

SUBMISSION FROM KEITH BELL AND SIMON GILL

We welcome the opportunity to comment to Members of the Scottish Parliament on the subject of security of electricity supply. Immediately below, we provide a short summary of the main points of our contribution. Then, we present our main contribution. This is followed by an Appendix that provides some background information. We recommend that anyone not already familiar with the electricity supply industry in Britain and how it is organised in respect of generation, transmission and distribution reads the appendix before reading the main body of our contribution. Finally, through short biographies, we outline why we believe we are qualified to comment on security of electricity supply in Scotland.

The views expressed below are those of the authors.

Summary of our contribution

We would like to highlight the need to be clear about the meaning given to 'Security of Supply' in this enquiry. In general terms, the expression means the extent to which a supply of electricity can be relied upon. This depends on (a) there being enough generation available to meet total system demand at a particular time; (b) there being enough transmission capacity to transfer power from large power stations or wind farms to 'grid supply points'; and (c) distribution network connections between grid supply points and consumers' premises being in service. The vast majority of British consumers' experience of interruptions to supply in recent decades has been as a consequence of faults on the distribution network. At the level of total available generation, shortfalls are expected to occur only very rarely and in most instances can be managed without unauthorised interruptions to supply¹.

In addition, we make the following observations.

- Whilst the capacity market should ensure sufficient GB generation, in its current form it does not ensure any new dispatchable generation in any particular region of the GB system, e.g. Scotland.
- Security of Supply for Scotland at a transmission level involves a combination of generation available to operate in Scotland and the transmission network's capability to import power from outside Scotland, assuming such power is available. Given the existing mix of generation in Britain and that expected in the next few years plus existing and planned transmission network capacity, the most economic solution for consumers in Scotland is unlikely to be one of zero imports from outside Scotland at any time.
- The greatest scope for improvement of security of supply for consumers in Scotland lies within the distribution networks. Particularly at issue is the Distribution Network Operators' (DNOs) ability to reduce the time taken to restore supply in the event of disconnections.

Based on detailed engineering discussion with the transmission licensees and our own high level modelling, it is our understanding that, in the short term, risk to meeting demand for electricity in Scotland associated with the unavailability of either Scottish generation or transmission interconnection with England is not significant when measured by international standards.

In our opinion, the general regulatory environment concerning 'security of supply' is broadly adequate. However, we feel that there are a number of things that are worth noting.

¹ Our appendix outlines the list of actions that the system operator would take in the case of a shortfall of generation before disconnecting customers.

1. The incremental costs of increasing reliability of supply become increasingly great, and the costs must be borne by someone. Willingness and ability to pay for this and the benefits that accrue must be considered carefully.
2. As far as we are aware, there is currently no clear and obvious mechanism through which a medium to long-term contract with generation capacity in a particular area might be judged in comparison with increased network import capability to meet demand in an area with a sufficient level of reliability.
3. There are licence obligations on the power network licensees in Britain to provide sufficient network capacity to meet a particular level of reliability of supply to consumers. However, in our view, the clarity of the transmission design standard could be improved in respect of areas that (a) normally export power but, from time to time, depend on imports of power and (b) depend on a small number of quite large generating units. Scotland as part of GB is an example of such an area.
4. In our view, Ofgem is notably passive in respect of technical issues and could be argued to be over-reliant on the network licensees to flag concerns. It appears to lack the engineering expertise either to challenge the network licensees or, indeed, its own economists. As regulator of an industry dependent on technical skills to ensure provision of appropriate infrastructure and reliable system operation, we believe this should be addressed.
5. Future challenges include ensuring sufficient system resilience to extreme weather; dealing with the possibility of more frequent major disturbances; and accommodating greatly increased renewable generation and, if heat and transport are largely electrified, much greater demand for electricity. Greater flexibility on the demand side will be extremely important in facilitating a lower carbon energy system. This will give a different meaning to 'security of supply' since there will be – or should be – a much clearer price associated with any individual consumer's total possible demand for electricity being met at any time and incentives to shift demand in time.
6. Meeting future electricity system challenges depends on enhanced expertise within the industry, commitment by companies to recruiting, developing and retaining it and acknowledgement by Ofgem of the associated costs. It also presents a challenge to universities and society as a whole from which engineers are drawn.

