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What is a **Smart Grid?**

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Cover images (clockwise from top left)

- Modern houses with solar panels on roof, Netherlands
- National Grid electricity pylon
- Electric vehicle charging station (kind permission of Elektromotive Limited)
- Wind turbine being assembled

Images in the document

- Electric vehicle charging station (kind permission of Elektromotive Limited)
- Image of a smart meter (kind permission of E.ON Energy)

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Introduction

This briefing paper seeks to explain, in non-technical terms, what a Smart Grid is, how it is different from the electricity grid we have today and why we will need it in the future. It also provides some examples of where Smart Grid ideas are already being put into practice.

The electricity system has not changed for a number of decades now but is about to enter a new phase of development. When electricity was first used over 100 years ago companies or local authorities designed and built independent systems to supply electricity, and sometimes heat as well, usually to large towns or a part of a large city.

In the 1930s we made a major change in the UK by connecting together all of these independent systems with what we now call the transmission system or national grid. The main reasons for this were to provide better supply security and to reduce costs. It allowed larger and more efficient power stations to be built far from where the power was consumed. As a result, the previously independent local systems gradually lost their generation and became the distribution systems we have today.

The Smart Grid will be the next major development of our electricity system.

When the Smart Grid, is fully functional around 2030, it will

> "cost efficiently integrate the actions of all users connected to it - generators, consumers and those that do both - in order to ensure an economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety."

This description of a smart grid is based on that proposed by the European Regulators Group for Electricity and Gas.[1]

What is the main difference between our current grid and a Smart Grid?

The electricity system forms a unique supply chain because the laws of physics demand that production, delivery and consumption occur instantaneously and have to be kept in perfect balance on a continuous basis. It's the ultimate 'just in time' delivery system. To operate the electricity system safely and securely in this way requires sophisticated, intelligent (i.e. smart) control systems as well as skilled oversight and interventions by control engineers.

The main difference between our current grid and a future Smart Grid will be the way that generation and demand is kept in balance. In our current system, the high-voltage transmission grid is a sophisticated, highly controlled network that supplies electricity to distribution networks, which can be viewed simplistically as wires delivering electricity to users. The transmission grid must meet whatever demand there is from the distribution system, that is from the users. It does this by controlling the supply from a relatively small number of large power stations.

Big changes are ahead, arising from the decarbonisation agenda, which will impact on transmission and distribution, customers and generators. At transmission level, the challenges include the connection of offshore wind generation and new interconnectors to other countries. At distribution level, the challenges relate to the potential for millions of customers to connect new loads, such as heat pumps and electric vehicles, and to connect generators so that they will consume and produce electricity. This will require a completely different approach to the way the system is controlled and this change is at the heart of the Smart Grid.

What needs to be controlled in the electricity system?

A Smart Grid is all about information and control. The three primary quantities that have to be controlled are:

- **Frequency** - this is done by matching generation and demand on a second-by-second basis to ensure stability of the system and to make sure that everyone receives electricity at a constant frequency.
- **Voltage** - this is done using many control devices, mainly generators and transformers, across the electricity system to ensure that voltages remain stable and that customers receive their electricity within specified limits.
- **Current** - every device and circuit in the grid has an upper limit to the current that it can carry without damage or failure. The grid therefore has to be designed so that these limits are respected at all times, even when fault events occur. This is done by providing spare capacity in the grid together with control and protection actions.

How is the Grid controlled now?

The high voltage transmission grid already has sensors and sophisticated control systems. However the predictability of demand at lower voltages in our distribution networks has meant that it has only been necessary to use quite simple control systems to ensure safe, secure, efficient operation. For further information about how the Grid is controlled today see **Table 1**.

Table 1: How is the grid controlled now?

