The Institution of Engineering and Technology

What's behind **your lights working?**

A briefing from the IET on power cuts and black outs on the British electricity system

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Background on power cuts and black-outs

Power cuts are disruptive to modern life. People in the UK have become accustomed to a reliable supply of electricity. Yet short, local interruptions are not uncommon, especially in rural areas, and there have been broader concerns expressed about long-term security of supply at local and national level as older power stations close.

This briefing report has been produced by the Institution of Engineering and Technology, many of whose members are experts on the issues faced by the electricity supply industry. It is intended to put the issues surrounding potential power cuts into context and to identify in a factual way the stresses and constraints on the system in the short and medium term.

The British electricity system

The electricity supply system in mainland Great Britain - Northern Ireland has a separate system - is extremely reliable: consumers on average enjoy over 99.99% supply availability. The GB system has traditionally been divided into three main parts:

- The generating stations;
- The high voltage transmission grid, recognisable by large pylons visible from several miles away;
- The regional distribution networks, consisting of smaller pylons, overhead lines and miles of buried cables feeding houses and businesses.

Since privatisation of the industry, these have been operated by four different kinds of business: the generators; the transmission system operator, currently National Grid; the transmission network operators or TOs; and the distribution network operators (DNOs). These businesses are separate from the energy supplier companies which many consumers recognise the names of as they are the companies that send and receive payment from electricity bills. Generating that electricity and maintaining the system which transports it to homes and businesses is the role of the four types of businesses that are often less known to consumers.

Power cuts and supply interruptions

Where power interruptions occur, they are generally for one of three reasons:

A. **Damage to or equipment failure within networks, usually at local level (i.e. network issues);**
B. **Planned shutdowns for essential maintenance or for upgrades (i.e. operational issues);**
C. **A mismatch between supply and demand in which not enough power is generated to meet demand (i.e. market and management issues).**

There is also potential for supply disruption through cyber-attack, although control systems are designed to withstand such attacks and none resulting in consumers losing supply has yet been documented.

A. Network issues

This section details the physical challenges that our electricity system can face and how the industry works to overcome these challenges.

Most transmission circuits are in the form of overhead power lines carried on steel pylons. High voltage distribution lines are also generally carried overhead in rural areas, often on wood poles.

The standards and specifications for overhead lines and their supports are designed to make them resilient to damage from lightning and high winds, and the industry also carries out regular tree work to reduce the risk of branches or whole trees falling on to lines.

Nevertheless, extreme weather such as severe wind storms can result in damage to lines, particularly those carried on wooden poles which are more vulnerable to damage from uprooted trees and foreign objects blowing onto the lines. Also, a rare combination of critical temperatures with severe blizzard conditions can cause a heavy build-up of ice on overhead line conductors which can bring down power lines.

These risks apply less frequently in urban areas, where the distribution networks are usually buried underground. Failures in urban areas can occur through damage from excavations by street works contractors or other utilities. Both rural and urban supplies can be at risk from flooding, where damage to substations may affect larger numbers of consumers. Network companies have carried out risk assessments and implemented flood protection measures to reduce flood risk at vulnerable substations.

Damage to overhead distribution circuits is a significant cause of power failures in mainland Great Britain , and in most cases service can be restored quickly by a combination of automated and manual switching to reroute power supplies. For consumers directly affected by the section of line where the fault is, repairs can usually be completed within a few hours.

On occasion, of course, the weather is more severe: in gales or heavy snow, there may be damage to several parts of the network, so rerouting supplies is more difficult, and fallen trees or lying snow may hamper access for repair crews. The industry as a whole has an agreement that network operators call on staff from other network companies to help with repairs under severe storm conditions.

Even so, there will be times when there are long power cuts, usually but not always, to small numbers of consumers. For example, over Christmas 2013 a succession of storms with high winds and heavy rain caused extensive damage to many networks, mainly through fallen trees, and more than two million consumers lost power supplies. For many, the interruption was short and supplies automatically reconnected within three minutes, but nearly one million people had a longer disruption and around 16,000 people did not have supplies restored within 48 hours.

B. Operational issues

This section highlights the role that regulation, standards and planned interruptions play to maintain the operation of electricity networks. It also looks at the challenges associated with matching energy supply and demand.

The design of the GB electricity system is heavily influenced by national security standards that require transmission and distribution network operators to maintain supplies as far as possible during faults and to restore them as soon as practicable if they cannot be maintained. These requirements are part of the operator licences.

