Smart Grids Power On

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A common definition of a smart grid is a digitally enabled electrical supply system that simply collates and distributes value added energy data. This data is activated by information from the functions of all participants including generation suppliers, network operators and energy demand consumers. The aim is to improve the efficiency, resilience, economics and sustainability of future electricity services and products serving these stakeholders.

Key global drivers accelerating the development of the smart grid include the transition to a decarbonised and decentralised energy business model. This is occurring as the percentage of renewable energy on both UK and EU networks rapidly increases and electricity demand is expected to increase with the advent of electric vehicles and heat pumps.

Renewable energy sources (RES) represented close to 26 per cent of UK generation in 2019 due mainly to a rapid expansion of onshore and offshore wind farms together with some further expansion of large scale solar farms. When taking into account other low carbon sources such as the existing fleet of nuclear plant and the newly converted large scale biomass stations, the penetration of low- and zero-carbon sources in the UK has risen to 37 per cent[1]. The EU in their European Smart Grid Technology Platform report (EUR 22040)[2] anticipates that electricity demand across the whole of Europe will continue to increase annually on average by 1.4 per cent to 2030 and for RES to sustain its long term growth trajectory from a current baseline of 13 per cent to reach 26 per cent over the next decade.

The proliferation of household solar photovoltaic (PV) panels in the UK, now numbering over 1m individual units[1] is also reducing net electricity demand at the domestic sector level. However, this is gradually being outweighed by other sources as the UK Government's Climate Change Policy prioritises decarbonisation and its current target to achieve net zero greenhouse gas (GHG) emissions by 2050. In accordance with this sustainability agenda, conventional transportation is being replaced with low-carbon alternatives including plug-in hybrids (PHEV) and battery powered electric vehicles (BEVs). Traditional forms of space and water heating and cooling solutions originally supplied by fossil-fuel boilers and air conditioning systems are gradually being replaced with lower carbon propositions such as (reversible) heat pumps, biomass boilers and solar thermal systems.

Scottish and Southern Energy (SSE) have implemented a fully operational smart grid on Orkney. Their network system monitors and controls the islands' electrical loads and generation to optimise the total capacity available within their subsea cable interconnection with the Scottish mainland. The smart grid has enabled the same amount of renewable generation to be connected to Orkney's distribution network as would have been made possible by conventional network reinforcement at a fraction of the cost[8]. Conventional network upgrading and reinforcement costs of £30m were avoided together with long lead times and a substantial impact on the environment. The total cost of developing and delivering the Orkney Smart Grid was in the order of £0.5m.

'Gateway' to smart grids

The rollout of smart meters across the whole of the residential sector in the UK will provide a 'gateway' into the smart grid and allow the individual consumer to become an active player in the new energy marketplace. Owning back-of-the-meter self-generation in the form of roof-top solar PV panels in conjunction with battery storage, BEVs and thermal storage, means the growth of the 'prosumer'. This new generation will be empowered to offer energy and balancing services to the local distribution network operator.

The mass of granular data will demand increased digitisation and encourage the development of micro-grids at the community level and virtual power plants. The idea has been posited by ABB Energy Industries[3] at a large-scale grid level. It capitalises on special software to allow intelligent trading of energy and capacity services within the new sophisticated energy marketplace.

From the 1930s to the late 1960s, power grids comprised mainly of a number of large centrally controlled power generation stations fired predominantly by fossil fuels which supplied electricity via high voltage transmission lines – national grid - in bulk to major load centres. Electricity was subsequently transported by numerous distribution networks to a wide-ranging portfolio of industrial, commercial and residential customers.

The main benefits derived included improved security of supply, reduced operating costs and relatively lower transmission and distribution losses.

Over the past decade this traditional 'business model' has gradually been transformed with the availability of competitively priced large scale renewable energy sources in the form of offshore and onshore wind farms and solar photovoltaic (PV) farms. In addition, electrical demand has become more dynamic and variable with the replacement of conventional heating systems with low-carbon alternatives and fossil fuelled transportation commonly referred to as e-mobility. The transition to renewable energy sources and distributed but weather-dependent power generation continues to impact the new energy landscape and the challenges of delivering safe and secure operation of the developing smart grid is becoming paramount. This is exacerbated by the significant increase in the total number of small scale and decentralised power generation units which are beginning to dominate the new energy network and compound the unpredictability faced by modern smart Grids.

