbon account for all six Kyoto greenhouse gases is at least 80 per cent lower than the 1990 baseline by the year 2050.

This legal target isn't just about electricity; it covers emissions from all sectors. In fact, many sectors will decarbonise through increasing electrification, increasing the demand for electricity. Clearly, if those other sectors are to decarbonise through electrification, then the electricity they consume must be decarbonised, which means that Britain's electricity sector has to all but decarbonise by 2050!

Grasping How the Energy System Is Changing

This section takes a look at the changes that are happening to the electricity system and why these changes are challenging the way the system has been designed and operated.

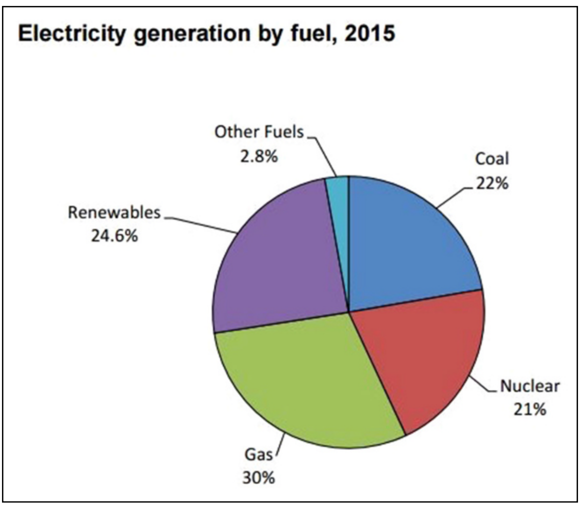
Although the fundamentals of electrical engineering aren't changing, both the nature of demand and the way that demand is met through the mix of generation technologies is changing. Even though that changes the dynamics of the system, it presents opportunities for designing and operating the system differently.

By simultaneously changing both the nature of demand and how that demand is satisfied, the fundamental principles that underpin how Britain's electricity system has been designed are also changing. Demand is becoming inherently more unpredictable. The progressive adoption of renewable micro-generation on the demand side, with its associated level of uncertainty of output, combined with it satisfying the base electricity needs of the premises, makes the demand profile of each home and small business appear more volatile to the electricity network.

According to the Digest of UK Energy Statistics (better known as DUKES), the percentage of Britain's electricity demand satisfied by household micro-generation grew by a factor of more than 50 between 2010 and 2015 (the latest figures available). It's continuing to accelerate, with the year-on-year growth between 2014 and 2015 being 26 per cent. That growth still only accounts for little more than one per cent of household demand, or 0.4 per cent of national demand.

Supply, the mix of generation technologies available to meet Britain's energy needs, is changing too. The amount of electricity supplied from renewable generation sources continues to grow, with the associated effect that their intermittent generation profiles have on the ability to balance the system. Although conventional thermal generation (that's gas, coal and nuclear power stations) still accounts for 73 per cent of Britain's energy needs, the level of consumption satisfied by renewables grew to 24.6 per cent in 2015, up from 19.1 per cent in 2014. That's a 29 per cent growth!

Figure 4-2 shows the 2015 generation mix, according to DUKES.



Source: www.gov.uk/government/uploads/system/uploads/attachment_data/file/541005/DUKES_2016_FINAL.pdf

Figure 4-2: Britain's 2015 generation mix.

The following sections examine what's changing in more detail.

Beyond the meter

Britain has to progressively adopt low carbon technologies beyond the meter in order to meet the climate change goals. Here are some ways:

- **Decarbonisation of transport:** This means that more of the miles people travel will be powered by electricity rather than petrol or diesel, on road or by rail.

- **Decarbonisation of heat:** Most energy that is used to heat people's homes and workplaces or used in manufacturing industry today comes from gas. Electrically powered technologies, such as heat pumps, or forms of demand-side thermal storage (such as storage heaters) will decarbonise that heat demand.
- **Micro-generation:** More demand will be satisfied locally through photovoltaic panels (PVs), micro-CHP boilers (that's *combined heat and power*, where the unit also produces electricity as a by-product of the heat it supplies), fuel cells or even micro wind turbines.
- **Demand-side storage:** Given that some forms of micro-generation (or indeed grid-scale renewable generation) aren't necessarily available on demand and may be generating when there is no demand, the ability to store that energy to meet demand when it occurs will be an important component in the new, decarbonised energy system. From battery units as a new form of white good (just in case there's some readers from around the globe, *white goods* is the term Brits use for electrical kitchen equipment, such as fridges and washing machines) to the batteries in electric vehicles, to thermal storage, they'll all play a role.

Even allowing for improvements in energy efficiency, Barclays Research estimates, based on an average of the four scenarios used in the Future Energy Scenarios (see Chapter 3), a net increase of 16 terawatt-hours of electricity consumption – the gross increase in electricity consumption from the electrification of heat and transport being 42 terawatt-hours!

On the supply side

So, for Britain to meet its climate change commitments, it needs to electrify a lot of its energy use. But here's the issue: there's little point to electrifying lots of stuff if the electricity it consumes isn't from low carbon sources. Indeed, if those legally binding carbon targets are to be achieved, Britain needs to pretty much fully decarbonise how it satisfies its electricity demand by 2050.

That means that the conventional, fossil fuel and thermal generation (from coal or gas) that accounted for meeting 52 per cent of Britain's electricity needs in 2015 has to be decarbonised or replaced over the coming decades. Indeed, around 40GW of unabated coal, gas and biomass generation capacity will be retired by 2030 – and not forgetting a further 7.7GW of nuclear capacity will need to be replaced.

Carbon capture and storage

The abatement of carbon released from fossil fuel–based electricity production could be achieved through new technologies like carbon capture and storage (CCS). However, although CCS is based on established technologies, it's still in its in infancy for capturing the carbon dioxide emissions from power stations.

Combine that with the £1bn of funding for the CCS competition being cut in the UK government's 2015 Autumn Statement and abatement appears not to be the preferred way forward for decarbonising electricity production from an energy policy perspective.

Coal and gas thermal generation

At the same time as the funding for the CCS competition was being cut, Amber Rudd, the Secretary of State for Energy and Climate Change at the time, announced in the so called 'Reset Speech' a consultation on the closure of all unabated coal-fired power stations, with a proposed timescale of 2025.

Coal-fired power stations produce around twice the carbon emissions of gas when used for electricity generation. Focusing on closing unabated coal generation has the potential to make a step forwards in making decarbonisation a reality. However, although coal's contribution to meeting Britain's electricity demand is falling, it still accounted for 22 per cent of the electricity generated in 2015, and with capacity margins (see Chapter 1) in single figures, that means there's a gap!

Although gas produces carbon dioxide, it's 'cleaner' than coal. Gas-fired power stations are easier to consent and quicker to build, meaning that new capacity from combined-cycle gas turbines is deliverable within the 2025 timescale. The trick will be balancing the need to meet short-term (if you consider 2025 short term) electricity demand while ensuring that the longer-term 2050 objective of decarbonising electricity production remains achievable.

Nuclear

Nuclear power stations don't produce carbon dioxide and are proven for meeting base load energy demand, although they lack the flexibility associated with more conventional thermal generating plant. When this book was published, 7.7GW of the existing 8.9GW of operational nuclear capacity is due to retire before 2030, and the new nuclear power station at Hinkley Point C is still awaiting the final go-ahead. Assuming Hinkley Point C is approved, it's scheduled to start generating in 2025. Plans for two other new nuclear plants are in development at Wylfa and Moorside.

