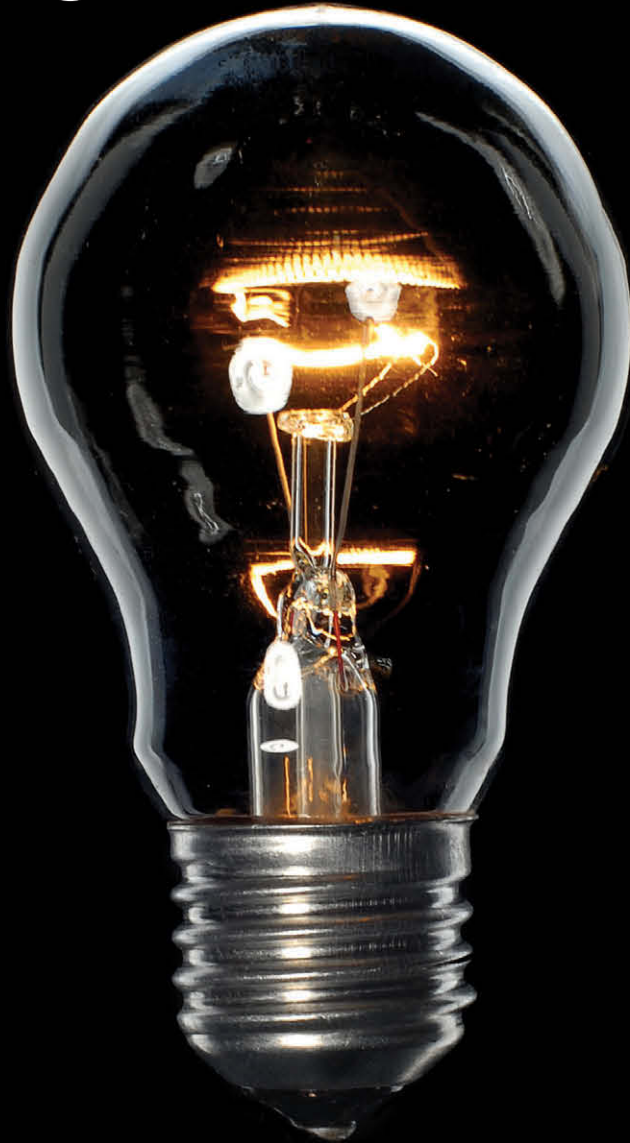


Smart energy systems: Transitioning renewables onto the grid



Modern society is dependent on flexible electrical energy, available on demand and at an affordable cost. Most of our electrical energy is produced by converting the carbon stored in coal or natural gas into heat energy and then via a turbine into mechanical energy.

But as we increase the amount of less-dispatchable renewable energy into our electrical systems we have to be much smarter about the way we use energy.

In the following two articles, we look at how the grid of the future will need to change to accommodate more renewable energy:

- Firstly, Professor Peter Crossley and Agnes Beviz of the **Joule Centre for Energy Research** explain exactly what the Smart Grid concept could mean for renewable energy;
- And on page 58, José Manuel Angulo and Santiago Arnaltes of **Wind**

to Power System S.L (w2pS), look at some of the problems posed to renewables by stricter grid requirements in places like Spain and Germany, and some of the solutions available.

Smart Grids: Low carbon electricity for the future

by Professor Peter Crossley and Agnes Beviz
Joule Centre for Energy Research

To incorporate intermittent energy resources, a category which renewable energy falls into, electricity networks will have to become 'smarter grids', with integrated communication systems and real time balancing between supply, demand, and storage.

While the EU's 2020 target will require a significant contribution from renewables, look forward to EU 2050 and the targets effectively dictate that all electricity will be produced by zero carbon energy sources (both nuclear and renewables), and that coal or gas will only be used with carbon capture and storage. In addition, most forms of land transport will be powered by electricity, hydrogen or biofuels and thermal heating will be based on zero carbon electricity, solar thermal, biomass or heat pumps.

To ensure security of supply, these shifts in electricity generation patterns will need to be matched with responsive energy use from consumers, and a smart electricity grid to balance supply and demand. For example, if wind farms become a dominant source of electrical energy in the UK, how do we cope with rapid changes in wind speed or extended periods of low wind, particularly when this affects large geographical areas during a winter anti-cyclone?