1 Introduction

We present our main comments under four main headings: “Ensuring future ‘security of supply’”; “Interactions between generation, transmission and distribution”; “Current issues”; and “Future challenges”. However, a reader who is not familiar with the electricity supply industry and how it is managed is recommended first to read the background information in the Appendix and then to read the main body of our contribution.

2 Ensuring future ‘security of supply’

In general terms, ‘security of supply’ means the extent to which a supply of electricity can be relied upon. This depends on (a) there being enough generation available to meet total system demand at a particular time; (b) there being enough transmission capacity to transfer power from large power stations or wind farms to ‘grid supply points’²; and (c) distribution network connections between grid supply points and consumers’ premises being in service. Most consumers’ experience of an interruption to supply is as a consequence of faults on the distribution network. At the level of total available generation, shortfalls are expected to occur only very rarely and in most instances can be managed without unauthorised interruptions to supply.

The design and operation of electric power systems worldwide are primarily governed by what are known as ‘security standards’. In respect of longer-term planning of the simple balance of generation and demand, the standard adopted by the Department of Energy and Climate Change (DECC) in Britain has been a ‘Loss of Load Expectation’ (LOLE) of 3 hours per year³. In respect of the design of distribution networks in Britain and the reliability of supply they provide to their customers (assuming that sources of power are available on the transmission system), Distribution Network Operators (DNOs) have an obligation to comply with a document known as Engineering Recommendation P2/6 (ER P2/6). The three transmission licensees in Britain⁴ are obliged to comply with the National Electricity Transmission System Security and Quality of Supply Standard (NETS SQSS). The SQSS defines the precise meaning of ‘N-1 security’ when planning or operating the system, i.e. broadly, the ability of the system to continue working following any single fault event such as the loss of a large generator or a transmission line. For a given future ‘generation and demand background’, i.e. the nature, size and location of future demand and generation capacity, it also sets out quite precise rules about the minimum secure transmission network power transfer capability that should be provided into areas of the system, i.e. power that can be safely transferred into an area even after an ‘N-1’ secured event. If the network’s capability falls short of that minimum, the transmission licensees are obliged to bring forward investments to reinforce the network to meet the minimum or, if there is an evident economic case to do so, exceed it.

3 Interactions between generation, transmission and distribution

The single GB electricity market provides generation in Scotland with a much larger customer base for the power it generates than would otherwise have been the case. The single GB market, a single GB electricity transmission system operator and a single GB transmission security standard also provide electricity users in each part of Britain with reliable access to power from the transmission system at a lower cost than would otherwise have been the case⁵. Given sufficient

² Small scale, ‘embedded’ or ‘distributed’ generation is connected to the distribution networks rather than transmission.

³ See the Appendix for an explanation of LOLE and what a shortfall of available generation would mean.

⁴ National Grid Electricity Transmission, Scottish Power Transmission and Scottish Hydro Electric Transmission.

⁵ For decades even before BETTA, the transmission system in Britain operated as a single system albeit with three separate system operators responsible for different areas and required to liaise with each other. That is, it is a long time since there was a Scottish power system that could be regarded as fully independent of that in England and Wales. Moreover, as an aid to security of supply in Scotland, the Scottish system was planned to have a certain ‘interconnection reserve’ with England.

transmission capacity between Britain and the rest of Europe, the European Commission's expectation is that further, similar benefits could be achieved on a bigger scale.