Hinkley Point C will deliver 3,200 mega-watts of generating capacity that, because it runs pretty much constantly, will produce around 26 terawatt-hours (TWh) of electricity each year. Twenty-six terawatt-hours (that's 26 billion kilowatt-hours) is the equivalent of around 7 per cent of Britain's total projected electricity needs in the mid-2020s, or enough to satisfy the electricity consumption of around 6 million homes, which is equivalent to more than one in five homes. If you're looking at the 7 per cent figure and scratching your head because it's not the same as one in five, that's because the 7 per cent includes all the electricity that's also used by businesses.

There is also growing interest in the potential of small modular reactors (SMRs). The British government's 2015 Autumn Statement committed to invest £250m in a nuclear research and development programme, which included support for a competition to identify the best value small modular reactor design for the British market.

Renewable generation technologies

The following sections look at the growing role of renewable generation technologies in meeting Britain's electricity demand. Renewables are those forms of low carbon generation that transform Mother Nature's own forces into electricity. But, when you hear people talk about renewables, it will almost certainly be preceded by 'intermittent'. The challenge with all forms of renewables is their flexibility or, more accurately, their lack of flexibility – their availability when demand occurs.

Wind

Wind is the most recognisable and perhaps most visible of the renewable generation technologies. The two types of wind technology are *onshore* and *offshore*. Figure 4-3 shows an example of these two types:

a) b)

Figure 4-3: Examples of onshore and offshore wind farms.

- **Onshore:** You're probably familiar with the sight of onshore wind turbines, as in Figure 4-3a. They're the land-based, smaller cousins of offshore wind turbines, which typically have three blades. You may well have noticed that they are stationary more than they are turning and wondered why that's the case when the wind is blowing. Onshore wind turbines have typical load factors between 20 and 25 per cent when commissioned. However, a study of the performance of onshore wind farms in Denmark and UK by Gordon Hughes in 2012 established that the load factor falls by 10 to 40 per cent respectively over 10 years as the turbines age.

  REMEMBER: The *load factor* is the ratio of the output of the wind farm (what it actually generates) to the maximum possible output (that's the wind turbine's rated output multiplied by 8,760 hours per year), expressed as a percentage.

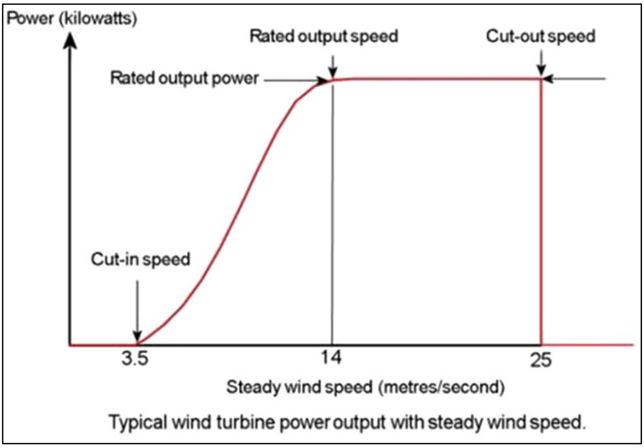
- **Offshore:** Offshore wind is essentially the same as its smaller onshore cousins, the difference being that offshore wind turbines are situated at sea (as in Figure 4-3b). As David MacKay showed in his book *Without the Hot Air*, modern offshore wind turbines located around the UK have typical load factors of 35 to 40 per cent (up from 30 to 35 per cent in the early 2000s) at commissioning, improving as the technology becomes more mature.

Indeed, a European Wind Energy Association (EWEA) report in 2015 claims that in the future offshore wind load factors could be as high as 55 per cent, which translates to offshore wind farms operating at their maximum output for around 4,800 hours per year. However, the previously mentioned Hughes study also looked at the performance of offshore wind farms in Denmark. The report claims that the load factor of offshore wind turbines falls by more than 70 per cent as the turbines age, with load factors dropping to below 15 percent (that's lower than onshore wind load factors at ten years old!). Two factors contribute to this – loss of efficiency due to wear in the more extreme offshore environments and lower run time due to breakdowns.

The potential for wind turbines to produce electricity obviously depends on the weather and, more precisely, wind speed. For those of you with a mathematical bent, the power of the wind converted into rotational energy of the wind turbine is directly propositional to the cube of the wind speed. However, the electrical power output from a wind turbine is more stable than that. Obviously a minimum wind speed gets the rotor turning, often referred to the *cut-in speed*, which, depending on design, is generally somewhere between 3 to 4 metres per second (that's 7 to 9 miles per hour), which the weather forecasters would describe as a light breeze.

However, wind turbines don't reach their rated output until the wind speed gets up to somewhere between 13 and 18 meters per second (or 29 to 40 miles per hour), that's somewhere between a strong breeze and a gale. If you've ever been out when it's literally blowing a gale and wondered why the wind turbines aren't turning, that's because they have a cut-out somewhere around 25 metres per second (or around 56 miles per hour) to avoid damage to the rotors. In fact, that's what the weather forecasters would be describing as a 'storm', or if you're a mariner, then you would be riding out a 'very high' sea, although I doubt that offshore wind turbines not turning would be the first thing on your mind! Figure 4-4 illustrates the relationship between wind speed and power output from a wind turbine.

The accuracy of weather forecasts becomes more predictable the closer to the actual time that the generation capacity is required. However, this is problematic for planning both mid-term and long-term capacity margins (see Chapter 3 for National Grid's Winter and Summer Outlook Reports and the Future Energy Scenarios that forecast the demand over their respective time horizons and the associated capacity requirements, which become uncertain for wind due to the weather dependency).



Source: www.wind-power-program.com/Images/turbine_characteristics.htm/Typical power output (500 x 330).jpg

Figure 4-4: The relationship between wind speed and power output from a wind turbine.

This lack of flexibility with wind generation means that additional generating capacity needs to be available, or the value of flexibility on the demand side increases to enable balancing of the system. Imperial College and NERA termed this the *system-integration costs for low carbon technologies* in their report (concisely titled, 'Value of Flexibility in a Decarbonised Grid and System Externalities of Low-Carbon Generation Technologies') commissioned by The Committee on Climate Change to support the Fifth Carbon Budget, published in November 2015. Refer to Chapter 5 for more on the importance of system-integration costs.

REMEMBER

Just in case you come from an IT background and have got all excited about a big new IT opportunity because system integration is all about IT, I'm sorry but the *system-integration costs* referred to in this context are the costs of integrating into the electricity system.

Equally, the year-on-year reduction in the load factor associated to wind turbines shown by Hughes for both onshore and offshore wind only serves to increase the level of intermittency and therefore additional capacity required to maintain a balanced electricity system.

Solar

Solar generation, both *grid-connected* (the fields of solar arrays you may have seen as you drive through the countryside as in Figure 4-5a, sometimes referred to as *solar farms*) and *micro-generators* beyond the meter, as in Figure 4-5b, (the solar panels you see on people's roofs), like wind, are dependent not just upon the weather, but also on the time of day.

a) b)

Figure 4-5: Solar farm array and roof top panels.