	Frequency	Voltage	Current
Why is it important?	Production and consumption need to be matched to ensure stability of the system. Consumers need to receive electricity at a constant frequency in order for motors and other equipment to operate correctly.	Voltages need to remain stable and customers must receive their electricity within specified voltage limits in order to avoid damage to their appliances.	Every device and circuit in the grid has an upper limit to the current that it can carry without damage or failure. In order to avoid power cuts, these limits must be respected at all times, even when faults occur.
Features	Frequency (measured in cycles per second or Hertz) is controlled by ensuring that generation matches consumption on a second by second basis. All power stations are able to assist with frequency control no matter where they are located on the grid.	Voltage (measured in Volts) is controlled using generators, transformers and other devices. This has to be carried out locally rather than nationally meaning that different methods can be used for different parts of the grid.	Current (measured in Amps) is controlled by a range of control and protection actions. Spare capacity is provided for exceptional operating conditions. This is a local issue so that measurement at many points on the electricity system is necessary.
How do we do it now?	Electricity production is currently dominated by very large power stations that are connected to the high voltage transmission system. The majority of these power stations are able to vary their output according to the needs of the total system. The system operator, National Grid, issues instructions continuously to make sure that the balance between production and consumption is maintained. Grid control monitors TV schedules around major events to predict when the nation gets up to make a cup of tea. Because generation has been fully controllable, and demand has been largely predictable, it has been demand that has determined how many power stations are operating and at what output on a second by second basis.	Voltage control at the high voltage **transmission** level is already very sophisticated. Voltages over long distances can vary quite significantly. The system operator is able to monitor the voltage across the transmission system on a continuous basis and can control it within set limits. In the low voltage **distribution system** that supplies houses and small businesses there is no monitoring or control capability in real time. The power flows are generally very predictable and so the variation of voltage can be calculated and confirmed as acceptable at the design stage. The distribution network was designed in such a way that the voltage limits will be met for a range of operating conditions.	At the **transmission** level, the current in every circuit is continually monitored and the system operator is alerted if the current approaches or exceeds set limits. The system operator may instruct a power station to run to help reduce current flows in heavily loaded circuits. Spare capacity is also provided so that circuits are not overloaded when credible faults and maintenance outages occur. In today's low voltage **distribution grid** it has not been necessary to measure the current flowing through the circuits. The Distribution Network Operator will only know if the current has exceeded a safe limit when a protection device (usually a large fuse) operates and there is a power cut. As current flow in the distribution grid has been relatively predictable and usually in one direction, this has been entirely sufficient for safe, reliable operation.

So why will we need a smarter grid?

The electricity system design and operating strategies described in **Table 1** have worked well for decades and can be found around the world. We therefore need to have good reasons for making changes, particularly if this involves making the grid more complex.

The main driver for change is the achievement of the government's 2020 and 2050 carbon reduction targets. The electricity supply sector will make a major contribution to achieving these targets and to do so users will need to become more involved in its operation. All the key components of the electricity system will have vital roles to play in achieving these targets but the most significant contribution to reducing greenhouse gas emissions from the electricity sector will be by replacing fossil-fired generation with low or zero carbon generation technologies. These generation technologies have a number of very different characteristics compared with the fossil-fired generators that they will replace:

- Renewable generators, especially wind generators and Photo Voltaic (PV) panels, cannot be controlled like a conventional generator. They rely entirely on an uncontrollable source of energy and because this energy is free, they should be allowed to generate whenever the sun shines or the wind blows.
- Nuclear generators are best suited to base load generation and cannot vary their output in the way that a coal or gas fired power station can.
- Distributed generators, including small renewable generators but also diesel standby units or generation associated with local combined heat and power schemes, are smaller devices connected to distribution grids and may also be less controllable.

The result of the widespread deployment of these technologies will be that the size and even the direction of power flows on the grid will be much less predictable and the system operator will need to find new ways of balancing generation and consumption to maintain a stable system and to ensure that the grid does not get overloaded causing loss of supply.

The challenge for the **transmission grid** will be developing new ways of balancing production and consumption as more intermittent generation is connected. Greater interconnection with other countries could be helpful and so could new interactions with distribution systems to enable demand side management and storage to play stronger roles. These developments will bring their own challenges.

It is expected that the changes necessary in the low voltage **distribution grid** will be more dramatic.

- Homes might increasingly have some form of generation or electricity storage.
- Space and water heating could be converted from gas to electricity.
- Hybrid and battery cars could replace petrol/diesel ones (their charge/discharge cycles could help balance the electricity system)
- Co-ordination will be needed for multiple loads and power sources, to provide integrated support to the operation of the network at local, regional or national levels.