The design criteria for the transmission network are driven by two aspects: the economics of electricity supply; and reliability (or 'security') of supply. For the former, investment in the transmission network is justified if its cost is less than the benefits of reduced cost of system operation. For the latter, given the generation capacity in an area (and the expectation that not all of it will always be available) and the peak demand in that area, a certain level of power import capability should be provided such that the probability of failing to meet all the demand in the area is small. In other words, for the case of any area of GB such as Scotland, the transmission licensees are obliged to provide sufficient transmission network capacity to enable consumers to have access to power available in the rest of Britain, and the capacity market should ensure that such power somewhere in Britain is available almost all of the time.

As has already been noted, most consumers' experience of interruptions to the supply of electricity is as a consequence of faults on their local distribution network⁶.

4 Current issues

It is our opinion that the general regulatory environment concerning 'security of supply' is broadly adequate. However, we feel that there are a number of things that are worth noting.

4.1 The cost of reliability

Perfectly reliable supply of electricity cannot be guaranteed – it is always possible for 'exceptional' circumstances to arise even if improbable. The cost of continually reducing the probability of interruptions to supply gets ever larger as the probability of interruption gets smaller (although never zero). These costs must, in the end, be met by someone. The willingness and ability to pay for increasing reliability of supply and the benefits must be considered carefully.

4.2 Improving 'security of supply' in an area: generation or network capacity?

In respect of improving 'security of supply' in a particular area of a power system, there are two broad options: (i) increase generation capacity in the area; (ii) assuming that there is sufficient generation capacity outside the area, increase the network's capability to (reliably) import power from outside the area. In theory, because consumers (or, under a different set of arrangement, taxpayers) should finally pick up the bill, the option that should be adopted to achieve a given target value of reliability of supply should be the cheapest one. In the short-term, it is our understanding that the National Electricity Transmission System Operator (NETSO) in Britain does compare contracting with generation (if it already exists) for 'balancing services' for the hours in which such services are required with building of new transmission facilities (if they can be built quickly enough). However, for the medium to long-term, the main system related incentive currently in place for generation to locate in a particular region arises from transmission network use of system (TNUoS) charging and the variation of zonal tariffs. Reform of the TNUoS methodology under 'Project TransmiT' has been a long and somewhat arduous process. Among the changes approved by Ofgem – but not yet implemented – is a split into (i) factors associated with year-round use of the network as part of market operation and (ii) factors associated with meeting peak demand for power. In principle, the latter might provide an incentive for additional generation in Scotland but, in practice, the methodology might not account for the variability of

⁶ Some generation is connected to the distribution networks and the distribution network design standards do assume some contribution from it to meeting demand. That is, although supplies from the transmission system are generally very reliable, if there is some generation on the distribution network, the capacity of the distribution network connection to the transmission system would generally be less than it would otherwise have been.

power flows around the peak⁷. Transmission network planners have no direct influence on how much new generation is built or where it is built⁸; they typically take the ‘generation background’ more or less as a given and then plan the transmission network accordingly⁹.

With the exception of systems on some Scottish islands, we are not aware of any example of a DNO contracting with generation as an alternative to providing additional network capacity to serve demand.

4.3 How ‘security driven’ planning criteria are expressed in the SQSS

The precise rules in the SQSS in respect of ‘security’ or reliability driven transmission capacity were first developed many years ago when the generation mix was quite different from what is now developing. In particular, they assumed most generation has the characteristics of fossil-fuelled plant in terms of availability. However, the characteristics of power from wind generation are very different. As a result, changes were approved to the SQSS in 2011 that assumed no contribution from wind in respect of security of supply in an area¹⁰. However, work conducted by one of us in 2006-7 suggests that, after disregarding renewables, inadequate account is taken of the risks associated with (a) an area that normally exports power but, from time to time, depends on imports of power and (b) an area that depends on a small number of possibly quite large generating units. Scotland as an area of the GB system exhibits both of these characteristics and, as a consequence, is particularly sensitive to the reliability performance of the few large units.