The big challenge for solar generation: Demand for electricity is generally higher in the winter period (really the autumn and winter seasons to the electricity sector), which coincides with the days being shorter!

From a mid-term to long-term capacity planning perspective, knowing the time of the sunrise and sunset is highly predictable. So, once again, the accuracy of weather forecasts creates the challenge for mid-term and long-term planning of capacity margins.

Clouds blocking direct sunlight decrease power output from solar panels. Understanding the output characteristics of solar panels and how they operate in varying levels of cloud cover will improve the planning and control of the available generation capacity. The more information that is available ahead of time and the level of confidence in the accuracy of any forecasts made, the better the planning will be.

Let me be clear: solar panels still produce electricity on overcast days, just not as much. Some solar advocacy groups even claim that solar panels produce more electricity on days when the sun shines through clouds, justifying their claim because of reflected light from the clouds adding to the direct sunlight received by the panels.

Here are some more objective references:

A growing body of evidence suggests that varying cloud cover doesn't affect the output from large-scale solar arrays (those that are one megawatt or greater) as quickly or as dramatically as was originally thought. In fact, the larger the solar array, the lower the variability in power output due to cloud cover. However, small-scale solar panel installations (and particularly those installed beyond the meter on people's rooftops) do respond rapidly (a matter of seconds) to changes in the level of sunlight available, leading to fluctuating power output from the units.

Two published studies, one in 2010 of large-scale solar installations in Kansas and Oklahoma conducted by the Lawrence Berkeley National Laboratory and another on the Hawaiian island of Oahu conducted by the National Renewable Energy Laboratory (NREL), concluded that the output from large-scale solar arrays is more stable under varying cloud cover compared to the rapid fluctuations and proportionally larger spikes and troughs in output from single solar panels or small rooftop solar arrays experienced when clouds pass overhead.

Indeed, paraphrasing the conclusion of the Berkeley lab study, the economics of managing short-term variability in large solar generating sites are similar to those of wind in the same areas.

Understanding the amount by which the output from solar panels varies is important to keeping the electricity system in balance. Again, Mother Nature plays a role in determining the level of demand. One of the conclusions of the NREL Oahu study was that the increased output from the 5MW large-scale solar array would be coincident with an increase in demand from air-conditioning units being ramped up to counteract the effects of the sun on building environments.

Britain unfortunately doesn't have the same level of air-conditioning demand as Hawaii, and the bigger concern with solar is probably its lack of availability as we Brits turn the lights on earlier as the nights draw in during winter!

Tidal

Britain is an island, which means the country has a lot of coastline. So what of tidal generation's potential to meet the electricity demand? In fact, a 2013 report by the Royal Society claimed that tidal generation could provide more that 20 per cent of Britain's demand for electricity.

Tidal generation has a significant advantage over solar and wind generation. It's not only renewable, but also the tidal currents that generate the electricity are highly predictable. High and low tides follow well-known and understood cycles, making it easier to plan the contribution from tidal generation into the available generation capacity.

On this basis, tidal generation sounds like it could be the silver bullet to resolve the potential trade-offs between decarbonising electricity production to meet those climate change goals and achieving reliability in electricity supply. Unfortunately, it's the third element of the so-called trilemma that is the challenge for tidal generation – affordability.

Although tidal generation has long life spans (around four times those of conventional gas thermal CCGT generation and twice that of nuclear), it has high initial capital investment requirements, which is often cited as bringing into question the economics of the tidal generation technologies. Unsurprisingly, advocates of tidal technologies challenge the economic assessment methodologies applied, claiming that they disadvantage tidal generation when compared with more conventional generation technologies.

Grid-scale storage

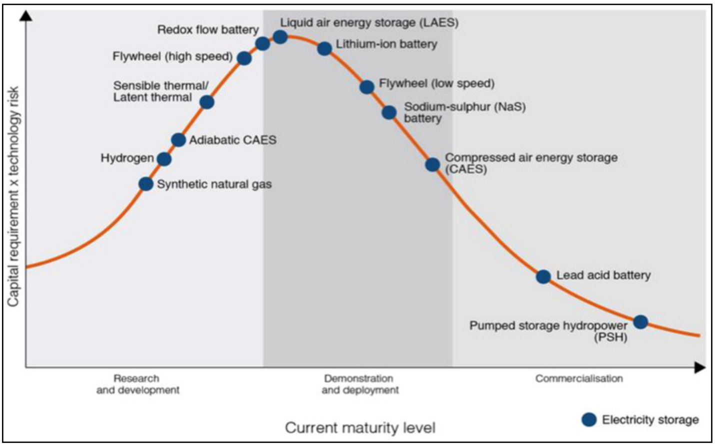
Chapter 2 discusses in more depth the different forms of energy storage. In the context of an electricity system that incorporates a growing level of generation capacity from intermittent sources such as wind and solar, storage will undoubtedly play a significant role. When generation outstrips the demand and demand turn-up isn't an option, then the option to store that excess electrical energy and draw electricity from storage when demand outstrips the available supply capacity clearly has value in helping to keep the system in balance.

The significant role storage will play as a catalyst for the low carbon energy transition in future electricity systems that incorporate intermittent renewables was recognised by Christoph Frei, Secretary General of the World Energy Council, in 2016 when he stated that storage is undervalued.

In its 2016 report 'E-storage: Shifting from Cost to Value Wind and Solar Applications' the World Energy Council predicts that the costs of energy storage technologies could reduce by as much as 70 per cent by 2030. This number is consistent with a survey of participants in the British electricity market published in June 2016 conducted by *Utility Week* on behalf of CGI that found a high degree of confidence that storage will have reached maturity and mass penetration, and therefore will make a significant contribution to the security of the electricity system by 2030. The same survey also found that storage is the most important low carbon technology in facilitating flexibility in the electricity system.

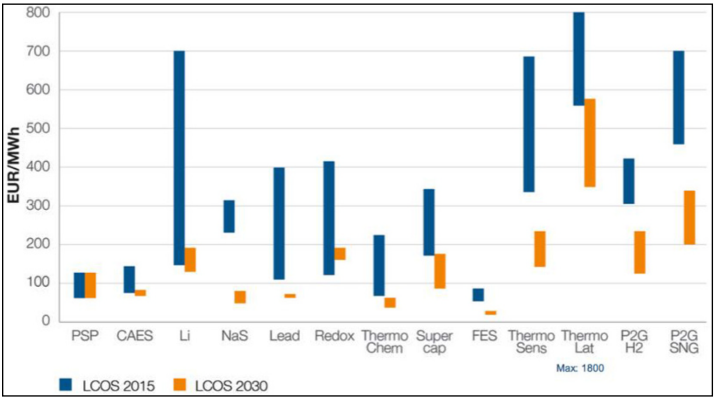
The World Energy Council report also acknowledges that the challenges to storage technologies aren't just technical and that electricity market design also needs addressing. Christoph Frei expressed his view that policymakers must review electricity market design to incentivise storage capacity and ensure reliable and affordable electricity supply with growing wind and solar electricity shares of the generation mix.

Figure 4-6 provides a view of the relative maturity of different storage options from the World Energy Council in 2016. Figure 4-7 provides a view of the economics of the different storage technologies both today and where they're expected to be by 2030 (also from the World Energy Council in 2016).



