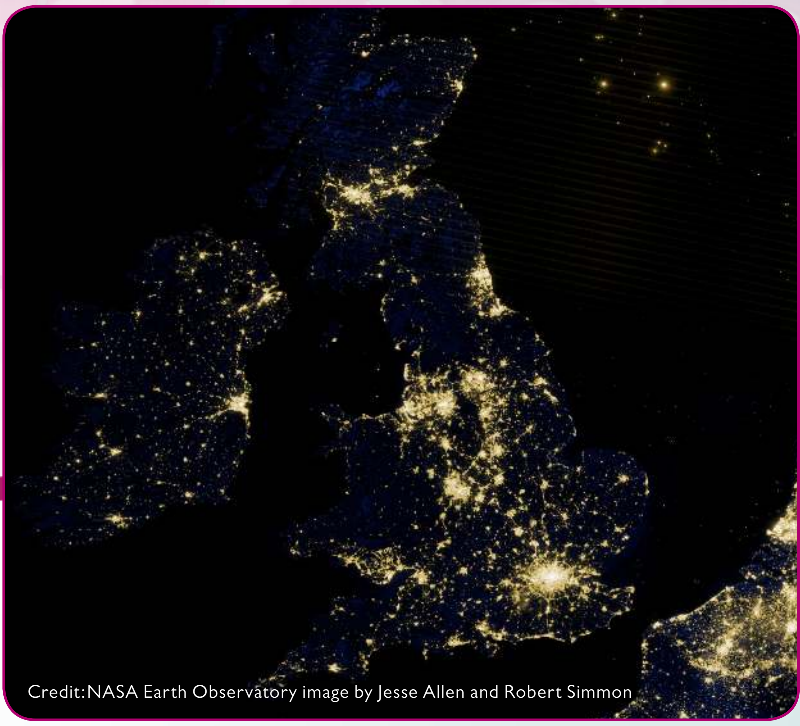
MATHEMATICS MATTERS

A smarter future for next generation local electricity networks

The vision of a low carbon future brings its own challenges when it comes to maintaining an effective electricity supply system. Mathematicians are working to give decision makers richer understanding, greater flexibility and a more solid evidence base on which to inform their important choices.



Credit: NASA Earth Observatory image by Jesse Allen and Robert Simmon

As part of a Europe-wide endeavour to reduce carbon emissions and deploy sustainable energy sources, the UK government has set a series of targets. In particular, it has set the long term goal of reducing the UK's greenhouse gas emissions by at least 80% compared to 1990 levels by 2050. However, this is likely to result in an increase in electricity consumption as consumers choose low carbon alternatives to heating and transport, for instance though electric vehicles and heat pumps. Additionally, although most power is generated in power stations, in the future there will be increased levels of local generation with up to 20% of our future energy coming from renewable, yet volatile, sources such as wind and solar power which are more dependent on weather and climate. The interaction between customers and such technologies will see the emergence of new types of energy usage behaviours and may drive potentially novel ways of mitigating high demands.

The electricity we receive in our homes is stepped down to a low voltage (LV) grid by our local substation. A substation will typically feed the needs of 80-200 nearby homes. This planning of the LV networks was established over the last sixty years by estimating total and peak usage to create a network capacity which can handle the expected future demands. Up until recently this approach has been successful with coping with the small changes in domestic and commercial usage. However, with many parts of the system due for renewal work, replacing them like-for-like would lock us in for up to 40 more years and fail to prepare the network for the anticipated shift in electricity demand.

> "Mathematicians are involved in conducting a smart meter trial in the Berkshire town of Bracknell as part of a £30m project for UK energy regulator OFGEM"

Faced with a less predictable supply, the energy industry is looking for a greater insight into time varying demand to maintain the crucial balance between supply and demand. To help meet the challenges of a low carbon future, the UK Government announced in late 2009 its plan to install smart meters in the UK's 27 million homes by 2020. A smart meter is a device that can monitor the consumption of electricity within the home and communicate such information to an external party. Smart meters have been increasingly deployed around the world since 2000. Awareness of the consumption patterns and consequent changes in demand behaviour might well result in a win-win-win: extending the lifetime of the networks without causing massive investments, reducing bills for customers, reducing losses for electricity suppliers.

