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Flexible Electricity Systems

The electricity system of Great Britain (GB) is becoming increasingly decentralised, with more complex patterns of power production, transportation and consumption. New types of flexibility are being developed to manage these changes. This POSTnote reviews ways of developing flexibility, as well as the technical and economic barriers to doing so.

Overview

- Changes to power, heating and transport require a more 'flexible' electricity system, where sources of supply and demand can be rapidly adjusted to help balance the grid.
- Flexibility may offer a more secure supply and consumer savings. Some users will benefit more than others, however, and flexibility may present cyber security issues.
- Supply-side sources of flexibility include more flexible generation, electricity storage, and interconnection.
- Demand-side flexibility provide incentives for consumers to increase, decrease or move the timing of their demand at key times.
- Network operators' roles are changing to facilitate flexibility. Some networks will need strengthening with new lines, but in places local flexibility solutions could offset this.

Background

The electricity system of England, Scotland and Wales (GB) has historically developed around a 'centralised' system, where a small number of large power stations provide the majority of electricity supply. Centralised power has been transported in one direction from generators to distant consumers via the transmission and distribution networks (Box 1). However, three processes are driving new long-term changes in the system:[1-5]

- **Decentralisation.** Small power generation (such as solar panels or combined heat and power plants), situated close to consumers, are providing an increasing proportion of GB power supply.
- **Decarbonisation.** In order to meet long-term carbon dioxide (CO_2) emissions reduction targets in the power sector,[6] fossil fuel use (particularly coal) is declining.[7] This is in part being replaced by intermittent renewable generation (POSTnote 464) which is decentralised.
- **Digitisation.** Ageing electricity networks and ICT infrastructure are being upgraded, increasingly using data and automated processes to make the system work more efficiently. This includes the rollout of 'smart' electricity meters.

Much of the new generation capacity is weather-dependent, meaning supply does not necessarily coincide with demand. Decentralised power can flow in multiple directions across the network between dispersed generators and consumers.[8] These factors will present challenges for balancing supply and demand.[5,9-12] Furthermore, the use of electricity to supply future heating and transport is expected to increase. This may require that parts of the network be 'strengthened' (by increasing their capacity with new wires and cables ('lines'), or reducing peak power flows across them).[13]

A more 'flexible' system is being developed to address these challenges.[14] According to the energy regulator Ofgem, flexibility is the ability to rapidly adjust supply or demand in response to a signal (such as changing prices) to help manage the electricity system.[15] New and established technologies are increasingly providing system flexibility, and the roles of network operators are changing. This POSTnote examines these sources of flexibility, changes to the networks, and potential associated policy challenges.

Grid Balancing and Flexibility

National electricity demand broadly follows a predictable pattern each day, with peaks in the early evening and lows in the early morning.[16] Electricity supply and demand are matched on a second by second basis.[17] National Grid, the system operator, is responsible for this 'grid balancing' (Box 2).[18] Increasing system flexibility will allow National Grid to

Box 1. Key Components of the Electricity System

- **Generators** produce electricity and sell it in the wholesale market.[19] In 2017, 40% of UK electricity came from gas, 21% from nuclear and 29.5% from renewables.[20] Peak demand during winter evenings is approximately 50 gigawatts (GW).[21]
- **The transmission network** is the network of high-voltage lines that carries power across long distances, from large generators (such as gas power stations) to large industrial consumers and distribution networks.
- **The distribution network** is the low-voltage network that has conventionally carried power from the transmission network to consumers. Fourteen distribution networks cover separate areas of GB. Six distribution network operators (DNOs) own and are responsible for operating and maintaining these.[22]
- **Suppliers** purchase electricity in the wholesale market and sell it to consumers.[23] They supply and fit smart meters (Box 4). [24]
- **Aggregators** are companies that have contracts with many users who can increase or decrease their demand. They can adjust these users' demand to sell balancing services (Box 2).[25] Some existing suppliers also act as aggregators.