Source: www.worldenergy.org/wp-content/uploads/2016/03/Resources-E-storage-report-2016.02.04.pdf

Figure 4-6: Maturity Level of Energy Storage Technologies.



Source: www.worldenergy.org/wp-content/uploads/2016/01/World-Energy-Resources-E-storage-wind-and-solar-presentation-World-Energy-Council.pdf

Figure 4-7: Comparison of general levelised cost of different forms of energy storage for 2015 and 2030.

Chapter 5

Exploring What's Coming Next

In This Chapter

- Eyeing the latest thinking
- Understanding the market
- Identifying who is driving discussions about future regulation
- Understanding the value of energy flexibility

This chapter looks at what is developing and what you need to watch to stay informed about flexibility in the electricity system. In the short period over which this book has been written, the UK has decided to leave the EU (the so called *Brexit*) and the government department that was responsible for policy (the Department of Energy and Climate Change [DECC]) has merged with another department (the Department of Business, Innovation and Skills [BIS]) to create a new department (now called the Department of Business, Energy and Industrial Strategy [DBEIS]).

The DBEIS has a broader remit and a completely new ministerial team in place. Innovation projects and proofs of concept are completing and providing new evidence on the value and economics of different approaches. At press time, the decision on Hinkley Point C is still awaited. The future continues to change, so this chapter is just a snapshot at this point in time.

Examining the Latest Thinking

The Climate Change Act 2008 makes Britain's climate change commitments legally binding. Achieving these commitments means that electricity production needs to be essentially decarbonised by 2050. That doesn't happen overnight, so milestones are established along the way to help track progress.

The Committee on Climate Change and the Fifth Carbon Budget

The task of holding the British government to account about progress against its climate change targets falls to the aptly named Committee on Climate Change (CCC).

The CCC was established under the Climate Change Act 2008 with responsibility for advising on emissions targets and reporting on progress. Formally, the CCC is an independent, statutory body.

In 2014 the intensity of carbon emissions by Britain's electricity sector was around 450gCO_2/kWh. In the CCC's recommendations for the Fifth Carbon Budget, proposed in November 2015 and finally accepted by the UK government in June 2016, the targets for 2030 are towards the upper end of the 50 to 100gCO_2/kWh range previously identified as necessary for 2030.

Supporting analysis for these recommended targets began to quantify the value associated to increasing flexibility (primarily from demand-side flexibility and energy storage) in the electricity system to compensate for the decline in flexibility on the supply side through the projected increased amount of generation capacity from wind and solar generation. The analysis determined a gross benefit of £3 to 3.8bn per annum at the upper end of the 50 to 100gCO_2/kWh range, rising to £7.1 to 8.1bn per annum at 50gCO_2/kWh. Even in a scenario of 200gCO_2/kWh (which would virtually be achieved through the planned retirement of existing coal and some gas generation assets), increasing flexibility is projected to deliver a gross benefit of £2.9bn per annum in 2030. Therefore, embracing new forms of flexibility is a low-regrets option.

REMEMBER

The concern, which is a common theme across most analyses, is whether the existing market arrangements provide the confidence and necessary incentives to attract the required investment in the existing and developing flexibility options.

Assessment of system integration costs

The *trilemma* (see Chapter 4) and specifically properly assessing the impacts that the decisions about how Britain will decarbonise its electricity system will have on affordability is crucial. The introduction of the concept of *system-integration costs* is an important step in properly understanding the relative economics of the different technologies in different energy mix scenarios.

Chapter 4 discusses the concept of system-integration costs that the Imperial College and NERA employed in their report 'Value of Flexibility in a Decarbonised Grid and System Externalities of Low-Carbon Generation Technologies'. (The CCC commissioned this report to support the assessment of the power sector scenarios for the Fifth Carbon Budget.)

TIP

The objective of establishing the true system-integration costs of different generation technologies is to provide a fully cost-reflective assessment of their economics. The challenge is that the assessment of these costs depends on the sort of generation mix and electricity system you start with and the sort of generation mix and the location of the generating assets you end up with.

REMEMBER

These sorts of system-integration costs include the following:

- The level of investment required to provide additional capacity margin to cover the level of intermittency or controllability of different generation options, which is a particular issue for solar and wind generation
- The degree to which the generation profile of a technology can be matched to the demand profile
- The investment required to reinforce existing or to build new transmission and distribution networks to transport the electricity from where it's generated to where it's needed (think of the new offshore transmission grids to support offshore wind and the locational challenges associated to solar farms)
- The increased costs associated with balancing the system

Clearly, when only a relatively small percentage of the generation capacity comes from intermittent and inflexible sources, the costs of integration associated with additional capacity margin and balancing are low because the existing level of flexibility in the electricity system is adequate and the impacts on the dynamics of the system are low.

However, as the levels of intermittent and inflexible generation grow, then the costs start to increase as existing sources of flexibility decline. This is reflected in the CCC's assessment of the increasing value of demand-side flexibility and storage as the intensity of carbon emissions from the electricity system reduces towards 50gCO_2/kWh and towards fully decarbonisation by 2050.

Grasping Market Arrangements

This section takes a look at the key market mechanisms used to attract investment in various forms of generation and how they affect the technologies that get adopted. It's fair to say that this area is a bit of a hot potato with all sorts of groups expressing concerns about the effectiveness of the current market arrangements.

The CCC isn't the only entity that has highlighted potential issues with the current assessment approaches.

Both the CCC and the Energy Research Partnership (ERP) have questioned the appropriateness of the use of *levelised cost of energy* (LCoE) as a key assessment criteria. LCoE covers the cost of building and operating low carbon generation, but doesn't take into account the system-integration costs. This leads to a concern that, on a LCoE assessment, forms of intermittent, inflexible generation look more favourable than alternative technologies that have a higher LCoE, but have a greater degree of flexibility, and therefore significantly lower system integration costs.

The Energy and Climate Change Committee in its review of the Implementation of Electricity Market Reform (2015) found that DECC, the government department responsible for policy at that time, was continuing to fail to ensure that providers of demand-side flexibility (referred to as *demand-side response [DSR]*) were being treated equitably within the capacity market. The National Infrastructure Commission built upon this in its 'Smart Power' report, which called for the government to "make future changes to the capacity market to reduce the costs and barriers to entry for demand flexibility."

Electricity market reform

Electricity market reform (EMR) is a response to help secure the estimated £100bn of capital investment in Britain's electricity infrastructure required to replace the retiring generation capacity and meet growing demand from the low carbon technologies being adopted beyond the meter.

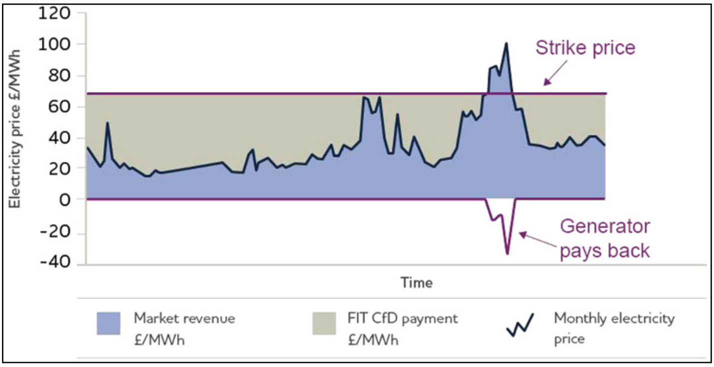
The two key instruments to attract that investment are contracts for difference (CfDs) and the introduction of the capacity market.