What is a 'Smart Grid' and how would it operate?

A 'Smart Grid' means different things to different people, but at a simplistic level it is a method of delivering electricity from suppliers to consumers using information technology and communication systems. An intelligent communications system between suppliers, consumers, storage systems, and the components of the electricity grid would save energy, reduce cost and maximise the use of national, local and domestic sources of low carbon energy. When we consider the electricity supplied to a town or city over a year, the energy delivered will vary based on time of day, climatic conditions, season, working/holiday day, television schedules, and special events.

At present, in most distribution networks, particularly those in the developed world, consumers can have as much electrical energy as they require whenever it is needed; generators provide the flexibility. For example, if an important football game is being shown on TV and the game has extended into a penalty shoot-out, the electrical demand in those parts of the region where a team is supported will be low, but once the shoot-out has been completed the demand will suddenly rise as the local community switches their kettles and cookers on.

The national power frequency will start to reduce, the steam valves on the generator turbines will open, the generator output power will increase and the frequency will return to normal. Currently, nuclear stations and less-expensive coal or combined cycle gas turbines are used for base load, while coal and gas fuelled generators and pumped storage plants are used for balancing during peak demand (see [figure 1](#)). Intermittent renewable generation, such as wind, is normally only a small percentage of the total and consequently is always allowed to generate, with a negligible role in balancing.

In a low carbon future, we will have to find a way of balancing supply and demand without resorting to coal and gas fuelled generators. The

term 'Smart Grid' refers to a system that would enable this integration of renewables and shift from reliance on fossil fuels, while maintaining a balance between supply and demand. Key components of smart grids therefore include:

Storage technology

In order to fully utilise intermittent renewable energy resources, excess generation will need to be stored when supply exceeds demand, in combination with exporting energy between countries through interconnectors. The stored electricity can then be fed back to the grid at times of peak demand. This storage can be centralised within the grid or distributed storage in individual homes or communities.

Demand side management

Even with additional storage, systems will need to be in place to ensure that energy use is sensitive to the supply available and enhance the reliability of the network. If for example, renewable generation remains low for extended periods of time, in an unmanaged system all the stored energy could be used up leading to electricity supply problems. To avoid such scenarios, consumers could have 'smart home' systems which receive pricing signals informing smart appliances that local energy costs are high and ideally that they should not operate.

To balance the supply, demand, and storage, electricity grids will need an intelligent communication system. Such an information system would provide 'real time' electricity pricing to smart meters in homes and integrate all elements connected to the electrical grid.

For example, a consumer could programme their washing machine to wash clothes within a time period of 24 hours, when the energy costs are low. This would reduce the magnitude of the peak demand by automatically shifting use to off-peak periods when the energy costs are lower (see [two graphs on page 56](#)).

Enhanced grid communications systems

To balance the supply, demand, and storage, electricity grids will need an intelligent communication system. Such an information system would provide 'real time' electricity pricing to smart meters in homes and integrate all elements connected to the electrical grid. In a smart grid the above components are linked in to an intelligent network infrastructure, adapted to incorporate distributed generation. Such a network would have remote management and fault monitoring, and respond in real time to external factors such as changes in weather patterns and therefore electricity generation.