4.4 Transmission level ‘security of supply’ in Scotland in the near future

Notwithstanding what we see as limitations in the precise framing of the design criteria of the SQSS, our understanding is that risk to meeting demand for electricity in Scotland associated with the unavailability of either Scottish generation or transmission interconnection with England is not significant when measured by international standards. This judgement is informed by detailed discussion of the engineering issues with the transmission licensees and our own high level modelling. What is perhaps regrettable is that clear explanations of the steps the transmission licensees have taken and continue to take have been so slow to emerge.

4.5 Reliability performance of distribution networks

Ofgem places an ‘Interruption Incentive’ on DNOs in order to ensure adequate reliability performance of distribution networks measured in terms of ‘Customer Interruptions’ (CI) and ‘Customer Minutes Lost’ (CML). However, although available computer modelling tools mean that it need not be the case, Ofgem regards the incentive as a ‘lagging’ measure, i.e. as only taking effect after excessive unreliability has already been experienced. The Interruption Incentive should act as a motive for additional investment in distribution network capacity above the minimum

⁷ It is not our intention to go through all the issues associated with TNUoS charging here. We would encourage anyone who wishes to contribute to discussion of the methodology not just to address generalities but to look at the numbers for both generators and demand, and to consider how the numbers would change with changes to the ‘generation background’ and the operation of generators.

⁸ As noted, there are indirect influences on new and existing generation not only through zonal variations in TNUoS charges but also short-term balancing service contracts. Although the provision of transmission network capacity, or failure to provide it, will influence both TNUoS charges and balancing service costs, the transmission owner has minimal influence, if any, over the methods used to determine either of these. It may also be noted that TNUoS charges and the opportunity to gain balancing service income are only two among many influences on the location and operation of generation.

⁹ Actually, a comparison of generation and transmission options would be difficult. The reliability performance, even of dispatchable generation, is very different from that of transmission (generation is generally worse) and, especially if a capacity contract represents a generator’s sole income, generation may be expected to be much more expensive. On the other hand, although transmission can be relatively cheap, depending on the precise nature of the transmission limitation to be overcome, it might not be. Moreover, it might present significant challenges in respect of planning permission.

¹⁰ See <http://www2.nationalgrid.com/UK/Industry-information/Electricity-codes/SQSS/Modifications/Concluded/>

already indicated by ER P2/6. However, in our experience, different DNOs and individual DNO planners are inconsistent in their interpretation and application of ER P2/6 and an assessment of the CI and CML impact of network operation, configuration or development options is not yet standard practice. Furthermore, we are not confident that the assumptions built into ER P2/6 in respect of the contributions of local generation to meeting distribution connected demand are robust and note that DNOs have little or no influence on the operation of distribution connected generation except where a connection agreement gives the DNO the right to curtail output¹¹.

Ofgem has criticised the performance of some DNOs in terms of their management of storms and, in particular, the time it took to restore supplies of power to all disconnected consumers over the Christmas period in 2013¹². Outages of longer than around an hour are clearly of great concern particularly in winter when there is a dependency on electricity for heat. Although it should be recognised that the issues involved in restoring supplies following storms are complex – for example, the same weather conditions that took down overhead power lines are likely also to have blocked access roads and the DNOs are not always immediately able to pinpoint the location and nature of the repair work needed – it would be interesting to know what steps the DNOs are taking to enable improved performance in future and whether Ofgem believes they are justified in economic terms.

Finally in respect of distribution networks, we note that the most recent CI and CML statistics that we could find on Ofgem's quality of service web pages relate only to 2008/9. Because most electricity users' experience of interruptions to supply is as a consequence of events on the distribution network, we would encourage both Ofgem and the DNOs to be more diligent in making more recent performance more transparent and accessible.