Box 2. Balancing Electricity Supply and Demand

Electricity is traded on the wholesale market in advance of use, based on forecasts of supply and demand. Forecasting inaccuracies, or a generator or line failure, require National Grid to take steps to balance the grid, by using **system inertia** and procuring **balancing services**.[26] There is generally an imbalance between supply and demand in the range of 0–2GW.[27]

- **System inertia** is provided by rotating turbines in conventional generation and allows power to be maintained for a short period of time following an imbalance.[28] Lower levels of conventional generation would lead to less inertia being available.
- A number of **balancing services** are used to make up for any remaining imbalance. Different services act over a range of timescales, from seconds to hours.[29-32] National Grid contracts these from different companies including generators, electricity storage providers and large consumers with the ability to alter their demand. National Grid recovers the costs of balancing services from generators and suppliers, who then pass them to consumers via electricity bills.[33]

The **Capacity Market** is an additional market in which actors (including generators, storage and DSR providers) are paid to provide additional electricity during peak demand times.[34] They are contracted to remain available in case of a spike in demand or failure of multiple large plants. These operators act as an insurance for the grid.[35,36]

balance at shorter timescales and will help distribution network operators (DNOs, Box 1) manage local networks more actively. A number of UK projects aim to develop more electricity flexibility (Box 3).

Supply Side Sources of Flexibility

New sources of flexibility may act either by varying the supply of electricity to the system or the amount of demand on the system.[37,38] Supply-side flexibility sources adjust the amount of electricity provided to the system to match demand. This may be provided by flexible generators, electricity storage or interconnection to overseas networks.

Flexible Generation

Combined cycle gas turbines currently provide the greatest proportion of GB supply and are typically used to provide power as a constant 'baseload', as well as to top up at peak times. They can vary their output to provide some balancing

Box 3. Flexible Electricity System Research & Innovation

There are a number of industry- and Government-led programmes that aim to develop electricity system flexibility.

- **The 2017 Smart Systems and Flexibility Plan** includes 29 actions for Government and Ofgem to adapt the regulatory framework to develop flexibility. By August 2018 11 had been completed.[14] The plan also allows stakeholders to have input into the development process, and includes £70 million to develop new smart technologies.[14,39]
- **National Grid's 2018 Innovation Strategy** outlines its plan to provide financial and technical support to electricity system innovation projects.[40] National Grid has launched a project to use small scale renewables to support the grid[41] and new solutions to grid balancing.[42]
- **The Energy Networks Association (ENA) Open Networks Project** allows network operators to share information and expertise on future flexibility needs. ENA's biennial Innovation Strategy identifies areas of innovation in the system and aims to increase collaboration between network operators.[13]
- **The Energy Systems Catapult's Future Power System Architecture Programme** examines how new technologies and processes may be needed to provide future system flexibility.[43]

services (Box 2), though not as quickly as electricity storage or demand side response (DSR) (see *Demand Side Sources of Flexibility*).[44,45] New designs are being developed that can provide greater flexibility while maintaining efficiency.[46] Gas generators that provide flexibility may need to be kept on standby more often (generating a lower power output) requiring Capacity Market payments to remain economical (Box 2).[36] This could lead to lower capital cost but less efficient generators being built.[47]

Currently, nuclear power in GB operates as a baseload for economic reasons.[48,49] It is technically possible to use nuclear power (particularly newer designs) to meet changing demand by altering output,[50-54] but operators would require new permissions and procedures to do so.[47] Designers of small modular reactors (POSTnote 580) suggest they may be able to generate power more flexibly in future.[55]

Electricity Storage

Energy storage (POSTnote 492) allows surplus electricity to be stored as other forms of energy until it is required, when it can be re-released as electricity. Storage can be used with variable renewable generation, such as solar, to help provide a more constant supply. It can also provide flexibility services, as well as help reduce the power that is needed to be carried on certain parts of the network. This can reduce the need to lay new lines (see *Network Strengthening*).

There are multiple electricity storage technologies operating in GB. Pumped hydropower and lithium-ion batteries are the most common (other forms exist but are in earlier stages of development).[56-59] In 2016 there were 3.2 gigawatts (GW) of storage capacity in the UK (primarily pumped hydropower).[60] Although the amount of storage is currently small compared to generation capacity (81GW in 2017),[20] decreasing technology costs have encouraged growth. Lithium-ion battery costs have approximately halved in the last 2 years.[61] Battery storage currently provides balancing services to the grid (Box 2), rather than storing energy across longer timeframes such as weeks.[62] Stakeholders suggest that battery storage has in part been restricted by regulatory barriers such as 'double charging' (whereby network operating costs and other charges are levied twice).[63,64,65] A number of actions under the Smart Systems and Flexibility Plan are seeking to address these barriers and facilitate the use of storage in conjunction with intermittent renewables.[14,66]

Interconnectors

The GB transmission system is linked to those of overseas electricity networks via a series of subsea 'interconnector' cables, allowing GB to import and export electricity (POSTnote 569). Currently there is 1GW of interconnection between GB and the island of Ireland and 3GW between GB and continental Europe (this is expected to at least double by 2030).[67] Interconnector cables provide flexibility as they can accommodate changes in the amount of power flowing across them in very short timescales, and they have previously been trialled in the balancing market.