Figure 1: Current UK Energy Supply over a 24hr Cycle

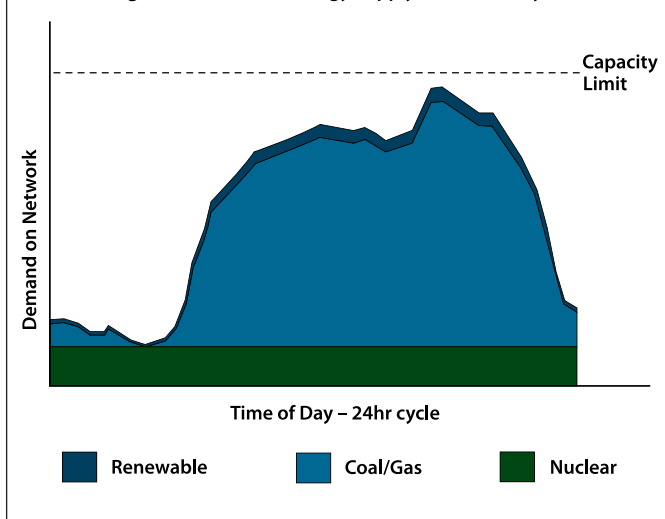
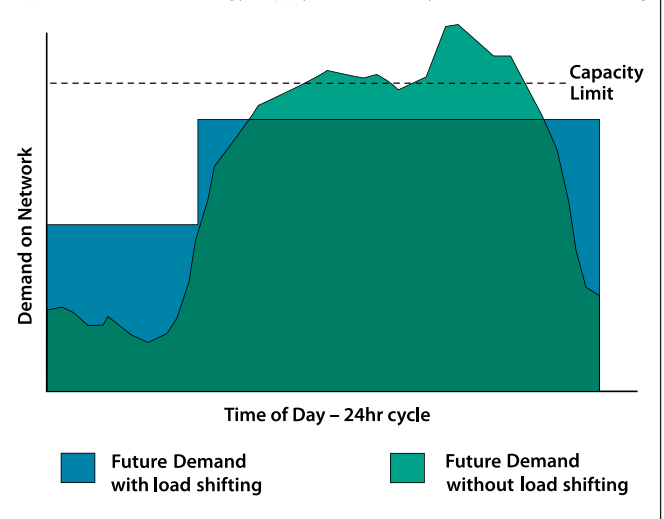


Figure 2: Current UK Energy Supply over a 24hr Cycle with demand shifting



What are the key challenges associated with smart grids?

As smart grids are essentially a way to adapt the grid to incorporate low carbon intermittent electricity generation, there are several challenges involved in their development, and maintaining a secure and reliable energy supply system.

In addition to intermittent and variable energy supplies, the electricity grid of the future will need to cope with increased demand. While we currently use fossil fuels for transport and heating (in the UK), these are likely to become electrified in the future as we shift to low carbon energy resources. This adds a significant additional load to the supply network. Even if the thermal efficiency of buildings is improved, together with the use of more energy efficient vehicles, electrification of heating and transport is still likely to quadruple electrical demand by ~2040.

In addition to meeting a larger average demand, the future electricity grid system will need the capacity to cope with (or be able to shift) an increase in peak demand due to electric vehicle charging. In order to meet these challenges, we will need to develop and deploy energy storage technologies and communication infrastructure to manage an increasingly complex energy supply mix. A key challenge is designing a communication system that can securely and reliably process a large volume of data, and identifying precisely what data needs to be transferred and where to.

As well as a diverse energy mix, Smart Grids will also have to deal with increased distributed generation, and the associated voltage and fault current control issues. Distribution Network Operators (DNOs) will need to understand the effect on the distribution network of widespread deployment of dispersed generation at both the high voltage level (e.g. 11 kV in the UK) or at the low voltage level (400 V 3-phase or 230 V 1-phase).

Some of the technologies that might be connected either directly or via power electronic converters include solar photovoltaic (PV), ground and air source heat pumps, domestic or community combined heat and power (CHP) systems or DNO-connected wind generators. The DNO also needs to be aware of the effect on their network of

electricity storage technologies, electric vehicles and dynamic or price controlled loads (i.e. smart consumers).

What does a Smart Grid mean for the consumer?

One of the greatest challenges for future electricity grids lies in demand side response and creating a system that can shift peak demand, at the same time as being socially acceptable. This is a key issue as major behavioural changes are necessary to change energy use patterns and the current demand curve, likely to be facilitated by suitable user-friendly technology platforms. There are also key questions surrounding how this will be implemented, as a price based incentive system is likely to push those on low income further in to fuel poverty.

On the electricity market where generators sell their electricity, prices fluctuate depending on the time of day and continuity of supply. These price fluctuations are not currently reflected in the electricity bills of the average consumer; most contracts have a flat price per kWh for electricity use. In the future it is likely that these will not be fixed, but will vary significantly at different times of the day or at different periods in the year, dependant on weather conditions and national, regional and even local behaviour. In this context a 'smart' consumer would need to change their energy use pattern to minimise the cost of their electricity demand, and this behaviour would add to the supply-demand balancing of the grid as a whole.