The gas and electricity markets regulator Ofgem monitors electricity network reliability performance through independently audited reports from the network companies. The companies are incentivised to perform against targets for the number and duration of consumer interruptions, and they receive penalties or rewards for how well they do against these targets. To help set the rewards and penalties triggered from meeting these targets Ofgem conducts and uses the results of independent "willingness-to-pay" surveys in which consumers are asked how much more (or less) they would be willing to pay for a more (or less) reliable supply.

The operational issues are important. The electricity supply network across the whole of the Great Britain is in constant need of upgrade and renewal: ageing assets have to be replaced, new technologies such as local microgeneration, like solar PV panels, put new demands on the network, and demand constantly changes, not just with the rhythm of days and seasons, but also through longer-term trends such as business and urban development. The networks are designed so that upgrades, renewals, and new connections can be accommodated without shutting down large parts of the system, and by rerouting supplies and use of live working procedures, work can be carried out without interrupting supplies in most cases. However, planned interruptions are sometimes necessary in order to carry out upgrades or renewals, for example to overhead networks in sparsely populated rural areas. In such cases, consumers are notified well in advance. Over the last 20 years there has been a significant reduction in the number, duration and impact of power failures experienced by consumers .

Unlike almost all other commodities, electricity cannot be stored in large volumes directly: storage systems such as batteries convert the electricity into another form of energy such as chemical energy that can be stored and then reconverted back to electricity. This means the system has to be operated second by second so that the amount of energy taken out of the system by consumers (or put into storage) exactly balances the amount being put in by the generators. The requirement for very high standards of supply reliability puts extra pressure on this critical balance.

Operational issue case study

Very occasionally, things go wrong operationally. For example, in August 2003, a relay at a National Grid transmission substation in London operated when it should not have done leading to supply interruptions to 500,000 consumers. At that time, a transmission circuit serving part of south London had been taken out of commission for routine maintenance but, during that period, a second circuit had to be de-energised following receipt of an alarm to allow a transformer to be inspected for a suspected fault. That meant that a part of south London was then being supplied from just one transmission circuit. Normally that would not have been a problem as the circuit had more than sufficient capacity to supply the demand. However, on this occasion, a relay, designed to detect faults, operated causing the circuit to trip out resulting in a supply interruption affecting 500,000 consumers. It was subsequently found that an incorrect relay had been fitted which resulted in it operating due to the higher than normal load on that circuit, not because of a fault. High-impact failures of this kind are very rare and are thoroughly investigated, with forensic examination where appropriate, to ensure lessons are learned.

C. Market and management issues

This section highlights the challenges of matching supply and demand on our electricity network.

The need to match supply and demand continuously is not just about balancing the generating capacity to the load from consumers. For historic reasons, such as the availability of fuel or the availability of cooling water supplies, generating capacity is not necessarily geographically located close to the big cities or industrial centres where much of the electricity is used. This is why transmission and distribution systems are needed, but these systems themselves have capacity constraints that have to be taken into account when balancing generation and demand.

So balancing supply and demand is complicated. For the GB system, it is the responsibility of National Grid. Apart from forecasting electricity demand and arranging for sufficient power stations to be on line to meet the predicted load, the Grid's procedures also ensure that there is always spare generating capacity to handle a sudden failure of the largest power station or interconnection.

There are schemes to assist National Grid in this task. Because keeping a power station up and running when it is not producing electricity is expensive, the Grid has agreements with large consumers, mostly big industrial users, who agree to reduce their demand at short notice in return for a contractual payment. Other commercial arrangements incentivise large users of electricity to lessen use at peak times.

To cater for the unexpected, the electricity system is always run with a safety factor, called the "capacity margin", which is the proportion of available generation that exceeds the predicted load. Traditionally, this was easy to calculate as large-scale power stations had clearly defined outputs that did not vary from day to day.

That is no longer the case. The growth in intermittent renewable energy, particularly wind and solar, means the calculation is more tricky. Combinations of overcast skies and low winds occur some days in most years, and the possibility of an anticyclone sitting across Europe on a winter evening, resulting in high pressure, very cold temperatures, and very little wind output (even via European interconnectors) at times of high national system demand does need to be considered.

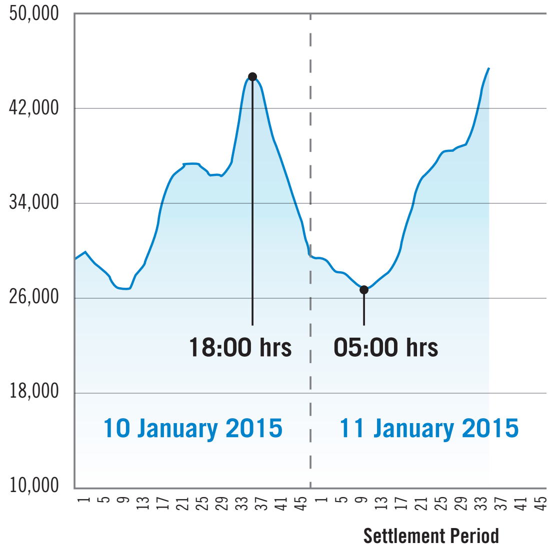


Figure 1: *Demand on GB electricity system*

Graph compiled using: www2.nationalgrid.com/UK/Industry-information/Electricity-transmission-operational-data/Data-Explorer