4.6 Ofgem's engagement with technical issues

Ofgem is often proactive in respect of market issues and developments¹³ but, in our view, notably passive on technical issues. These include: security of supply, and the issues that drive costs relating to generators' connection and operation on the system. Ofgem's approach appears to rely entirely on the industry to flag up technical issues and possible solutions and whenever anything is flagged, however minor, time-consuming consultations are conducted. In order for anyone who might usefully contribute to keep up, these require almost full-time monitoring. Our impression is that Ofgem lacks the technical expertise to make its own informed judgments on where issues exist that should be addressed, to proactively initiate review work or to critically appraise the outcomes of reviews. It is arguably over-reliant on National Grid Electricity Transmission (NGET) for transmission issues and the DNOs for distribution. Some might allege that NGET and the DNOs have vested interests in only raising particular issues under particular circumstances. Whether or not this is the case, we believe there would be considerable value in Ofgem having sufficient technical expertise in-house as to engage fully with the network licensees and challenge them where appropriate or, on occasions, challenge the assumptions made by their own economists.

5 Future challenges

5.1 Power system resilience

¹¹ As an aside, we believe that the future development of distribution connected generation and efficient utilisation and development of distribution networks depends on the development of new frameworks for distribution system operation.

¹² See "December 2013 storms review – impact on electricity distribution customers", Ofgem, March 2014. According to the Department of Energy and Climate Change (DECC), 95 per cent of the one million properties affected in Britain over Christmas 2013 had their power supply restored within 24 hours. DECC said of this, "In the context of the conditions and difficulties experienced this is considered to be a strong response by industry". ("Severe Weather – Christmas 2013: A review of Electricity Distribution Industry Performance", DECC, March 2014).

¹³ Some would argue that Ofgem is not nearly proactive enough on market issues, but that is a discussion for another time.

As was already noted above, it is impossible to guarantee perfectly reliable supply of electricity. Normally, any losses of supply are quite limited in both scope and duration. The widest spread outages are generally associated with storms and the longest with damage to air insulated electrical equipment such as overhead lines. However, the meshed nature of transmission networks, designed that way so that, the vast majority of the time, there is no material, adverse impact from individual faults, means that, on very rare occasions, critical combinations of two or more unplanned events might lead to a cascade of outages and a regional or whole system blackout.

In our own living memory, the GB power system has never suffered a whole system blackout. However, it has happened in other countries, e.g. Italy in 2003, or to large parts of continental systems, e.g. in the North-Eastern US also in 2003. 'Black start' of the system is then required and is a complex operation for which broad plans should already be in place that system operators have practised in simulations. Demand is restored in stages with the last stage often taking between 24 and 48 hours from the initial blackout.

Some engineers have argued that higher transfers of power on transmission networks make the system more vulnerable to major disturbances¹⁴. A number of disturbances worldwide have been triggered or exacerbated by extreme weather and there is a growing body of opinion that climate change will bring with it more frequent occurrences of extreme weather or greater extremes.

5.2 Smarter grids

Electric power systems worldwide are changing and already present significant new challenges due largely to the connection and operation of renewable generation. However, if excessive global climate change is to be avoided, the real power system challenges are yet to come. In Britain, we are very likely to need considerably more renewable generation but may also require carbon capture and storage and relatively inflexible nuclear generation if demand for electricity is to be met with minimal carbon emissions and least cost. Moreover, it currently seems likely that decarbonisation of heat and transport will lead to a massive increase in the demand for electricity.

There has been much talk about the ability of 'smart grids' to facilitate a decarbonised electricity system at least cost with a similar reliability of supply to what we have now. A key dimension to that will be much greater flexibility on the demand side so that we do not depend entirely, as we mostly do at present, on reserve generation to balance out the variability of demand and the power available from renewables. This will give a different meaning to 'security of supply' since there will be – or should be – a much clearer price associated with any individual consumer's total possible demand for electricity being met at any time and incentives to shift demand in time.

Another dimension is the ability of 'smart' grid operation to make better use of the underlying network infrastructure. Most of the ideas have already been practised at transmission level for many years. There is scope to roll many of them out to distribution and to extend their use on the transmission system. However, this presents many challenges, not least the possibility that, while on average being just as reliable as now, the system will be more vulnerable to occasional major disturbances.