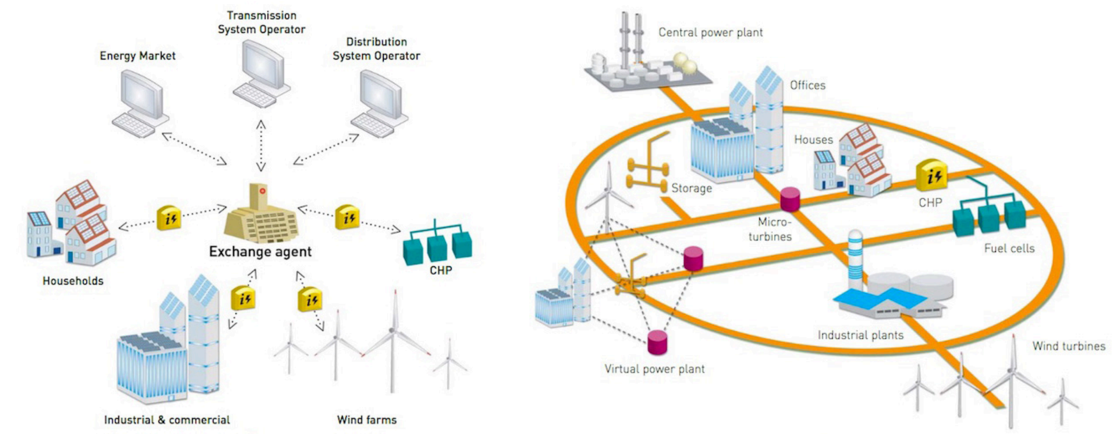
Ensured perfect balance

In the past, electrical systems simply acted as a continuous supply chain which matched instantaneously the supply of electricity from large power stations to customer demand. This ensured a perfect balance as there is little scope for storage to facilitate 'smoothing' of critical peak demands especially during the winter months. This challenge will be exacerbated by the acceleration in the number of small-scale distributed generation units whose output will be determined by whether the 'wind blows' or 'the sun shines'. This will be further compounded by the increased complexity associated with flexible and less predictable customer demand and behavioural patterns due predominantly to changes in the frequency, duration and level of charging (in the short to medium term) of a wide range of BEVs and the variation in the output of heat pumps during the winter months.

Therefore to operate the electricity system of the future - the smart grid - both securely and safely there will be more reliance on the expertise of skilled control engineers and sophisticated, intelligent control and monitoring systems[4]. The three main parameters that need to be controlled for a smart grid are:

- **frequency** – matching generation and demand on a second-by-second basis to guarantee stability of the system and ensure delivery of electricity at a frequency maintained within designated limits;
- **voltage** – generators and transformers ensure that voltages remain stable and electricity is supplied within specified limits; and
- **current** – provision of spare capacity ensures that the current limit of every component and circuit comprising the electrical system is not exceeded and consequently limits the risk of damage or failure and mitigates the potential impact of blackouts.

Fig 1 and 2 : Smart grids and how they might operate[2]



The planned rollout of smart meters at the household level has facilitated the monitoring and control of energy usage in real time at the commercial and domestic level as well as mitigating the inherent intermittency of renewable generation. Apart from the main benefit of being capable of reading meters remotely, smart meters will enable accurate and timely measurement of solar panel-derived electricity exported to the grid and facilitate payment measures. In addition, smart meters will help utilities and independent energy suppliers to formulate different electricity tariff structures which reward consumers for demand management services. This is already leading to increased adoption of smart appliances in the domestic sector and home energy management and control systems such as Nest and Hive.

The new business model for the supply and consumption of energy that is now evolving places more emphasis on the consumer. The latter can both self-generate and store electricity locally providing them with the possibility to become self-sufficient and go 'off-grid' and even export any surplus power back to the new grid structure. In the past, power flow have always been in one direction from the centralised power stations which controlled both the security and quality of electricity supplies but future smart grids will enable bi-directional energy flows and encourage the growth of ancillary services in flexibility, voltage and frequency management to maintain future security of supplies to critical businesses.

Zero energy emissions

One of the key drivers for the development of smart grids is the global transition to achieve a target of zero energy emissions by 2050 or sooner. This has involved decentralisation of legacy fossil-fuelled power generation stations and the associated decarbonisation of key activities such as heating and transportation. The universal rollout of smart meters has enabled more accurate monitoring and control of both micro-generation and dynamic demand but has resulted in a plethora of granular energy-related data. The latter has to be constantly synthesised and manipulated by sophisticated communication networks relying on artificial intelligence and detailed algorithms to deliver reliable and resilient power delivery and informative actions.