To provide such an insight, mathematicians at the University of Oxford and University of Reading's Centre for the Mathematics of Human Behaviour (CMoHB) are analysing data from domestic smart meters. If every household has a smart meter, then a wealth of data suddenly becomes available for analysis, as required; and a number of options may open up for consumers, including opportunities to reduce their energy bills by getting a clearer picture of their power consumption. To test the benefits to the distribution process, Oxford and CMoHB mathematicians are currently involved in conducting a smart meter trial in the

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Berkshire town of Bracknell as part of a £30m, Scottish and Southern Energy Power Distribution led, collaboration funded by the UK energy regulator OFGEM. Data on domestic and small scale commercial properties' electricity usage are recorded every half an hour. This data can be used to help categorise the customers' behaviour and plan and forecast future energy demands across the short, medium and long term.

Currently consumers are characterised based on their socio-economic profile and postcode. This is because existing meters are only read at most every quarter so there is no indication as to how such aggregated demands are produced. However, with half hourly data on electricity usage from smart meters, characterisation could be based on solid numbers. Using an area of mathematics known as unsupervised discrimination, Oxford and CMoHB mathematicians are using the trial data to classify electricity customers into ten to twenty different groups based on their consumption patterns of behaviour, and their volatility.

From there it is possible to look at which combinations of behaviours on an LV network are more likely to put strains on the system. For example, a substation that supplies to customers with relatively heavy evening demand with volatile (unpredictable) behaviour could be flagged as an area of concern to the distribution network operator.

There are also times of day where the demand on the LV grid is likely to come under particular strain. Currently this occurs at late afternoon and early evening. As new technologies are introduced and taken up, such as electric vehicles, there could be some new critical pinch points, as aggregated demand approaches the LV network's maximum capacity. This problem is local: so "keeping up with the Joneses" – social network driven take-up of assets might make things even worse. Smart storage or smart control of demands might create headroom where demand is predictable; whereas volatile events can only be managed through increasing capacity.

This is entirely different from predicting large scale demands on national high voltage power networks, where the sum effect of large numbers of local fluctuations in demand tends to average out. On LV networks consumers' behavioural patterns may well conspire to compromise the supply headroom very briefly during a day or a week. Mathematically speaking any short term forecasting is problematical, since, for management and control purposes, such "rolling" or live forecasts will need to exhibit realistic demand peaks, and so any inherent smoothing will be misleading. The peak demands need to be anticipated even if these are slightly misplaced in time. This leads to the use of statistical methods that can allow for some elasticity in the timing of forecasted peaks in demand compared to the actuals. Medium term forecasting, over a period of one or two years ahead, is also required for essential network renewal. The challenge here is to define and recognise some alternative potential drivers for types of LV network compromise. There will be some networks that have a combination of consumer demand behaviour that requires intervention (replacing the copper in the ground), management (that can be achieved by smart control of local energy storage); whilst some networks may require monitoring yet not be at a critical situation. Other networks may be fine. In the past there has been almost no monitoring of the time dependent demands at domestic LV substations so the extent to which the current headroom is reduced is largely unknown (it cannot be breached often, if at all, as the supply is maintained: but for how long will this remain so?). A key challenge for the mathematical forecasting is to discriminate between such situations based on the newly available and anticipated information. In Bracknell, the project creates a situation that will be the norm in a few years time. Hence it is a chance for creative and rapid mathematical modelling, inference, and learning and dissemination.
Longer term planning, between three and five years down the track, is naturally more speculative and so new methods will be required so that policy decisions can be based on harder evidence.

Professor Peter Grindrod, of the University of Oxford, commented that the whole energy sector needs to change from being supply centric to becoming consumer, and consumer demand, centric. This has happened in other sectors such as retail and mobile telecoms. The culture must be inclusive for all types of customers yet its implementation must be flexible to deal with new technologies and devices in the future. We have a clearly specified set of problems to solve and the prospect of data for the first time at all end points, available 24/7.

The challenge for mathematical analysts is to devise efficient, effective and scalable methods and insights which will underpin the next generation smart LV grid technologies, both within the home and on the local network.

References

[1] **https://www.gov.uk/government/policies/helping-households-to-cut-their-energy-bills/supporting-pages/smart-meters**

[2] Thames Valley Vision, see **http://www.thamesvalleyvision.co.uk/**

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