Contracts for difference (CfD)

The use of *contracts for difference (CfD)* is intended to provide confidence and help secure investment in all forms of low carbon generation (renewables, nuclear, CCS). CfDs reduce exposure to the price volatility in the half-hourly wholesale electricity market.

Low carbon generators with a CfD still sell electricity into the market as usual, which helps to reduce the level of market and industry process changes. CfDs reduce exposure to changing electricity prices by effectively guaranteeing the price that the generator is paid, irrespective of the wholesale market price. If the market price is below the *strike price* agreed in the CfD, then the price the generator is paid is *topped up* to the strike price. CfDs aren't all one way: when the market price exceeds the strike price, the generator pays back the difference between the wholesale market price and the contracted strike price. This provides the generator with the confidence it needs to secure the investment to develop the new capacity while protecting the consumers' bills from excess costs. Figure 5-1 illustrates the principle of how a CfD works.

CfDs aren't some new invention of the British electricity market; they're an established form of financial contracting. The parties to a CfD effectively take opposing positions. Each makes a value judgment on the level of risk and level of reward that they're prepared to accept. Some of you may think that sounds a bit like spread betting, and some people have compared CfDs to spread betting.



Source: www.emrsettlement.co.uk/about-emr/contracts-for-difference/

Figure 5-1: An example of CfD payments.

Contracting for a CfD for new generating capacity has a couple of challenges:

- **Agreeing to the contract's duration:** Agreeing on a fixed strike price for CfD durations of anything between 20 years and, potentially, more than 100 years if a CfD were to be granted for the lifespan of a tidal generation project is challenging because of the uncertainties of what the market price will do over the long term.
- **Predicting how the wholesale electricity market will vary over the long term:** Judging whether the contract is good value for money can be more difficult.

Potential low carbon generation projects apply for a CfD. Depending on whether the technology is *established* or *less established*, the project might have to compete in an auction in order to be awarded a CfD.

Table 5-1 shows which types of generation technologies are classified as established and which are classified as less established. Clearly, different technologies vary in their impact on the flexibility of the electricity system.

Table 5-1 Technology Classification for CfDs

Established Technologies	*Less Established Technologies*
Onshore Wind (>5MW)	Offshore wind
Solar photovoltaic (PV) (>5MW)	Wave

Established Technologies	*Less Established Technologies*
Energy from waste with combined heat and power (CHP)	Tidal stream
Hydro (>5MW and <50MW)	Advanced conversion technologies
Landfill gas	Anaerobic digestion
Sewage gas	Dedicated biomass with combined heat and power (CHP)
	Geothermal

If a project is granted a CfD, then the generator contracts with the Low Carbon Contracts Company Ltd (LCCC), which is also responsible for calculating and managing the payments to and from the generator under the CfD. The British government owns the LCCC. The costs of the *top-up payments* from the wholesale market price to the agreed strike price to generators with a CfD are funded through the Supplier Obligation Levy, which is a levy on the electricity suppliers – so that's a slightly long-winded way of saying that consumers fund the CfD payments, because the levy is passed through to consumers on their bills.

Considering a few CfD successful allocations

In the first CfD allocation round in February 2015, 27 projects were successful, with 25 eventually agreeing to contracts. The first of these successful contracts, the Charity Farm solar PV project, was commissioned on target at the end of June 2016 and has begun generating. The LCCC has therefore started to fulfill its purpose and make payments under the scheme, paying the generator the difference between the wholesale market price and the agreed strike price in the contract.

However, perhaps the highest profile examples of the use of CfDs are for the proposed new nuclear power station at Hinkley Point C and the Swansea Bay Tidal Lagoon. Hinkley Point C has a strike price of £92.50/MWh generated (this often-cited figure is based on a 2012 price, but is linked to inflation) over 35 years, although the plant life will be considerably longer. By comparison, the Swansea Bay Tidal Lagoon is reported to have an agreed strike price of £96.50 over 90 years. The CfDs for both of these high profile projects are being negotiated bilaterally outside of the usual CfD allocation system!

Capacity market

The objective of the *capacity market* is to ensure sufficient reliable capacity is available to make sure the lights come on when you throw the switch.

The capacity market is open to providers of all types of capacity, including the following:

- New and existing power stations
- Electricity storage plants
- Negawatts of capacity provided by demand-side flexibility (if you're not familiar with the term *negawatt,* it's another one of those made-up words, indicating a reduction in demand and is obviously a play on a negative *megawatt*)
- Interconnectors

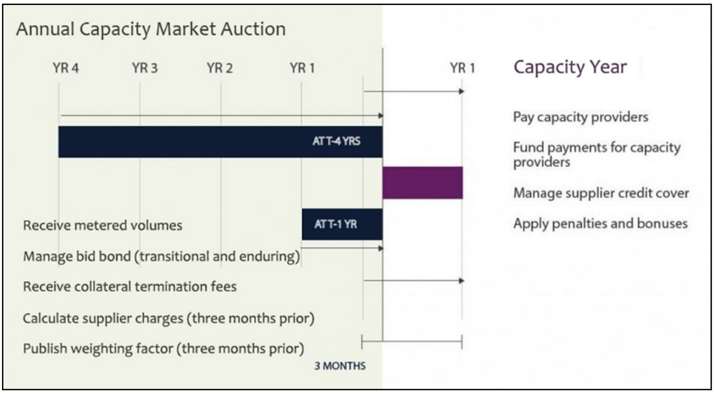
The companies contracted to provide capacity within the capacity market benefit from predictable revenue streams, which are intended to address concerns about investor confidence. In return, providers have to be able to deliver the contracted capacity when contracted to do so, at times when the electricity system would otherwise be forecast to be capacity constrained.

The capacity market sounds great for the capacity providers, but could be potentially costly. So how do consumers (who ultimately pay for it) know they're getting a good deal that's keeping electricity both affordable and reliable? Contracts aren't just handed out to anyone who applies for them. The following explains how the contracts are awarded:

- Companies have to bid into a competitive auction process (referred to as the *capacity auction*). The auction effectively sets the level of *capacity payments* (what the successful bidders will get paid).
- Like any good auction, the more capacity being bid into the auction relative to the level of capacity required to deliver the specified level of security of supply, the better the price that will be achieved. (The only difference here is that the definition of a good price for the consumer is a lower price!)
- A provider doesn't have a reason to lowball its price to secure a capacity agreement. If the provider can't deliver

the capacity when required, then it's subject to penalty clauses in the contracts.

- The capacity auctions take place four years ahead of delivery, with a subsequent auction held one year ahead. Figure 5-2 shows the timeline for capacity auctions. The first capacity auction took place in December 2014, for delivery obligations beginning in October 2018.