A 'smart' domestic consumer would have a domestic energy computer to maximise the demand when the electricity price is low i.e. charge the car; activate smart-appliances; maximise heat in the hot water and thermal storage systems. It should be possible to take a large proportion (up to ~60%) of the daily demand during low cost periods, reducing the electricity use when the price is high.

Engagement with all consumers and encouragement of behaviour changes will probably be the most difficult challenges for the wide spread dissemination of Smart Grids and hopefully will be one of the important issues considered by demonstrators. As Smart Grids represent the adaptation of our electricity grid to incorporate renewable energy, they carry all the challenges of maintaining energy security and reliably while meeting future CO₂ emissions targets.

A modern day solution to LVRT: regulatory prescriptions and technological responses

by José Manuel Angulo: CEO of Wind to Power System S.L (w2pS), and Santiago Arnaltes, w2pS Co-Founder, and Professor at Carlos III University of Madrid.

As the percentage of renewables in a given grid edges above 10-15%, the problems of integration begin to multiply due to issues of intermittency. And increasingly, regulators are responding with higher technical standards for renewable energy generators to meet.

These standards impose more sophisticated technological requirements on wind farm operators and, by extension, wind turbine manufacturers – which, while within the capabilities of first-tier manufacturers, have proved a challenge for others. And, in the case of legacy generating assets, new grid codes can require or at least incentivise wind farm owners or operators to retrofit existing turbines.

A number of technology companies have stepped forward with solutions for turbine manufacturers and wind farm owners. But when it comes to the most pressing renewable energy grid integration issue – that of **low-voltage ride through (LVRT)** – how is this being addressed by regulators, and how have companies such as w2pS developed new technology solutions to meet evolving regulatory requirements.

While LVRT is of little concern to grid operators where renewable energy penetration accounts for a mere few percent of overall capacity, it can become a significant problem if penetration rates climb substantially into double figures.

The challenge

All electric grids can fall victim to sudden drops in voltage caused by a short-circuit within the transmission system. While the fault is usually speedily isolated by automatic protection systems – typically within milliseconds – until that point the voltage on the transmission system falls (in theory to zero at the point of the fault). The effect of this voltage drop becomes less severe the further it is away from the source of the problem, but its effects can be significant over several hundred kilometres.

Conventional generating capacity uses synchronous generators, which respond well to short-lived voltage dips and are able to rapidly change the amount of reactive power they produce or consume. Reactive power – which is produced predominantly by generating plants, and consumed by electricity consumers – is a complex concept, but it is essentially used by system operators to control voltage levels. The injection of reactive power into the grid by generating plant has the effect of counteracting the effect of voltage drops.

However, many older or less advanced wind turbines – those using directly-connected induction generators – are not able to react in such a fashion. They consume large amounts of reactive power, which can exacerbate the voltage dip. Instead, in order to protect their power electronics, they are designed to shut down instantaneously in the event of such a drop in voltage. While this is of little concern to grid operators where renewable energy penetration accounts for a mere few percent of overall capacity, it can become a significant problem if penetration rates climb substantially into double figures.

In principle, the problem of LVRT could be dealt with at the transmission system level, by installing power-electronic equipment to inject reactive power. However, very large devices would be required to produce the effect required, and high-voltage switchgear and transformers would also be needed.

The response from regulators in larger renewable energy markets – with Spain being one of the first to move, with regulations drafted in 2006 – has been to **enhance grid codes**, requiring that renewable energy generating equipment has LVRT capability and reactive power control capability.

These typically have three aspects:

- A voltage-time graph which defines an envelope defined by the extent of voltage drop-off and duration outside of which generators are permitted to disconnect from the grid;
- A requirement for the provision of reactive power during the fault; and
- A requirement for the restoration of active power after the fault.

The policy solution

As an early mover in introducing regulation, Spain, via its P.O 12.3 regulation, is relatively lenient in terms of the requirements it imposes on renewable energy generators. It requires that wind farm generators should remain connected to the grid if network voltage falls to as little as 20% of nominal for up to 0.5 of a second, with the requirement becoming less onerous in terms of voltage drop up to one second. The regulation also specifies the reactive power that the wind farm is required to generate during the fault.