5.3 The provision of expertise

A much greater penetration of renewables will dramatically change the physical characteristics of the power system, in particular its dynamics. A relatively small system such as that in Britain will be especially sensitive to that. The NETSO is clearly a critical party in ensuring operability of the future power system but it will need to work closely with all the network licensees, both transmission and distribution. In our opinion, they will all require significantly enhanced technical

¹⁴ See, for example, the report of CIGRE Working Group C1.17 on "Planning to Manage Power Interruption Events".

capability in terms of both tools and expertise. In the DNOs' case, in particular, that means retaining and enhancing skills among fitters and craftspeople but also developing deeper levels of core power systems understanding and creativity among professional engineers. This requires an investment in recruiting, developing and retaining people that, in our view, needs to be recognised and committed to by both senior network licensee managers and Ofgem that sets cost recovery allowances.

As academics, we are conscious of the universities' role in providing basic professional education. Worryingly, across the UK as a whole, the number of people choosing to study electrical or electronic engineering at university fell by more than 40% between 2002 and 2009 and, if it has improved since, has done so only moderately. However, given the technical challenges that will be faced, we believe that it will be increasingly important to attract a sufficient number of the most able individuals to electric power engineering degrees not only at a Master's level but also in order that at least some will benefit fully from training to a doctoral level and beyond and go on to form a critical core of senior industry engineers.

We are pleased to report that the University of Strathclyde bucks the UK trend in developing power engineers and is educating growing numbers. Although it is only one of eight universities across the UK in the IET Power Academy, it has provided more than 35% of the students on the scheme. However, if the future needs of the power industry and, ultimately, of consumers are to be met, simply admitting more students is not sufficient in itself. Only so much can be done to build people up to a certain level of understanding and professionalism, and that requires investment in teaching capacity. If that is not done correctly, the tensions inherent in academics' traditional role in both providing core teaching and leading research will be increasingly irreconcilable.

Universities in the UK can play a key role in helping the power companies transition to the new, low carbon world. This requires not only individual academics who meet standard university performance metrics by churning out learned papers but teams that are capable of helping industry navigate the challenges facing them, resolve key uncertainties and adopt appropriate innovations. The University of Strathclyde has a long and proud record of close industry engagement. We believe it is a measure of the ongoing success of the culture that the University has established that we face a continual challenge in respect of our capacity to accept invitations from people to work with them.

Appendix: background information

The market context

The 1989 Electricity Act required separation of the planning and operation of generation, transmission and distribution. Competition was expected to be effective in controlling cost of generation and wholesale electricity prices. Transmission and distribution were seen as being natural monopoly activities for which particular licence conditions and tight regulation were required. However, as is noted below, although generation, transmission and distribution should be managed independently, 'security of supply' depends on all three.

Since implementation of the British Electricity Trading and Transmission Arrangements (BETTA) in 2005, Scotland has been an integral part of the GB electricity market¹⁵. BETTA was enabled by legislation in the UK Parliament. Among the aims cited by the Office of Gas and Electricity Markets (Ofgem) were¹⁶: to enable the benefits of competition in the wholesale electricity market to be seen by consumers across Great Britain; to create a situation where more efficient price signals inform economic decisions over production and consumption; and to encourage greater competition in the supply of electricity in all regions of GB.

In 2012, further legislation was passed in the UK Parliament to enable Electricity Market Reform one key feature of which was the introduction of a capacity market in response to growing GB-wide concerns about lack of investment in new, dispatchable generation capacity to replace that which was closing or due to close largely as a consequence of European emissions legislation. The amount of capacity to be procured was determined as being that required for the 'Loss of Load Expectation' (LOLE) to be no greater than 3 hours per year, i.e. that the power available from generation across the whole of GB would be less than the total GB demand for electric power in no more than, on average, three hours in a year. The results of the first round of auctions for contracts under the capacity market were published in January 2015 and resulted in contracts being awarded to 49.4 GW of capacity¹⁷.