Apart from the domestic sector, local councils are also embracing new developments in technology such as smart LED street lighting systems. These are gradually being integrated with battery storage to provide fast charging electric vehicle (EV) capability particularly for future EV owners without off-street parking. As the battery capacity of future EVs increase, a number of utilities are exploring the potential commercial benefits of vehicle to grid (VtG) technologies – as well as similar concepts such as Vehicle to Home and Business applications. Aggregators and partnerships between car manufacturers and utilities[5] – such as Nissan and EoN – have been formed to trail the provision of demand management services from a collection of to exploit advances in VtG technologies and virtual power plant (VPP) software. This would also allow the incorporation of hydrogen-fuelled technologies and fuel cells.

Some of the key benefits of smart grid are to:

- enhance the connection of low and zero carbon generators;
- encourage and reward the entry of new demand management service providers to stabilise the operation of the grid;
- facilitate further growth in electricity demand that minimises the reinforcement of existing network capacity or avoids the commissioning of new transmission lines;
- reduce the overall carbon footprint of the grid in compliance with the UK Government's Climate Change agenda and 2050 net zero emissions target.

Therefore, unlike traditional network grid structures, a smart grid-based system facilitates two-way communication between established utilities of third party renewable energy providers and their direct and indirect customers allowing future networks to respond dynamically to variable power demand profiles and stabilise network operation.

The key challenges include:

- the opportunity to immediately manage voltage and frequency on grids to guarantee security and quality of supplies mitigating the impact of total power failure – blackouts – or diminished power delivery capability –

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brownouts.
• the incorporation of smart meters will need to be subject to rigorous security evaluation particularly in regards to anonymising individual customer data to ensure data protection;
• the extensive use of advanced technologies to identify and resolve system faults in real time and support 'self-healing' networks that will minimise the impact on business critical operations and vulnerable household customers;
• the adoption of innovative and pragmatic solutions especially involving the distribution grid which has operated historically in a traditional but very reliable fashion for the last 60 years;
• the novel and reliable provision of demand, voltage and frequency management services by third parties;
• future progress in meeting decarbonisation targets and sustaining a positive trajectory in renewable energy growth and the number of new nuclear plant being commissioned in future years.

Sustainable power system

As smart grids mature there is likely to be more congruence with the Internet of Things (IoT) as more advanced telecommunication protocols develop such as 5G permitting the cost-effective integration of all energy users. This will result in the delivery of a high-quality, sustainable power system exhibiting the highest standards of security and quality of power supplies. As governments worldwide are compelled to accelerate the transition to a low-carbon economy, smart grids will significantly support a more holistic concept which not only encapsulates electricity flows but also incorporates different technologies in the areas of heat, cooling, fuels, transport and water. This new state of the art network will interact proactively within local districts leading to micro-grids as well as in large cities leading to the concept of 'smart cities'.

Networking protocols such as 'Zigbee' will enable wireless control of household appliances and eventually lead to universal communication and co-ordination between all relevant stakeholders operating home energy management systems.

Technical giant Microsoft and the European natural gas utility Snam have recently launched their first Cloud and Internet of Things (IoT) project for energy networks. The ability to collate, process and enhance larger amounts of data will lead to predictive maintenance operations and more accurate and timely analysis of energy demand through the use of neural networks[6]. Digitalisation forms a strategic role in Snam's programme for innovation and the energy transition to low carbon sources in which the company is investing £1.3bn as part of a £5.9bn overall expenditure plan by 2023.

Digitisation within the smart grid will offer the capability for all energy consumers to proactively participate in its daily operation. This will be facilitated by rapid technological advances enabling all stakeholders to become more informed, involved and active in the formulation, design, planning and utilisation processes. In addition, there is likely to be more development from IT and software developers of smart grid solutions in areas such as demand flexibility response and the provision of ancillary services in the form of frequency and voltage management.

Smart grids will generate a mass of 'big data' and as the majority of sophisticated sensors and technologies such as connected edge meters and EV home charging stations will operate at the 'edge' of the new grid, they are likely to become more susceptible to cyber attacks. This will also inevitably lead to increased risk and complexity for future IT and communication designers as new protocols such as 5G and advanced artificial learning (AI) develop and become an integral component of future smart grids. Key challenges with granular data will include problems associated with impersonation, data tampering, authorisation and privacy as well as cyber attacks.