A number of other jurisdictions with high levels of renewable energy penetration have introduced, or are contemplating, new grid codes. And, in many cases, these are more onerous than those introduced in Spain. For example, in both France and Germany newly connected generating plant must remain connected during voltage dips as low as 0% – a technically much more challenging requirement than the 20% retained voltage specified in the Spanish regulations.

Meanwhile, the **Electric Reliability Council of Texas (ERCOT)** – which has mandated 10 GW of renewable energy capacity by 2025 – accounting for some 15% of total capacity – is in the process of implementing regulations addressing LVRT and reactive power. These policies are expected to come into force in 2011, and the industry assumption is that a substantial proportion of existing capacity will not be able to meet these new standards.

The industry responses

Leading players within the wind energy industry have been fully aware of the challenge of LVRT for some time, and newer turbine models from industry leaders come with LVRT as integral.

For example, 'full converter' (FC) turbines, where power passes through a power-electronic converter, have the greatest ability to meet the more onerous grid codes (although many products currently on the market do not). These also offer the highest levels of flexibility in generator technology, and are gaining ground in the marketplace. For example, **Enercon** has a full converter turbine, as does **Vestas** in its V112 3MW model.

Case study – w2pS Coverdip

w2pS, with a background in the Spanish market, was intimately involved in the discussions around the introduction of Spain's landmark regulation around renewable energy grid codes.

In 2008, it introduced its *Coverdip* product, which provides an LVRT solution for most turbines between 600kW and 1,650kW (with a 2,000kW model under development).

Coverdip provides a quick and inexpensive solution for wind turbine manufacturers entering into markets with stringent grid codes. One of the advantages of Coverdip – and related solutions – is that it is technology agnostic, and does not require trigger manufacturer warranties. Rather than requiring installation within the turbine mechanics itself – potentially voiding manufacturers' warranties – the equipment is installed at the base of the turbine providing severe balanced and unbalanced voltage dip faults tolerance (to a 0% voltage drop). This also facilitates installation and maintenance.

This is particularly important given that grid standards are unlikely to be harmonised internationally in the near future, and may indeed vary between different grid operators in the same country.

Furthermore, standards will most likely be gradually raised, as technology improves and falls in cost, and as the economic viability of more reliable and stable renewable generating capacity improves. Both of these factors enhance the appeal of technology-agnostic solutions.



However, while it is one thing to require that new turbines are certified to higher standards, legacy-generating assets are proving more of a problem. Older fixed-speed induction generator (FSIG) turbines consume reactive power, requiring power-factor correction equipment, and are typically unable to meet more onerous grid requirements. These continue to be used for new projects as they are highly reliable, and therefore often are the only solutions that can be deployed for particularly remote or harsh environments.

Similarly, turbines based upon the more popular doubly-fed induction generator (DFIG) concept, which use relatively small power-electronic convertors, are also in almost all cases unable to meet rising LVRT and reactive power requirements. This is the dominant technology in terms of existing capacity in OECD markets.

With recent consolidation in the marketplace, many of the dominant turbine suppliers have grown by acquisition – making it problematic for them to offer retrofitting solutions to a range of legacy models that they have adopted via acquisition.

Older fixed-speed induction generator (FSIG) turbines consume reactive power, requiring power-factor correction equipment, and are typically unable to meet more onerous grid requirements.

Technology solutions to the LVRT issue

An important role for technology suppliers has been in working with regulators and turbine manufacturers – to reassure that an economically viable technological fix is available. The default position of a transmission grid operator would be to ensure grid stability, at the expense of increased renewable energy penetration.

However, by demonstrating that stability can be enhanced cost-effectively, environmental and energy security objectives can be preserved, and a number of technology companies have stepped into this vacuum to provide solutions to LVRT.

Companies such as **Green Power** and **ELSPEC** have introduced systems to inject reactive power, while **AMSC** and **ZIGOR** have developed uninterruptible supply solutions. And **w2pS** (see case study opposite) has developed a solution that works as a parallel solution, connected in series, protecting the wind turbine.

Ultimately, issues around renewable energy intermittency and variability will be dealt with by the widespread and economic availability of energy storage technologies, and by a genuinely smart grid that is better able to balance high percentages of distributed energy generation.

In the mean time, technology providers are facilitating the transition from the energy-generating technologies of the first half of the 20th century and the low-carbon energy networks of the 21st.