If this happens it is likely that more electricity will need to be delivered to each house and the patterns of consumption will change significantly, so power could flow in both directions at different times. More intelligent network monitoring and control will provide the lowest cost means of providing the capability to meet this very different pattern and innovative devices such as power electronics can be expected to improve the utilisation of existing network plant.

It is also possible that with the roll-out of smart meters and the introduction of home automation (for example controls that decide when domestic appliances run on the basis of the real-time electricity price) many consumers will be encouraged to actively manage their demand to help balance the electricity system and help manage grid constraints. This demand management could add another element of unpredictability.

So, in summary, the main reason we will need a smarter grid is to help the network companies meet consumer requirements more quickly and cost efficiently, by accommodating a growing but less predictable demand for electricity and absorbing generation embedded at the lowest levels of the system. This is summarised in **Table 2**.

Table 2: Why will we need a smart grid?

	What is changing?	Technical consequences and solutions
High voltage transmission grid	As the mix of large scale electricity generation changes to meet environmental targets it will be less flexible: ■ large renewable sources such as wind farms have no fuel costs and have to be used where and when available. ■ Nuclear plants run best as continuous "base load" Power flows on the grid are likely to be much less predictable and the system operator will need to find new ways of balancing production and consumption to maintain a stable system.	System control at this level is already smart to a large extent. The transmission system will continue to evolve and take advantage of new technologies but it is quite possible that its fundamental operation will not change dramatically. There is likely to be: ■ More interconnection with other countries e.g. Netherlands, Norway and Ireland ■ Large scale energy storage, where this is technically feasible and cost effective. (See the IET Briefing on Electricity Storage.) ■ Increasing use of automation and 'DC' connections.
In the local low voltage distribution grid	Smaller renewable generation is connected to the distribution grid creating two-way flows in a network designed for one-way flows. Householders are installing renewable generation (e.g. solar panels). Larger demands (e.g. electric vehicle charging at 7kW for several hours compared to 3kW for a couple of minutes for an electric kettle) increase the peaks in demand and their duration. Space and water heating could be converted from gas to electricity by the 2030s creating increased demand for electricity and increased winter peak demand. Distribution Network Operators need to ensure that the network does not get overloaded and that supply quality is maintained.	The Distribution Grid requires the measurement and control capability to handle two-way power flows. Smart meters enable householders to be paid for electricity they generate. Demand side management (i.e. consumers who are willing to time-shift some of their demand for electricity to lessen peak demand being rewarded for this.) Smart meters provide measurement information to assist in network design and operation. Increased focus on efficiency in network operations in order to avoid the need for costly and disruptive new power lines. This will include the use of more automation, intelligent systems and devices such as power electronics and local power storage.
In the whole system	Higher peaks in demand will be met by a range of options to optimise the grid's efficiency including time-shifting of demand rather than relying on over-sizing generation and transmission to cope with the highest predicted demand.	Increasing need for measurement, communication and modelling actions that cut across company boundaries between transmission and distribution.

What are the benefits of Time-shifting Demand?

The demand for energy varies greatly between different times of day and different seasons. Electricity at peak times costs more to generate and is potentially more damaging to the environment than at times of lower demand. This is because the most efficient and carbon neutral plant is usually dispatched first and the nearer to peak capacity the system is run, the more non-renewable generation plant has to be added. So it is more cost effective and better for the environment to shift some demand by 2 -4 hours than to build and operate more flexible but non-renewable generation.

Commercial consumers such as supermarkets will be among the first to adopt demand management and some, e.g. Sainsbury at Hythe in Kent, are already saving money and lowering their carbon footprint by timing their refrigeration load to avoid peak times. In the future, the charging of electric vehicles may provide good opportunities for time-shifting demand in ways that are convenient and financially rewarding to vehicle owners. It is also possible that the development of home automation may make 'Time of Use' tariffs a practical and economic option for domestic consumers.

Could the changes be more radical?

Some think they could. If the number of small generators, controllable loads and storage devices grows dramatically then it might be possible to have robust, local networks that are actually capable of operating as stand-alone systems, as they did before the transmission grid was built. This could dramatically change the way we operate the overall system, moving away from the current model based on a single system operator, and potentially offering benefits for managing future complexity and also providing energy resilience to weather extremes created by climate change.

