Expert Insights

The Trends toward Greater ICT Control and Integration into the Grid

Underlying Policies and Market Drivers

Dr Aidan Rhodes

Research Fellow, RCUK Energy Strategy Fellowship,
Imperial College

Dr Rhodes holds a PhD in analytical electrochemistry and is currently Research Fellow at the Centre for Environmental Policy at Imperial College London. His research interests are in energy policy, market design, and regulation, with a particular focus on smart grids and future networks. He has authored several substantive pieces of work in this field, including two reviews of the UK's smart grid capabilities for the Technology Strategy Board, and has contributed to fostering collaboration between the UK and Japan by leading a substantive mission of UK smart grid experts and industry stakeholders to Japan to discuss joint interests. Currently, Dr Rhodes is working on a large research project comparing and benchmarking the energy innovation systems of different countries, with an emphasis on smart grid technologies in the UK and the Asia-Pacific region.

Electricity networks have long been characterised as mature and conservative technologies, relying on proven concepts of power engineering and electrical design dating from the late 1800s. Power flows from large-scale generating plant through high-voltage transmission and lower-voltage distribution networks before being delivered to consumers. This system is used throughout the world with great success, and is an essential enabler of modern living.

Recently however, both government policies and market forces have produced drivers that challenge the notion of an electricity grid being a simple unidirectional series of wires and transformers and make the case for a 'smart grid,' in which information and communication technologies (ICT) are integrated directly into the electricity networks. These advances have the potential to transform the way customers and supply companies interact with electricity, and provide significant new commercial opportunities for communications, monitoring, control, and data aggregation technologies throughout the electricity system, from generation through to the consumer.

European governments have heavily invested in large-scale demonstration and development projects to trial smart grid and metering technologies, with current investments totalling approximately €5 billion. These projects are being driven by:

(1) Policies to decarbonise national electricity systems being led by governments
(2) Concerns regarding security of energy supply and the resilience of electricity networks to extreme events
(3) Moves towards greater competition, choice, and innovation in the energy supply market
(4) The integration of electric vehicles, electric heating, and distributed generation
(5) The development of 'smart' meters and home appliances

Decarbonisation policies and incentives are the first key set of drivers towards a smart grid, and have far-reaching consequences for the energy system. The UK, for example, has a legally-binding target of an 80% reduction in carbon emissions by 2050, which most models suggest would require a virtually decarbonised electricity sector by 2030 in order to meet. The European Union has set a target for 20% of EU primary energy to come from renewable sources by 2020. Due to the difficulty of providing economical renewable heating and transport, a large majority of this energy will need to come from renewable electricity generation. The UK's share of this primary energy target has been set at 15%, which will require renewable generation providing 30% or more of total electricity supply in the UK on a regular basis. The integration of this quantity of renewable generation into an existing electricity system leads to some significant challenges.

In a traditional electricity system, supply is adjusted to match current demand. This becomes an issue with large proportions of renewables and other low-carbon forms of generation due to their particular characteristics. Low-carbon generation can generally be divided into two major forms. Firstly there are those, such as nuclear power or carbon capture and storage (CCS), which provide base-load electricity but are inflexible, meaning it is uneconomic or technically infeasible to change their output levels. Secondly, renewable energy generation sources such as wind and solar are intermittent, providing variable levels of power based on the strength of the energy source.

Large quantities of expensive and polluting fossil fuel-based backup generation would be required to meet shortfalls and balance the system in a traditional electricity network. However, advances in network monitoring and control technology will make it possible to use the network in a more efficient manner, allowing electricity to flow multi-directionally through the grid from energy storage units and distributed generation sources to nearby centres of demand. This more advanced network would save money on backup generation by efficiently allocating low-carbon electricity and actively managing demand. Several European nations, notably Denmark, Germany, and Spain, are already managing large quantities of renewable generation (Denmark generated over 100% of its electricity demand from wind several times in late 2013), and are aggressively exploring smart grid technologies to manage this supply.

Two other major drivers seen in Europe are the cost and security of electricity. The cost of electricity has increased substantially in response to higher fossil fuel costs, subsidies for low-carbon generation, and from major shocks such as the Fukushima incident and the resulting suspension of nuclear power in many nations. High energy prices are both politically unpopular and have the effect of increasing costs, and therefore decreasing competitiveness, in energy-intensive industries. An average of 10% of generated electricity is lost in the networks before consumption, and improving this figure through new, more efficient network assets combined with improved network control and routing is an important economic driver for utility companies.

Electricity access is essential for developed countries' economies and the cost of brown- and black- outs, even for short periods, are very high. New monitoring and control technologies in networks can automatically sense faults when and where they occur and reroute power via different routes to minimise disruption to supply, making the grid more resilient to significant weather disruption and extreme events. The recent extreme flooding and resultant power cuts in the UK have made network resilience a significant political issue for example, with consumers more aware of the reliability of their electricity supply. Technologies that can dramatically reduce grid maintenance costs and penalty charges for supply disruption while increasing reliability are therefore of great and increasing value to network operators.