Directives of the European Commission (EC) have been approved that oblige the development of an integrated European market for electrical energy. As a first step, so-called 'implicit' auctions of interconnector capacity are required to better facilitate the trading of electricity across international borders. In light of the introduction or planned introduction of capacity markets in, for example, Britain and France, it may be noted that, in their guidance on public intervention the EC asserts that capacity mechanisms can be expensive and can over-reward generation that does require support: "Mechanisms based on capacity payments do not ensure that the identified adequacy gap is filled and create significant risks of overcompensation"¹⁸. Meanwhile, it may also be noted that the contribution assumed from imports of power across international interconnectors by National Grid and the Department of Energy and Climate Change (DECC) when determining the capacity to be bought through the capacity market has been challenged by DECC's capacity market technical advisory group.

What 'security of supply' depends on

The storage of electrical energy has always been very expensive and limited in efficiency. In large power systems worldwide, it has therefore proved more economic to balance generation of power

¹⁵ Northern Ireland is part of a separate electricity market on the island of Ireland.

¹⁶ See <https://www.ofgem.gov.uk/ofgem-publications/55611/427-20may02.pdf> and <https://www.ofgem.gov.uk/ofgem-publications/64116/1105-factsheet070215april.pdf>

¹⁷ See <https://www.emrdeliverybody.com/Capacity%20Markets%20Document%20Library/T-4%202014%20Final%20Auction%20Results%20Report.pdf#search=final%20auction%20results>

¹⁸ http://ec.europa.eu/energy/sites/ener/files/documents/com_2013_public_intervention_swd01_en.pdf and "Generation Adequacy in the internal electricity market - guidance on public interventions", Brussels, November 2013

with demand minute by minute. To meet all demand for power at any one time therefore depends on sufficient availability of power from generators at that time. However: (i) demand varies through a day, week and year and depends not only on general socio-economic factors influencing the use of electricity but also on the weather; and (ii) availability of generation varies for several reasons: because of unplanned, 'forced' outages of plant due to technical problems; variability of energy sources, not least wind, water and solar radiation; and planned outages to undertake maintenance.

The availability of sufficient generation somewhere on the system to meet total system demand does not, in itself, guarantee that all demand will be met. Generation facilities and demand are geographically distributed and power must be transferred from one to the other. At a national and regional scale power is transferred over the high voltage transmission network which allows the cheapest sources of generation to be used to supply electricity across the country. It also provides for back-up generation capacity (reserve) in the event that local generation is unavailable. Most demand, along with some generation capacity, is connected to the low voltage local distribution networks. Thus, to meet all demand also depends on there being sufficient power transfer capability on the transmission and distribution networks.

How failure to meet all demand is manifested

As noted above, the new GB capacity market is based on an LOLE standard. The term 'Loss of Load Expectation' is somewhat misleading: an hour would be flagged as including a 'loss of load' event if total available generation were short of total system demand by only 1MW of demand for only a few minutes. However, in reality, a 'loss of load' event is unlikely to mean that *any* consumers' load would actually be involuntarily disconnected simply as a consequence of a shortage of generation. In the event of a shortfall of available generation relative to total demand, the National Electricity Transmission System Operator (NETSO) would undertake the following steps first: call upon 'maxgen' services (where a number of generators' outputs can exceed their nameplate ratings temporarily); decrease interconnector exports or increase interconnector imports where possible; exercise pre-arranged contracts for demand side management (which would reduce total demand); or implement voltage reduction on the distribution networks (which would have the effect of reducing demand). Only as a last resort would a minimum amount of demand be disconnected in order that total generation and total demand would be balanced.