Another radical option is to envisage a much more integrated approach to transport, energy, water and waste. They could become a 'system of systems' or a so-called Smart City. This approach might be particularly applicable in urban centres where the need to reduce emissions is greatest.

Where do Smart Meters fit into this?

The evolution of the power system into a Smart Grid will be achieved incrementally over several decades. One important part of this transformation will be the roll-out of smart meters which will be completed for most homes in Britain by 2019.

A smart meter is different to a conventional meter in a number of ways. Firstly, it can measure and store a lot more information about the electricity flow passing through it. Secondly, it can send and receive data from another party. This makes possible a range of new services:

- A smart meter will allow electricity suppliers to read meters without visiting the property and an end to estimated bills.
- For those who generate electricity, for example by having solar panels installed on the roof of their home, the smart meter will provide accurate measurement of electricity they export to the grid and make it easier for them to receive the payment.
- Smart meters will enable retailers to offer a wide choice of tariffs such as at different times of the day and night. This will help reward consumers who are able to shift some of their demand away from peak times.

These services are all ones that the energy retail companies provide which is why the Government has mandated that energy retailers will be responsible for smart meter roll-out in the UK. It is possible to consider smart grids and smart meters as separate issues. However, there is a consensus view that it is logical to consider their development together for two main reasons:

- Both smart grids and smart meters require a communications infrastructure.
- Smart meters offer an opportunity to bring measurement of network conditions that is currently lacking in the Distribution Grid. The raw data (e.g. voltage and current) that a smart meter can collect, once anonymised and aggregated so no individual home is identifiable, is valuable to the Distribution Network Operators (DNOs). It will help the DNO design and operate its system more efficiently, thus keeping network costs to a minimum.

The specification of the smart meters that will initially be installed in the UK has now been agreed. The process to put in place the communications infrastructure is underway and its design will be finalised later this year.

What might the benefits of a Smart Grid be?

The Grid exists to provide connections between generators and consumers of electricity. The benefits of a Smart Grid are that it will provide the services that future users will require more cost effectively than today's approaches while also ensuring the safety and security of the system.

Recent analysis by the Smart Grid Forum[2] has indicated that there will be real economic benefits in deploying smart network developments rather than continuing simply with 'traditional' solutions for new network demands.

It is expected that smart solutions will offer cost effective ways to:

- better facilitate the connection and operation of low and zero carbon generators;
- facilitate the involvement of demand response in the operation of the electricity system;
- permit growth in electricity demand while minimising the provision of new network capacity; and
- reduce the carbon impact of the grid itself, for example by minimising losses.

As deployment grows across the world in the next few years, better data will become available that will allow more accurate assessment of the benefits of specific smart grid solutions.

What are the challenges?

Security: The nation's electricity grid provides a vital service for society and is therefore classed as part of the Critical National Infrastructure (CNI). All aspects of the running of the grid are subject to rigorous security and any new aspects, such as smart meters, added to the system have to achieve the same high level of overall system security.

Transformational Change: The most far-reaching changes will occur in the Distribution Grid which has previously operated in the same highly reliable way for the last sixty years. Leadership and knowledge sharing are needed to enable the electricity industry to adopt novel solutions in addition to tried and tested methods.

Demand Management: it is not yet clear how this will be organised from commercial and regulatory perspectives so that both consumers and industry can get the expected benefits from it.

Uncertainty: the lack of certainty about how we will meet our 2020 and 2050 decarbonisation targets adds to the challenge. For example, the extent to which renewable and nuclear generation will be deployed is unclear. This means that the extent to which a smart grid will be needed is also unclear and this could hamper strategic investment in future-proof solutions.

Who is using Smart Grids now?

Smart grid demonstration projects are being built in many countries right now.

Both Denmark and The Netherlands have working examples.

In Great Britain, incentives put in place by Ofgem are delivering one of the most significant demonstration programmes anywhere in the world. The Low Carbon Networks Fund[3] has made available up to £500m for the distribution companies of Great Britain to trial new technical and commercial solutions to help deliver the low carbon economy. The primary purpose of these projects is to create and share learning between network companies so that they can more be more efficiently developed to meet the needs of their users and affordably deliver the emissions targets that we are committed to. These projects explore new ways of developing Britain's electricity system using innovations in our homes right through to the connection of large wind turbines to high voltage distribution networks. This approach will be extended to all gas and electricity network companies under Ofgem's RIIO price control incentives [4].