Demand Side Sources of Flexibility

Demand side sources of flexibility provide financial and other incentives to consumers to alter their demand, enabling it to coincide with times of high availability of renewables or low prices. Demand side sources of flexibility comprise demand-side response (DSR) (POSTnote 452) and demand side management (DSM):[68]

- **Turn-down DSR:** Users reduce power consumption, reducing demand on the system.
- **Turn-up DSR:** Users increase demand during times of excess supply.
- **DSR by on-site generation:** Large consumers use on-site generators such as storage and combined heat and power systems to provide for their own needs, lowering demand on the system.
- **DSM:** Users change the timing of an energy-using process to shift demand away from peak hours.

These can be procured from energy-intensive industrial or commercial consumers, or from more distributed sources such as residential consumers or electric vehicles (EVs).

National Grid aims to procure 30–50% of balancing services from demand-side sources by 2020,[69] and DNOs are expected to increasingly procure them in future (see *Upgrading the Network for Flexibility*). A large proportion of DSR in the UK is operated by aggregator companies (Box 1).[70,71] Aggregators control assets from a central control room. They are able to adjust their customers' demand to provide 'pooled' flexibility in response to signals from network operators.[25]

Industrial and Commercial Demand Side Flexibility

Industrial and commercial consumers account for around two thirds of UK demand. They can provide flexibility in a number of ways, for example by temporarily adjusting refrigeration,[72] energy-intensive activities (such as manufacturers' cast iron furnaces),[73] heating or motor and pump use.[74] These activities may be shifted to times of low demand using DSM.

Industrial and commercial DSR could potentially reduce energy-intensive consumers' costs while offering significant system flexibility.[75,76] In 2016, Ofgem estimated that it was technically feasible for UK industry and commercial consumers to provide 3GW of turn-down DSR and 2GW of turn-up DSR (around 6 and 4% of UK peak demand). [21,74] Most of this is currently unused, but government and National Grid initiatives aim to address this (Box 3).[14,77] Barriers to industrial and commercial DSR identified by Ofgem include companies' concerns around potential risks and interruptions to their main business operations, and difficulties in understanding its monetary value. [78,74]

Flexible Residential Demand

DSM can be used by domestic consumers to adjust their consumption patterns, using less electricity during times of high demand or more during times of low demand. Historically this been done manually, using domestic appliances at night with an Economy 7 tariff to benefit from lower electricity prices.[79] There is currently little use of residential demand-side flexibility, partly because of a lack of price incentives. In future, automated DSM may be provided by smart domestic appliances and smart heating thermostats. Future smart meters and half-hourly pricing (Box 4) would help facilitate residential DSM with time-of-use pricing. Supporting smart homes and businesses is a key aim of the Smart Systems and Flexibility Plan.[14] However, uncertainties exist around the extent to which consumers are likely to engage in residential DSR.[80-83]

Flexible Demand and Electric Vehicles

EV ownership is expected to increase significantly.[5] UK Government policy aims to end the sale of new petrol and diesel cars and vans by 2040, and to install EV charging points in all new-build homes.[84] EV charging could present challenges and opportunities for network operators.[85] A large number of owners choosing to charge at peak times could place large capacity burdens on the transmission and distribution networks. National Grid has forecasted that EVs may add 2.6–8.1GW of peak demand by 2030.[5] National Grid and DNOs are looking at ways to manage this using 'smart' infrastructure (chargers that can send and receive data) and incentives for off-peak charging.[86] Forecasts

Box 4. Smart Meters

As part of a Government rollout programme, all GB households are being offered a smart electricity meter (POSTnote 471) by 2020.[87] These provide consumers with real-time information on their electricity usage, and allow more accurate billing and potential energy savings.[88] Smart meters could help to facilitate automated residential DSM and allow suppliers to record electricity demand over half-hourly periods across the day (which current meters cannot do). This allows suppliers to make more accurate demand forecasts (reducing the level of balancing required by National Grid) and provide time-of-use pricing that is more responsive to demand.[89] However, smart meter rollout has to date been slower than expected, and consumers have reported technical problems with first-generation meters.[90,91]