A conventional assessment of LOLE does not take into account the fact the almost all customer disconnections are actually due to faults on either the transmission or distribution networks, most often the latter, *not* a lack of available generation or a lack of sufficient transmission network capacity access to generation available in a remote area. The NETSO or its pre-BETTA predecessors have implemented 'maxgen', interconnector actions or voltage reduction only on rare occasions in the last 25 years since electricity supply industry privatisation, and the involuntary disconnection of demand due to simple shortage of generation even more rarely. In comparison, the most recent statistics on distribution network performance published by Ofgem on its quality of service website¹⁹ (for 2008/9) suggest that 100 customers would typically experience around 75 interruptions between them in an average year, i.e. an average of 0.75 interruptions per customer, while the average total time for which any one customer might be off supply in any one year would be around 70 minutes²⁰.

Network faults cannot be entirely avoided. As a consequence of the design of distribution networks and the cost of providing significantly increased reliability, single distribution network faults often cause customer disconnections. However, (a) particular network configurations can permit faster

¹⁹ See <https://www.ofgem.gov.uk/electricity/distribution-networks/network-price-controls/quality-service>

²⁰ As a consequence of the different historic patterns of development of different distribution networks and different geographies, electricity users' experience of disconnection does vary by distribution network operator area and location. For example, disconnections are much more common and restoration times longer in rural areas than in urban areas.

restoration of service than others and (b) only a limited, generally small, number of customers is affected by a distribution fault. Because of the much higher amount of power carried by each branch of a transmission network than on a distribution network such that, without alternative routes being readily available, an outage would have a very large impact, transmission networks around the world are typically designed and operated to provide what is known as ‘N-1 security’. That is, in general, any one failure event would not have any adverse impact other than to leave the network exposed to a particular, critical further event were it to occur before the system could be ‘re-secured’. As a result, according to National Grid, in a typical year, 99.9995% of the energy that should be delivered by the GB transmission network is successfully delivered, at least to the grid supply points to which the distribution networks are connected. In 2013/14, there were 44 events on the GB transmission network that led to any disconnection of demand anywhere in GB. At the time at which these events occurred, between 0.1MW and 130MW were disconnected²¹.

Biographies of the authors

Keith Bell is the ScottishPower Professor of Smart Grids in the Department of Electronic and Electrical Engineering at the University of Strathclyde. He joined the University in 2005 having previously gained his PhD at the University of Bath on the subject of power system operation and conducted research in Naples and Manchester, specialising in analysis of risk in power systems. For a number of years, he was a power system engineer in the electricity supply industry in the UK where, among other things, he led the development of new software tools and the revision of the security standard for BETTA. Since joining Strathclyde, he has been involved in a number of UK and European transmission and distribution research projects concerned largely with grid integration of renewables but also regulatory issues. He is a Chartered Engineer, a co-Director of the multi-disciplinary UK Energy Research Centre (UKERC), an invited expert member of Conseil International des Grands Réseaux Electriques (CIGRE) Study Committee C1 on System Development and Economics and a member of the Council of the IET Power Academy, an initiative to promote electric power engineering as a graduate career.

Simon Gill is a ClimateXChange Research Fellow in Energy System Modelling based in the Department of Electronic and Electrical Engineering at the University of Strathclyde. He received the MPhys. degree in astrophysics from the University of Edinburgh in 2003 and PhD from the University of Strathclyde in 2013 on the subject of dynamic optimisation of electricity distribution network operation. In the past three years, he has worked closely with Scottish network operators on major innovation projects such as the “Northern Isles New Energy Solutions” (NINES) project with Scottish Hydro Electric Power Distribution and “Accelerating Renewables Connections” with Scottish Power Energy Networks. His research interests include grid integration of renewables and smarter operation of power systems.

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²¹ See <http://www2.nationalgrid.com/UK/Industry-information/Electricity-transmission-operational-data/Report-explorer/Performance-Reports/> By way of comparison, total GB demand for power from the transmission system typically ranges between around 19,000MW and 56,000MW.