Elsewhere in the world a number of countries are deploying smart meters at scale (for example Italy and Scandinavia), and countries such as Korea, China and Denmark also have impressive smart grid demonstrations.

Case Studies

UK
There are now fifteen major projects funded under Ofgem's Low Carbon Networks Fund. Full details can be found at their website[3] and also on the Energy Networks Association's website[5]. Many of these projects have their own websites. For example, the "Customer Led Network Revolution"[6] is a £54 million project which involves 14,000 homes and businesses, mostly in the North East and Yorkshire. It is designed to help find ways for customers to reduce both their energy costs and carbon emissions in the years to come. It is trialling smart network technologies and flexible customer demand responses to see how they can reduce the network costs associated with the mass take up of low carbon technologies. These technologies include photovoltaic (PV) solar panels, heat pumps and electric vehicle (EV) charging points. Northern Powergrid is leading the project and also proposes to deploy enhanced voltage control, dynamic thermal rating and storage.

Orkney
SSE have implemented a fully operational smart grid on the Orkney islands. This Active Network Management system intelligently monitors and controls loads and generation to maximise the available power capacity available from the subsea cables to the Scottish mainland. It is a leading example internationally as it is a fully operational commercial system rather than a demonstration, and it utilises semi-autonomous real time processing to optimise the connection of new wind generation. SSE report that the connection of this level of renewable generation on Orkney by conventional network upgrading and reinforcement would have cost around £30 million, and would have meant long lead times and substantial environmental impact. The total cost of developing and delivering the Orkney Smart Grid has been around £500,000[7].

Bornholm, Denmark
Bornholm is a Danish island that is the focus of an EU Framework 7 project named EU-EcoGrid. The island has wind power

together with diesel generation and an HVDC interconnector to Sweden. Local politicians, industry and residents on Bornholm want to find solutions to the challenges of 50% penetration of wind power that many regions of Europe are expected to meet in the near future.

The project combines market, commercial and technical solutions in a trial with the inhabitants and includes management of home appliances based on the real-time market pricing of electricity as a means of alleviating congestion on the local power network.

Oestkraft, the local electricity company on Bornholm has established the "Villa Smart" which is a normal residential house equipped with Smart Grid equipment. The house will function as a showroom where interested customers as well as those already participating can learn how the EcoGrid EU might impact the everyday life of a typical household. The target of 2000 participants in the demonstration will provide a realistic level for scaling of results.

The project has participation from politicians, industry, academia, research institutes and local community groups.

Amsterdam

Amsterdam New West district contains approximately 40,000 households, of which around 10,000 are served by a new Smart Grid. New West has a high penetration of smart meters and contains the largest amount of solar panels in Amsterdam.

This intelligent electricity network contains additional intelligence and sensors. Current and voltage are monitored continuously to provide more accurate monitoring and control functions. In the past these functions weren't available at this level. The Smart Grid enables the following consumer benefits:

- reduction of the number and duration of power outages;
- better opportunity to feed consumer-produced electricity back to the grid;
- increased capability to support the integration of electric-powered vehicles;
- prevention of large price increases for electricity transmission;
- enablement of active participation in a sustainable energy supply

The network company can operate the distribution grid completely remotely, something that was not previously possible. In addition, the existing network capability has been increased in key areas and the network structure has been improved. In the future, incipient power outages will be visible in the smart grid and can therefore be prevented. This network will eventually be cheaper because maintenance can be targeted where it is most needed, the number of power failures decreased and the grid capability will not have to be increased for a long time.

The program is managed by the Amsterdam Smart City foundation, which is 50% owned by the City of Amsterdam (represented by the independent organization (Amsterdam Innovation Motor (AIM)) and 50% by Liander the Dutch energy transportation operator.

Funding: the foundation is 50% funded by AIM, which receives EU subsidies, and 50% by Liander. Service expenses and some outsourcing deals are under Liander responsibility and account for its contribution to the foundation[8].

Further Reading

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