Source: www.emrsettlement.co.uk/wp-content/uploads/2014/03/capacity-diagram-v3-1024x579.jpg

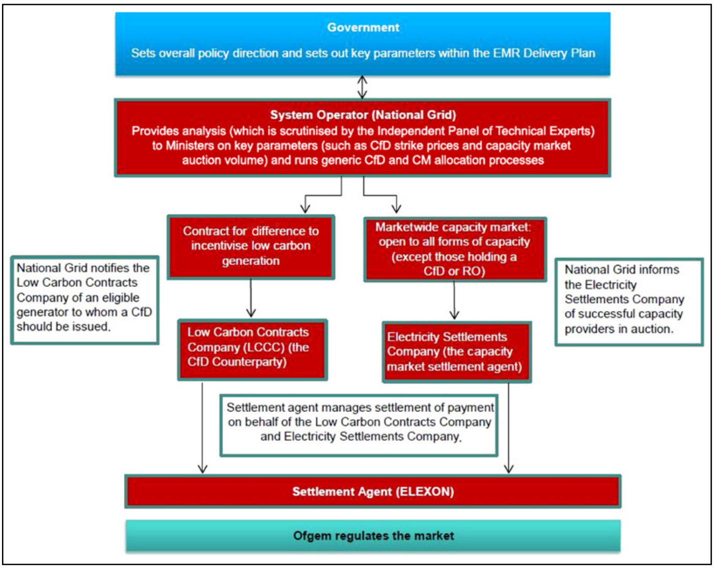
Figure 5-2: Capacity auction timeline.

However, concerns have been expressed about how unfair the treatment of demand-side response (those *negawatts*) is within the capacity mechanism. Although capacity agreements for new generation can be of up to 15 years duration, providers of DSR-based capacity are limited to bidding for capacity agreements of up to one-year duration. The Energy and Climate Change Committee views this as a clear barrier to the development of demand-side response and the potential for demand-side flexibility. The lack of certainty created by the year-by-year time frame for demand-side flexibility is seen as a disincentive to both investment and to potential providers changing their business practices.

The Electricity Settlements Company (ESC) oversees settlement of the capacity market. However, the LCCC, on behalf of the ESC, undertakes the actual capacity market settlements operations. The capacity market settlement services provider manages the payments to capacity providers who have met their capacity market obligations in their capacity agreement.

Similar to CfDs, the costs of the capacity payments are funded through a levy on electricity suppliers, which of course means that consumers ultimately pay, because the costs are passed through to consumers on their bills.

Figure 5-3 illustrates the respective roles and responsibilities of the different parties involved in CfDs and the capacity market.



Source: www.emrsettlement.co.uk/wp-content/uploads/2014/03/Institutional-framework1.jpg

Figure 5-3: Responsibilities of the key actors in EMR.

Knowing Who's Who in Driving Thinking

Britain faces many challenges in the current market structure to ensure that electricity available when needed so that people's smartphones stay charged and that they can still seek out Pokémon or whatever the latest fad is.

These sections discuss the key players helping to transform the trilemma into a virtuous circle.

The Energy Systems Catapult (ESC)

The Energy Systems Catapult (ESC) is one of a number of catapult initiatives set up by Innovate UK (an executive non-departmental public body, sponsored by the Department for Business, Energy & Industrial Strategy with the purpose of identifying and accelerating scientific and technological innovations that have the potential to grow the UK economy).

The ESC's role is not simply to accelerate technology innovations that will transform the energy system (so its remit is more than just electricity), but also to address the market mechanisms and business models that will enable investment in and commericalisation of those technologies.

In the context of electricity system flexibility, the ESC's work on the Future Power System Architecture (FPSA; refer to the nearby sidebar) and the associated recommendations will undoubtedly play a significant role in informing thinking about the shape of Britain's power system in the future and the policies needed to enable that transition. If you're not familiar with it, be prepared to hear whole-system approach a whole lot more. The *whole-system approach* is about treating the electricity system in its entirety, from power station to beyond the plug, and ensuring that decisions are made in the context of the whole system.

What's the FPSA project?

The Future Power System Architecture (FPSA) project was commissioned by DECC and led by the Energy Systems Catapult (ESC) and the Institution of Engineering and Technology (IET). Its objective is to anticipate the transformative level of change to the power system architecture by 2030 in order that it can continue to function both demand and supply change in response to decarbonisation, technological change and the new business models. The project identified 35 new and significantly modified functions needed to meet the 2030 goals.

The Institution of Engineering and Technology (IET)

The Institution of Engineering and Technology (IET) is one of the world's largest engineering institutions. It collaborated with the ESC on FPSA. The IET produced the 'Handling a Shock to the System' report in 2013. The subsequent reports on 'Transforming the Electricity System' and the 'Case for a System Architect' in 2014 were precursors to the FPSA. The IET also introduced the concept of the whole-system approach.

The Smart Grid Forum

The Department of Energy and Climate Change (as it was in 2011) and Ofgem jointly established the Smart Grid Forum as a platform for industry, government and other stakeholder groups to collaborate on the challenges of transitioning Britain's energy system to one that is capable of supporting a decarbonised world.

The Department of Business, Energy and Industrial Strategy (DBEIS)

DBEIS was formed in July 2016, taking on the responsibilities formerly held by the Department of Energy and Climate Change.

DBEIS is ultimately responsible for setting the policies and enacting the required legislative frameworks that will determine the future shape of Britain's electricity system and whether the lights stay on. So no pressure then!

REMEMBER

DBEIS is working on areas that are important to delivering the right level of flexibility in the electricity system, including the following:

- Reforms to the capacity market
- The government's role in enabling smart energy
- The Smart Metering Implementation Programme

- Independent Review of Consumer Advice, Protection, Standards and Enforcement (also referred to as the "Bonfield Review")
- Competition for Small Modular (nuclear) Reactors (SMRs)

Ofgem

Ofgem has a number of initiatives underway to support the transition to a smart electricity system. They are as follows:

- **Smarter markets:** Creating a more dynamic and competitive energy market by getting consumers more involved and addressing barriers to consumer choice
- **Electricity settlements:** Removing barriers to half hourly settlements
- **Demand-side flexibility:** Incentivising the availability and use of sources of flexibility
- **Faster switching:** Improving the change of supplier process and customer experience and increasing consumer choice
- **Non-traditional business models:** Understanding the barriers to new business models that exist and how these should be regulated in the future
- **The Network Innovation Competition:** Funding distribution and transmission network operators to understand how they'll operate with smarter grids

National Infrastructure Commission

With the publication of its 'Smart Power' report, the National Infrastructure Commission set a clear direction towards the value of flexibility in a decarbonised electricity system.

Releasing the Value of Flexibility

Flexibility in the electricity system is important to ensuring that the lights stay on and that the electricity you consume is at a reasonable price. Also, the system is flexible today, so this isn't something new, but things are changing.

Existing generation capacity is due to close (some of it's just old and has come to the end of its life, and some of it has to close to achieve those legally binding climate goals). Add to that demand being on the increase (through economic growth and the electrification of energy consumption from other sectors). And then add in that the current evaluation criteria seem to favour investment in intermittent, inflexible generation and there's a whole set of challenges that have to be handled.

The good news: the size of the prize for accessing new sources of flexibility is significant. All the market participants see the strategic significance of flexibility to their businesses growing by 30 per cent by 2030, with demand-side flexibility being projected as the most important source of that flexibility.

However, the different market roles see the value to their businesses having different drivers. For example, the network operators eye the main value coming from the ability to manage constraints on their infrastructure and therefore defer or avoid capital investment in reinforcing their assets. On the other hand, the energy companies see the value coming from new business opportunities and balancing the system.