Daily variations in load further complicate the calculations. Figure 1 shows demand on 10 and 11 January 2015. The maximum load at 18.00 was 45GW, while the minimum of 26GW was at 05.00. Capacity margin is calculated on the basis of the highest anticipated load during a reporting period, which might occur for only a few hours each year, and produce a conservative view of available generating capacity. The caution is in line with the consumers' requirement for certainty of supply, but it costs money, since excess capacity will, in one way or another, be paid for by consumers.

There is thus no simple answer to how much capacity should be available. Until recently, capacity margins were not, in themselves, an issue in the GB electricity system. For much of the post-war era electricity use grew steadily year on year; then the discovery of North Sea gas led to a switch in domestic and industrial heating from electricity to gas, so for many years there was an over-provision of power stations and a generous capacity margin. That is not the case now. Old nuclear stations have reached the end of their lives, old coal stations are environmentally unacceptable, and old gas stations are uncompetitive. These changes have contributed to a reduction in capacity margins.

Prospects for future security of supply

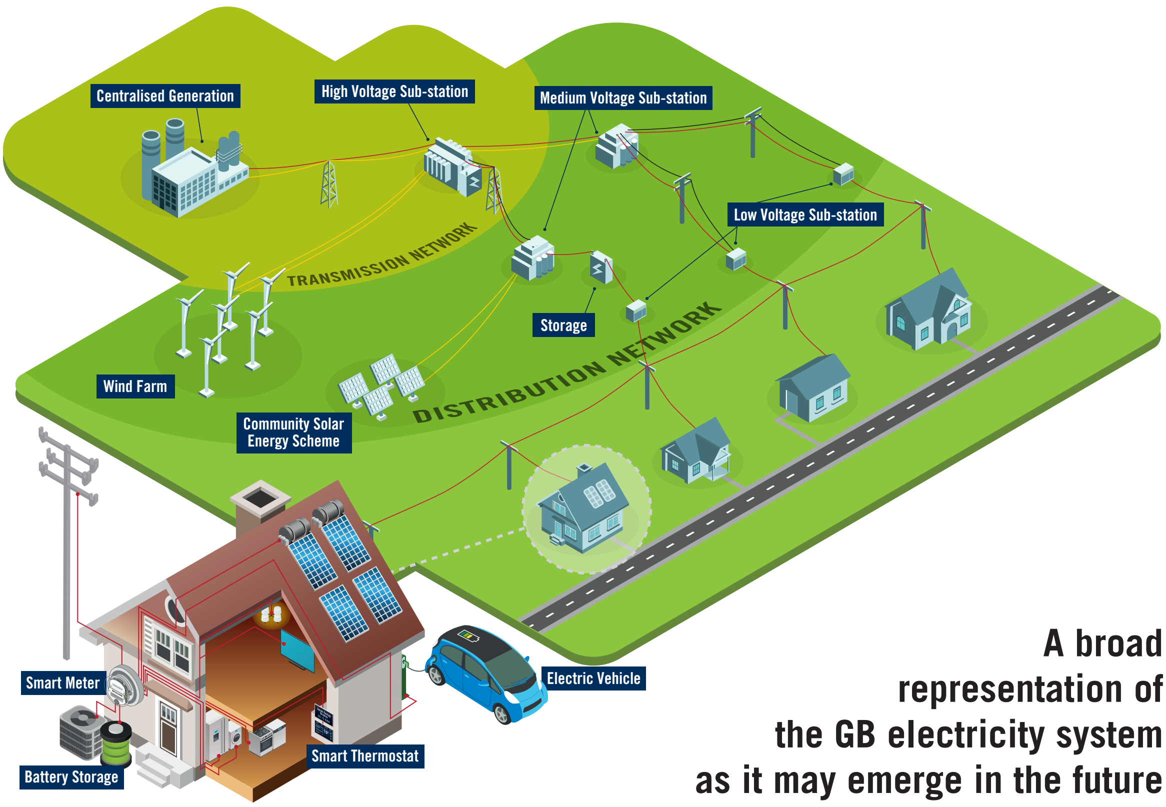
This section highlights emerging technology trends which may mitigate power cuts in the future. It also highlights industry and policy mechanisms which can be used to reduce the likelihood of power cuts.