The rollout of smart meters can be regarded as one of the preliminary stages of development of the smart grid. This has the dual benefit of providing a compelling business case to the incumbent energy utility by leading to substantial reduction in the labour required to fulfil manual meter readings. In addition, it enhances the accuracy of energy invoices and accelerates the automation of bill processing. Real time access to business energy usage provides increased visibility of manufacturing and commercial activities that can lead to the provision of valuable demand, voltage and frequency management services and other grid-balancing options.

Leverage financial benefits

Domestic consumers connected to the 'edge' of the new smart grid can leverage the financial benefits of small-scale solar PV generation in combination with battery storage to function as prosumers. It is possible for them to export their excess power to the grid and receive appropriate monetary benefits.

The formation of numerous micro-grids could develop. These could comprise small energy autonomous communities 'islanding' themselves from the main network. The communities will be characterised by sufficient self-generation capability to adequately meet their seasonal energy demand. Alternatively, they have long-term power purchase agreements with reputable and local energy services companies (ESCOs) that supply their total requirement for energy both in terms of electricity and heating. ESCOs may be operated by established utilities or third-party energy service providers. They generally operate large scale combined heating and power (CHP) units in combination with possibly commercial scale solar photovoltaic farms and battery storage. This arrangement will support the transition to net zero emissions and in particular reduce levels of greenhouse gases (GHG) such as NOx and SOx.

Smart grids have also encouraged the development of small-scale virtual power plants (VPPs) which effectively balance renewable generation and variable consumption patterns. They can comprise a network of decentralised power generating units such as wind farms, solar parks, and combined heat and power (CHP) units and downscale activities associated with power consumers and both battery and thermal storage systems. All the key elements are interconnected and despatched via a central control room of the VPP but maintain independence in their operation and ownership[7]. They can provide both load management benefits and the ability for the power generation and power consumption elements of the network in the VPP to effectively trade in any future energy exchange.

The concept of smart grids encompasses major benefits including more advanced grid visibility, asset controllability, enhanced performance and security and support key network activities such as operation, scheduled maintenance and planning of future developments incorporating low and zero carbon technologies.

Amsterdam New West district contains around 40,000 households of which 10,000 are served by a new smart grid. The area is characterised by a high penetration of smart meters and the largest number of solar panels in Amsterdam[9]. The smart grid has delivered a number of key benefits including: reduction in the frequency and duration of power outages; increased capability to accommodate E-mobility; facilitate active participation from sustainable energy suppliers and has avoided sharp increases in the price of electricity transmission.

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Please mark your answers below by placing a cross in the box. Don't forget that some questions might have more than one correct answer. You may find it helpful to mark the answers in pencil first before filling in the final answers in ink. Once you have completed the answer sheet, return it to the address below. Photocopies are acceptable.

QUESTIONS

1) The establishment of the main transmission grid began in which decade?
- ☐ 1940s
- ☐ 1930s
- ☐ 1960s

2) Which key parameters need to be controlled by smart grids?
- ☐ Voltage and frequency
- ☐ Frequency and current
- ☐ Voltage, current and frequency

3) What's the main source of large-scale renewable generation connecting to the grid?
- ☐ Biomass
- ☐ Wind farms
- ☐ Solar farms

4) What are the main forms of variable electrical loads connecting at the household level?
- ☐ Electric vehicles and heat pumps
- ☐ Smart meters
- ☐ Home automation devices

5) What is the main threat to smart grids?
- ☐ Cost of implementation
- ☐ Cyber attacks
- ☐ Lack of experience and expertise

6) What are the main benefits of smart grids?
- ☐ Reduce the need for centralised power generation
- ☐ Encourage connection of electric vehicles
- ☐ Facilitate the connection of distributed renewable generation and variable loads such as electric vehicles and heat pumps

7) What does the abbreviation VPP stand for?
- ☐ Volume purchase programme
- ☐ Voluntary protection programme
- ☐ Virtual power plant

8) Electricity cannot be stored in large quantities by householders?
- ☐ False as only large utilities and industrial/commercial energy providers can provide storage facilities
- ☐ False
- ☐ True as householders can store electricity in standalone batteries or when charging their electric vehicles

9) What is the main benefit of smart meters?
- ☐ They avoid the need for meter readers
- ☐ They provide accurate and timely information on power flows across the smart grid
- ☐ They facilitate the export of surplus electricity from household solar PV panels

10) What does the technology VtG represent?
- ☐ Variable Geometry Turbochargers - designed to allow the effective aspect ratio of a turbocharger to be altered as conditions change
- ☐ Volume of Trapped Gas associated with respiration
- ☐ Vehicle to Grid enabling EV batteries to discharge to the grid to 'smooth' high electricity peak demand profiles.

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