Therefore, the question is whether the value to the different market roles is coincident or conflicting. In other words, by seeking to increase demand to take advantage of low wholesale energy prices due to an abundance of supply, does the energy retailer create a constraint on the network, causing the network operator to seek to reduce demand? If so, then the market structure needs to be able to balance the benefit accruing to one party with the loss of benefit caused to the other party, which seems to support the calls (again) for a whole-system approach that recognises the market structure and arrangements need to be considered an integral part of that 'system' if the full value of flexibility is to be realised.

Chapter 6

Ten Tips about the Value of Energy Flexibility

In This Chapter

- Realising that economic assessment depends on the assessment criteria
- Spotting when sound bites are less that the whole picture
- Understanding the importance of *system-integration costs*

Here's a collection of key takeaways about flexibility that can assist you in understanding the topic in a nutshell. They may even help you to sound like you know what you're talking about in the unlikely event that the conversation around the water cooler turns to flexibility in the electricity system.

Don't Allow Sound Bites to Blind You

A lot of opinions differ about the future of flexibility in the electricity system, and it seems like everyone has a favourite statistic to support her or his view, albeit about the value (£8bn per annum in 2030) or the adoption rates of low carbon technologies. The challenge is to move beyond the headline-grabbing sound bites (both visual and auditory) and understand the basis of the numbers being quoted and their relevance to any decisions.

For instance, the £8bn per annum figure in 2030 is based on reducing the carbon intensity of the GB electricity production to 50g/kWh and is a *gross* benefit. The Committee on Climate Change's Fifth Carbon Budget suggests that the goal should be to reduce the carbon intensity to closer to 100g/kWh with associated gross benefit of £3bn to £3.8bn per annum – which still isn't to be sniffed at!

Be Wise – Build on the Experience of Others

A lot of relevant experience is around, so all you need to do is tap into it to see what others before you have discovered. For example, the industrial and commercial electricity users have been benefitting from providing demand-side flexibility for years. Ask yourself how that information may apply in the mass market where there are lots of consumers, all with a small amount of demand flexibility, which when aggregated becomes material.

Some of the innovation projects funded through Ofgem's Low Carbon Network Fund and its replacement, the Network Innovation Stimulus, have delivered some important lessons about consumer attitudes and responsiveness to price signals related to the availability of intermittent renewable generation. A great example is the Wind Twinning approach employed within UK Power Networks' Low Carbon London Programme. Utilities in other countries have similar programmes, such as ENEXIS in the Netherlands with its Jouw Energie Moment (Your Energy Moment) smart home project, or the transactive energy approach in the United States.

TIP

You can also check out other sectors for relevant experience besides the utilities sector. Other sectors have been through transformative change of both the technologies in networks and of what is connected to those networks to create a system that embraces innovation in the products and services offered to consumers. For instance, take a look at the telecommunications sector and how, over a 30-year period, it moved from pretty crude analogue devices that just about allowed you to speak to someone to where the sector is today where you carry your life on your phone (if it's fair to call it a phone these days).

I'm not suggesting that any of these examples provide the answer for how flexibility in the electricity system might work in Britain in the future (they have their own advocates, with their own sound bites and their own reasons for promoting them as the answer to every problem). The challenge is to understand why those projects have been successful (or not). Consider these issues:

- What are the drivers in the local market?
- What are the differences to the drivers here in Britain?
- What's relevant? Dismiss what's not.

Who knows, the experience of others may stimulate some new thinking that is relevant to your market.

Avoid Predicting the Future Based on the Past

Fundamental change continues to happen in both the generation mix on the supply side and on the demand side through the progressive adoption of low carbon technologies. But that's not occurring quickly. Indeed, change may feel like it's not happening at all, that is until you take a look back and see how much has already changed.

How often have you heard people say that something has been tried before and that it didn't work then, so it won't work now? Just because something didn't take off in the past doesn't mean that it won't now or in the near future. Maybe that something was ahead of its time and its time is coming now. Its costs may have come down (think about solar PV costs approaching grid parity), or the costs of alternative solutions may have gone up (think about the fossil fuel price fundamentals). Maybe people's attitudes have become more receptive, or an enabling infrastructure has been implemented (think about smart metering, you can't offer dynamic time of use tariffs without it and approaching ten per cent of homes now have one). Or maybe the rules of the game have changed (think about the new policies, regulation and incentives).

Stay Resilient

There is no single panacea for a perfect electricity system; there are just too many variables. The electricity system has proved to be remarkably effective at keeping the lights on in the face of falling capacity margins and supporting an evolving mix of generation technologies and ever changing demand.

A lot of new technologies and services are coming along all the time and, if anything, the pace of innovation is accelerating. The challenge is to ensure that the system remains resilient as today's innovations mature and eventually become redundant tomorrow.

Don't Let Uncertainty Be an Excuse for Doing Nothing

With the increasing complexity of the electricity system and the differing pace of change in different parts of the system, the only common factor is that the pace of innovation is increasing. In other words, waiting may seem like the safest option.

A good option may become cheaper or a better option may arrive and you know no one will thank you for making a decision that could leave investment stranded when a pause could have provided more certainty. The problem is that something cheaper or better will always be just around the corner; and no one will thank you for doing nothing when you should have done something!

Keep moving forward, but follow a strong innovation process that controls your risk exposure – and remember that a decision to do nothing isn't risk free. Of course, you'll have accepted that there is no magic answer and that you'll have a diverse mix of solutions live at any time, helping to spread your risk.

Recognise Some Options Are Mutually Exclusive

How often have you heard people say, "Let the market decide"? That's fine when you're talking about fast-moving consumer goods, but does it hold true for major investments in critical national infrastructure? If you're going to resolve the *trilemma* and create a virtuous circle where decarbonising the electricity system affordably delivers security of supply, then you're going to need a view of the economics of the whole future power system architecture. (Refer to Chapter 4 for discussion on the trilemma.)

For instance:

- A drive towards decarbonising electricity production through solar and wind increases inflexibility on the supply side, which has the effect of increasing the value of storage and demand-side flexibility to compensate.
- Cost-effective carbon capture and storage or a push towards tidal would create more flexibility in the generation mix, meaning storage and demand-side flexibility have a lower value in such a system.

Follow the Money

The comparative economics of the different technologies determine how successful they are in being adopted into the electricity system. The question is whether the assessment criteria being used produce a fair comparison of those economics. Does the *levelised cost of energy*, which covers the cost of building and operating generation capacity, truly reflect the overall costs associated with different technology choices?

TIP

Get you head around the significance of the *system-integration costs* (the costs associated to operating different types of generating capacity in the context of the whole electricity system). Adopting a *whole-system approach,* which is receiving ever increasing advocacy, must mean that system integration costs need to be factored into the assessment of different generation-mix options and that the levelised cost of energy approach gives too narrow an assessment. (Check out Chapter 5 for specifics about these two different approaches.)

With growing availability of demand-side flexibility from the progressive adoption of low carbon load and storage becoming more economic by the day, then increasing inflexibility in the generation mix becomes less of a challenge. Demand-side flexibility and storage may just be the solution that turns the trilemma into a virtuous circle by providing the additional flexibility that compensates for the system integrations costs associated to inflexible, intermittent, low carbon generation.

Be Flexible in Your Flexibility Plan

Any electricity system is a complex, interconnected beast. Overlay layers of deregulation onto an already complex system and what do you end up with? Well, the British electricity market model of course.