There is no recent history of programmed power cuts in Great Britain due to lack of generation capacity: the last time regular power cuts happened was during the coalminers' strike of 1973-74, when electricity was rationed to preserve coal stocks, not because of a lack of generation capacity. Since then Britain has had sufficient, sometimes more than sufficient, generating capacity. But now capacity margins are lower than they have been for many years.

Two factors will have a bearing on whether this raises the likelihood of future power cuts or not:

A. Strategic technology and market changes

B. Tactical options and judgements by the industry



A broad representation of the GB electricity system as it may emerge in the future

A. Technology and market moves

As the UK and other countries move forward with plans for the decarbonisation of energy supply, it is expected that the use of energy will become smarter. This will include a greater ability to match usage with the availability of generation, particularly with renewable sources, which are often smaller in scale and more intermittent in availability. Energy provision at community level may also include heat as well as electricity and this can create more flexibility by enabling the timing of heat and electricity production from the same plant to be varied: heat is relatively easy to store. There is also likely to be greater use of battery and other storage systems as the costs of these devices come down.

The questions over technology development are mainly to do with timing: how fast the transition to these new ideas will occur and how to handle the variable availability of intermittent renewable resources. Storage could prove to be a key technology as it enables mismatches between the timing of demand and supply to be managed and there are significant research projects in the UK and globally exploring this. The markets for some other technologies are less clear and less obviously commercial, and may require stimulus from politicians as well as from business.

The politicians are already involved in other areas of the market. The previous Coalition Government recognised the need to maintain the capacity margin and established an annual auction under its Electricity Market Reform project. In these auctions providers of existing or new capacity would bid for contracts in which they are paid to have capacity ready to contribute to the electricity system if needed. The first auction was held in 2014 for capacity to be delivered from 2018.

Meanwhile National Grid can now enter into shorter-term and more straightforward capacity contracts with generators and with consumers able to reduce their demand.

B. The industry's options

One of the challenges for the industry is to judge the risks of coincident events, such as the likelihood of several power stations being out of service at the same time, or extreme weather conditions that reduce capacity and the availability of imported energy from Europe if they were to occur all across Western Europe.

Even in these circumstances, there are options open to National Grid to reduce demand without having to resort to widespread power cuts. These include:

- Contracting with industrial and commercial consumers to turn off loads that are not needed and switch to standby generators where available;
- Reducing system voltages (which has the effect of automatically reducing power consumption); and
- Using contractual provisions with industrial users to temporarily interrupt their supplies.

In the event that these routes are exhausted, the next step would be to implement a pre-planned controlled sequence of supply interruptions involving a small percentage of consumers for a set period on a rota basis, until supply and demand are back in balance. These power rationing programmes are designed to ensure essential users such as certain hospitals are exempted from interruptions.

The prospect of mass black-outs of whole cities or regions remains extremely remote, and would probably require all the eventualities above, plus multiple and large-scale equipment failures. The industry has contingency plans for this type of event and has equipment and processes to enable the system to be recovered, with gradual resumption of supply to consumers: a situation known as a "black start".

Black start conditions depend on many variables, including the availability of intermittent generation and the amount of load waiting to be re-energised. The expectation is that the majority of the national transmission system would be restored within 12 hours of a total shutdown, with DNOs' major substations re-energised within 24 hours.

There remains a further unknown. The growth of the internet has increased the vulnerability of systems of all kinds to cyber-attack, whether for criminal, terrorist or merely mischievous purposes. Important national infrastructure such as electricity generation and networks could be targets and so the critical systems used to control generation and networks are designed to have a very high level of resilience to such attacks. Although no country has yet suffered an attack that has had serious consequences, the increased use of "smart" systems both within the supply network and by the potential hackers may raise the stakes, and the effort and resources needed to manage this risk are likely to increase.

Conclusion

Modern life is dependent on electricity, and power failures are a rare experience for most consumers. The interruptions that do occur are mainly network-related and affect small numbers of consumers for short periods. Events that affect many consumers at the same time are relatively rare and normally a result of extreme weather or the simultaneous occurrence of multiple power system events or faults.

The likelihood of a situation arising whereby Britain runs short of generating capacity over the next few winters remains relatively low, and is likely to improve beyond 2018 because of the Government's ability to intervene through annual capacity auctions. However, even in the event that there arose a capacity shortfall there are provisions to allow the situation to be managed without widespread consumer impacts. Should these provisions prove inadequate, a programme of controlled and managed interruptions would be implemented on a rota basis such that, at any given time, only a small percentage of consumers would be interrupted, and only for a limited time. The chances of wholesale or prolonged blackouts remain extremely remote.

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