Box 5. DNO To DSO transition
DNOs have conventionally held a passive role in maintaining the distribution network. They are currently undergoing a transition towards a 'distribution system operator' (DSO) role. DSOs will take a more active network monitoring role and are developing a framework for using flexibility services to manage flows across their networks. All DNOs are currently undergoing this transition and are working with the Energy Networks Association on the Open Networks Project. A BEIS-commissioned independent review on electricity costs recommended that this process be extended to the creation of regional system operators, who would take on some of the roles of National Grid and DSOs for specific areas.[92,93]

suggest that peak charging is likely to be manageable with smart charging.[5,94]

Aggregated EV batteries could also be used to provide 'vehicle-to-grid' (V2G) DSR, acting as a source of electricity storage when plugged in and not in use.[95] V2G is in early development, and uncertainty exists around how consumer behaviour and technology will develop.[96] In 2018 the UK Government announced £30 million in funding for 21 V2G projects covering 2700 vehicles.[97,98]

Using Flexibility within Networks
Developments in the electricity system will require changes to transmission and distribution network infrastructure.[43] The increasing need for flexibility at the distribution level, and future use of electricity for heat and transport, requires that the role of DNOs changes. They are becoming more active 'distribution system operators' (DSOs) (Box 5), whose role is similar to that of National Grid at the transmission level. Some network infrastructure may need strengthening to accommodate changes in power flowing across them, and visibility is increasing across the distribution network to track these flows more easily.[99]

Network Strengthening
New sources of demand (such as increasing EV ownership and electrification of heat), in numerous different locations, will place new pressures on networks.[3] Network lines have limited capacities, and in some places networks need to be strengthened by laying new lines to allow more power to flow. Alternatively, localised storage or flexible demand can be used to reduce the power flowing in or out of a specific area.[100,101] This may in some cases provide a lower cost or quicker solution than new lines.[13,102]

Monitoring and data
DNOs currently have a limited ability to view how power flows around the distribution networks,[103] and are increasing network monitoring as part of the DSO transition process (Box 5). Increased monitoring, including via smart meters, will allow DSOs to take a more active role in operating their networks and relieving local constraints. The growth in the amount of data collected has prompted some operators to investigate the use of machine learning for some processes.[104,105] Collected data could be utilised at the DNO level or higher up the network, and there are concerns around cyber security (*Cyber Security and Data Security*).

Localised Grids
Some stakeholders have suggested that it may be more efficient to balance flexible systems at a more local level (such as within a postcode) than at the transmission level. This could use, for example, decentralised generation and storage, including smart EV charging and V2G services.[106] Any remaining imbalance would then be balanced at the distribution and ultimately national level. Trial 'microgrids' (which use a range of flexibility assets and distributed ledger technology (POSTbrief 28) to allow electricity trading between local consumers) are in development in a number of places including Cornwall and Brooklyn, US.[107-110]

Policy Challenges
In 2016 the National Infrastructure Commission (NIC) suggested that developing a more flexible electricity system could increase the security of electricity supply while lowering carbon emissions and providing significant savings for consumers.[3,12] However, potential policy challenges of increasing flexibility include the distribution of costs and benefits, and concerns around cyber security and privacy.

Distribution of Costs and Benefits
The NIC estimated that a more flexible electricity system could save consumers £8 billion a year by 2030.[3] However, there are costs associated with developing flexibility, such as network and balancing costs, which are expected to rise, and are ultimately paid for via consumer electricity bills.[111-113] Citizens' Advice have expressed concerns that some consumers may pay a disproportionate amount of these, and that they may not benefit fully from flexibility.[114] Less well-off consumers pay a greater proportion of their income in electricity bills,[115] and are less capable of investing in personal generation, storage and smart devices. Vulnerable consumers, such as the elderly may also be less able to benefit from flexibility, such as by using DSR or taking advantage of variable prices.[114] Ofgem is considering network charging reforms to address these issues.[116,117]

Cyber Security and Data Privacy
There are potential concerns around the cybersecurity of the electricity system (POSTnote 554) arising from increased flexibility.[118] Increasing the number of access points to the network (such as from new internet-connected devices) may create new vulnerabilities.[119,120] Energy companies that lack effective cyber security measures face financial penalties from the UK Government.[121] There are also privacy concerns around the use and access of customer data from smart meters.[122] BEIS has introduced a data access framework:[123] DNOs currently are able to access anonymised and aggregated data at the postcode level, and can only access anonymised individual customer data if they meet specific security requirements set by Ofgem.[124,125]

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