This means that it's impossible for any plan to cover all scenarios, and as soon as you start to make interventions, then you start to change the system and your plan begins to be undermined.

So, make sure your plan for flexibility has flexibility!

Ask a Question If Something Doesn't Make Sense

When you look at the *whole system* (which includes the market arrangements as well as the power station to beyond the plug) in Britain, it's significantly more complicated than other countries that have *vertically integrated models* (one company has responsibility from its power station to your plug).

There's very good reasons why the British electricity system has got to where it is today, but there's a lot of accepted wisdom about that – some of which is opinion rather than fact. With fundamental changes coming, don't be afraid to ask, and keep challenging, why things are the way that they are.

May You Live in Interesting Times

The energy sector is going to be one interesting place to work over the coming decades, so I hope you view *interesting times* as a blessing rather than a curse.

Oh, and if you have kids, nephews or nieces who are still at school and they're wondering what career to take up, then give them this book for Christmas if they're up for a challenge. As Chapter 5 discusses, the future looks bright (and, yes, the pun is intended).

Glossary

BIS: The *Department of Business, Innovation and Skills* was merged with DECC to form DBEIS in July 2016.

Capacity margin: The level by which available electricity generation capacity exceeds the maximum expected level of demand, expressed as the percentage. Normally shorthand for *de-rated capacity margin.*

Capacity market: Established under electricity market reform (EMR), the capacity market makes sure that sufficient reliable capacity is available, when required, so that the lights come on when the switch is thrown.

CCC: The *Committee on Climate Change* was created under the Climate Change Act 2008 to advise the UK government and devolved administrations on setting emissions targets. The CCC reports to Parliament on progress made in reducing greenhouse gas emissions and preparing for climate change.

CCS: *Carbon capture and storage* is an approach to enabling fossil fuel generation to be decarbonised by collecting the carbon dioxide produced before it's released into the atmosphere and then storing it (potentially in retired gas and oil fields).

CfD: A *contract for difference* is an established form of financial contracting, often compared to *spread betting.* In the context of EMR, a CfD is used to reduce exposure to electricity price volatility.

CHP: *Combined heat and power* is a form of generating heat that also produces electricity as a by-product.

Climate Change Act 2008: Parliament enacted it, making Britain's climate change commitments legally binding.

DBEIS: The *Department of Business, Energy and Industrial Strategy* is a government department created in July 2016 that picked up responsibility for energy policy from DECC.

DECC: The *Department of Energy and Climate Change* was the government department that held responsibility for energy and climate change policies until they transferred to *DBEIS*.

De-rated capacity margin: A measure of the *capacity margin* in which the total available capacity is de-rated by weighting factors that reflect the level of availability of a generation technology during the seasonal period being evaluated, for example, capacity available from onshore wind is de-rated far more than capacity available from nuclear generation.

DSR: *Demand-side response* is generally considered to be the reduction of demand in response to insufficient generation capacity being available. However, it can be equally applied to increasing demand in response to excess generation or shifting demand to avoid short-term constraints.

DUKES: Standing for *Digest of UK Energy Statistics*, it's an useful reference for quantitative data on the UK energy markets.

EMR: *Electricity market reform* is a mechanism intended to attract the required investment in Britain's electricity infrastructure by providing investors with the level of certainty that they require to take investment decisions.

ESC: The *Electricity Settlements Company* is responsible for overseeing the settlement of payments under the capacity market.

ESC also stands for the *Energy Systems Catapult*, which is responsible for accelerating technology innovations that will transform the energy system, including the associated market mechanisms and business models.

FES: The National Grid annually publishes the *Future Energy Scenarios* to support future capacity planning.

FPSA: The *Future Power Systems Architecture* is a project originally commissioned by DECC and being jointly run by the IET and the ESC (the *Catapult* one) to understand how the end-to-end architecture of the electricity system needs to evolve to support low carbon technologies on both the demand side and on the supply side.

Gross capacity margin: A measure of the *capacity margin* in which the total available capacity is the total or 'rating plate' capacity of all generation capacity, without 'de-rating' factors being applied. If the *capacity margin* is higher than you were expecting, then it's most likely the *gross capacity margin* that you're looking at.

HPC: Widely used abbreviation for *Hinkley Point C*, the first of a new generation of nuclear reactors that, at the time this book is being finalised, is still awaiting final approval from the British government.

IET: The *Institution of Engineering and Technology* is one of the world's largest engineering institutions. It collaborated with the ESC on the Future Power System Architecture (FPSA) project.

LCCC: *Low Carbon Contracts Company Ltd* (LCCC) is the contracting counterparty for *CfD*s and is responsible for calculating and managing the payments to and from the generator under the CfD.

LCoE: *Levelised cost of energy* covers the cost of building and operating low-carbon generation and is used to compare the relative merits of different forms of generation. However, LCoE doesn't take into account the *system-integration costs*.

MW: *Megawatt*, or a thousand kilowatts, is the preferred unit of power output or capacity of a power station, although bigger power stations may be given in gigawatts (GW), which is one thousand megawatts.

Negawatt: *Negawatts* of capacity is one of those made-up words that have come into common(ish) use. It's intended to indicate a reduction in demand and is a play on a negative megawatt. Negawatts are provided by demand-side flexibility.

NIC: The *National Infrastructure Commission*, the author of the 'Smart Power' report, is influential in the thinking about the significance of flexibility in the electricity system.

NIC also stands for the *Network Innovation Competition*, one of Ofgem's innovation funding mechanisms for the distribution network operators.

NISM: A *notice of insufficient supply margin* is one of the system operator's more recognised, if uncommon, communications to the market that the forecast demand is approaching the available generation capacity. It's a precursor to demand reduction.

Ofgem: The regulator of the gas and electricity markets in the UK.

PV: Photovoltaic solar generation. Photovoltaic materials transform the sun's energy into electricity.

SGF: The *Smart Grid Forum* provides a platform for industry, government and other stakeholder groups to collaborate on the challenges of transitioning Britain's energy system to one that is capable of supporting a decarbonised world.

SMR: *Small modular (nuclear) reactors* are an alternative approach to nuclear generation where the reactors are smaller and produced to a standard design in a factory and shipped to site rather than the conventional approach of building the reactors on site.

STOR: *Short-Term Operating Reserve* refers to contracts put in place by the system operator for access to reserve capacity in the form of either generation or demand reduction.

Supplier obligation levy: This levy is the means of funding the CfDs. The electricity suppliers fund the CfDs, which of course means that ultimately the customers pay through their bills.

System-integration costs: The costs associated to bringing different types of new generation into the electricity system, providing a fully cost reflective assessment of the economics of these technologies. The system-integration costs for a technology vary depending on the generation mix when they're being integrated.

Trilemma: Another made-up word that has come into common(ish) use within the sector. It refers to the three pillars of energy policy (security, affordability and climate change) and the choices that need to be balanced between the three elements.

TWh: *Terawatt-hour*, which is one billion kilowatt-hours of energy. It's the preferred unit used to describe the national annual energy demand or the output from a power station.

Whole-system approach: This approach is being advocated by the ESC (the Catapult one) and the IET in their work on the FPSA project. It's used to describe the need for the electricity system to be considered in its entirety, recognising the changing nature of supply (generation) and demand (consumption) through the adoption of low carbon technologies at both ends of the system.

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