The consumer end of the electricity system is where some of the most significant advances could be seen from the integration of ICT into the grid. The role of the consumer is constantly changing as new technologies and demand patterns are adopted. The rise of portable electronic devices has increased electricity consumption over the past decade, for example, while improved insulation and more efficient lighting technologies have decreased heating and lighting costs. In the future, a predicted mass adoption of electric vehicles combined with a switch from gas to electric heating in many countries could increase peak consumer electric demand dramatically. This will have significant consequences for traditional electricity networks, as major physical reinforcement to the grid as well as substantial extra generation would be needed. If no demand-side management (DSM) systems are put in place to spread the load of electric vehicles and heating systems throughout the day, the peak load on the system would increase dramatically – models for the UK system suggest that peak electricity demand with the addition of vehicles and heating could reach up to 10 times that of off-peak demand. This extreme variation provides a significant business case for smart demand management systems, as the cost of the needed physical reinforcement in a conventional system would be very high.

The rise of distributed generation will also require dramatic changes to the grid in years to come. Distribution networks have historically been designed to move electricity in one direction, from the generation plant and transmission networks to the consumer. If consumers themselves are feeding electricity into the grid from solar photovoltaic (PV) systems and other forms of distributed generation, major changes will need to be made to the structure and control systems of the distribution networks in order to maintain the stability and efficiency of the electricity system. More localised control of distribution networks, allowing electricity to be brought, sold, and transmitted across a local community, is a natural response to this challenge. Although more difficult to control, these decentralised microgrids can allow communities to own and control their own electricity production and aggregate many individual sources of distributed generation into a 'virtual power plant' able to sell their generated electricity on the open national market. Domestic energy storage units could also participate in the market, storing electricity at times of low demand and selling it back to the grid at peak times. These developments would mark a dramatic shift in the relationship between consumers and the electricity system, moving them from passive consumption to active ‘prosumers,’ engaging with the energy market on their own terms and taking ownership of their own generation sources. Test projects in communities in the UK and the Netherlands, as well as the Danish island of Bornholm, aim to test consumer-facing systems and local grid balancing technologies.

Future consumers would also be able to participate in DSM programmes, shifting or curtailing their energy use in response to signals from the grid. Although many large industrial users participate in such programmes today, smaller users and the domestic market currently cannot. As seen above, demand response and DSM will become increasingly important in order to balance an increasingly complex electricity system. These services have a great deal of value potential as the flexibility of supply becomes more constrained, especially on islanded systems such as the UK network that have limited interconnection with other national grids.

The first step in enabling DSM across the domestic sector is to install smart meters. These meters can automatically transmit electricity usage back to suppliers, but can also receive pricing and control signals from the grid. In response, the meters can communicate with household appliances – refrigerators, dishwashers, washing machines, and heating systems, to give some examples. These appliances can be temporarily stopped, or have their start times delayed until a period of low electricity demand, in order to help balance the grid in times of constrained supply. A successful DSM system would need to have nearly invisible effects to the end consumer, and be easily and transparently operable. This will require careful research into consumer behaviour and attitudes, as well as high-quality ICT products that are secure, stable, and simple to operate. The potential commercial market in this area, however, is extremely large. The EU has mandated that member states roll out smart meters in their countries by 2020, assuming a positive cost-benefit analysis. Approximately half of EU member states have currently decided to install smart meters by this date, totalling 170-180 million installed meters and a cost of approximately €30 billion.

Finally, an ICT-enabled smart grid provides a platform for new technologies, business models, and services. Energy suppliers, through smart meters, will be able to offer their customers a wide range of time-of-use and flexible tariffs, opening up new opportunities for innovative energy service models and personalised tariffs. New technologies such as energy storage and electric vehicle-to-grid systems provide new business models and significant potential value in providing grid balancing and resilience services. It is best to think of a smart grid as analogous to a 3G mobile network – it is an enabling technology, allowing new technologies, innovations, and models to be developed to use its services.

Policies to enable the rollout of smart grid technologies differ by nation due to diverse local electricity market and regulatory structures. In the UK, the regulator Office of Gas and Electricity Markets (Ofgem) oversees new network technologies, and has put into place several policies to accelerate uptake. Regulatory mechanisms for the network operating companies have been changed to incentivise spending on innovation and an annual competition, the Low Carbon Networks Fund, has been established with a budget of £500 million between 2010-2015. Consortia of companies and researchers, led by network operators, bid for funding to conduct demonstrations of new network technologies in communities across the UK, with the results of these projects made publically available.

The development of new monitoring, control, communication, and aggregation technologies for future electricity networks requires knowledge of both ICT development and power systems engineering, two disciplines which traditionally house different characteristics. While ICT development is fast-moving, with horizons of only a couple of years, power systems engineering is a slow-moving, conservative discipline that prizes security and stability. In addition, knowledge of consumer behaviour and acceptance will be necessary for developing consumer-facing devices. A successful player in the future networks market will be a company that can successfully manage and intermarry these differing disciplines to create secure, stable, and technologically advanced products. Future networks and smart technologies provide a significant and sustainable business opportunity for the future, and we are only at the beginning of a long and exciting road ahead.