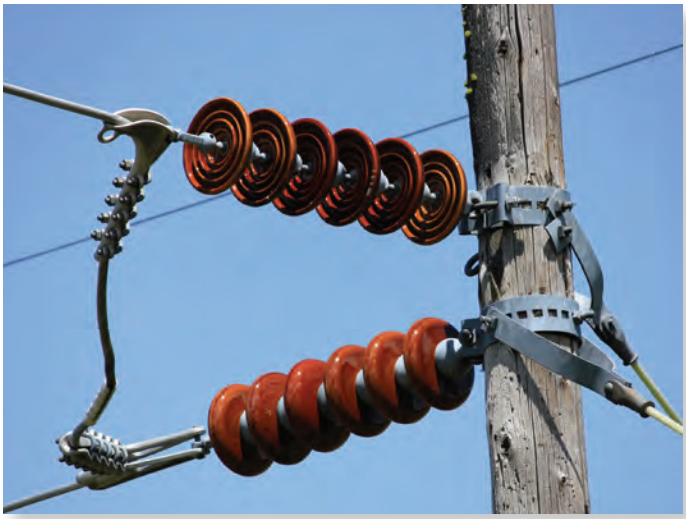
The Institution of Engineering and Technology

Electricity **Networks**

Handling a Shock to the System

IET position statement on the **whole system challenges** facing Britain's electricity network



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About This Position Statement

The Institution of Engineering and Technology (IET) acts as a voice for the engineering and technology professions by providing independent, reliable and factual information to policy makers and the public.

This IET Position Statement developed in collaboration through the IET Energy Sector and Energy Policy Panel is informed by a technical review conducted by the IET Power Network Joint Vision expert group, the report of which is also available on the IET website.

The Institution of Engineering and Technology

The IET is a global organisation, with over 150,000 members representing a wide range of engineering and technology fields. Our primary aims are to provide a global knowledge network promoting the exchange of ideas between business, academia, governments and professional bodies; to enhance the positive role of science, engineering and technology; and to address challenges that face society in the future.

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The IET has recognised that the demands on the modern engineering community have changed. By prioritising five Sectors; Built Environment, Design & Production, Energy, Information & Communications and Transport, the IET has provided an access point to the vast array of knowledge, experience and content available to its members and the international engineering and technology community.

The Energy Sector's vision is to become a focal point for all those working or interested in Energy. It also recognises the importance of promoting professional qualifications and certifications in this field.

It focuses on:

- Promoting key energy topics, issues and challenges
- Providing essential engineering intelligence on projects, good practice and innovation
- Publishing special interest publications, sector insights, case studies and other thought leadership.

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Executive Summary

Britain's electricity sector is grappling with the triple challenges of decarbonisation, maintaining security of supply, and affordability to customers. Much has been written on this subject, but little on the impacts of this on the **electricity networks** that connect generators to end users. However the impact of changes such as solar photovoltaic (PV) farms and large scale adoption of domestic solar PV energy, electric/hybrid vehicles, replacement or supplementing of gas fired heating by electric heat pumps, community energy schemes, and the introduction of large scale wind generation have **potentially profound impacts** on networks and on the electricity system as a whole.

The electricity supply chain is already a **highly complex interconnected system**, and decarbonising securely and affordably will increase this complexity substantially. At the transmission level, traditional tasks such as system balancing and maintaining system stability will become increasingly complex while at the distribution level, managing the impacts of reverse power flows, fault levels, and voltage rise will become increasingly challenging. Solutions might include moving to automatic controls for new applications such as solar panels, electric vehicle charging, and for the adjustment of carrying capacity of transmission and distribution lines according to weather conditions (dynamic thermal rating). The implementation of such wide-scale automation needs to be handled with care to ensure stable operation of the power grid and avoid unexpected and serious outcomes. Network companies are already beginning to see the influence of all these changes on the electrical behaviour of the power system, nationally and locally.

These changes are potentially disruptive to electricity supply security and the cost-effective operation of the grid, and this will become progressively more severe. But they also create an opportunity to act in ways which reduce cost and create worldwide opportunity for innovation and UK leadership. **The scale and complexity of the challenges ahead is new,** and potentially even greater than when the national grid was first developed in the 1930s. Fresh thinking is needed.

The IET has undertaken a scoping assessment and has compiled this Position Statement and a report drawing on technically informed senior practitioners to describe the challenges, the severe consequences we foresee if action is not taken, and makes recommendations for a way forward to allow timely development and implementation of solutions. A separate IET Technical Report provides further information.

It is clear that these challenges cross conventional industry boundaries, and extend also into the policy arena. Coordinated action by government, industry and a wide range of stakeholders is needed, and we must maximise learning from international experience. **It is essential that we look at the challenges and develop solutions from a "whole system" perspective to address the many interdependencies involved.** Engaging the right people from the outset in a planned and coordinated way will deliver major benefits to customers and the environment, and reduce the risks to vital national infrastructure.

The IET's key recommendations

We invite the parties affected to consider these recommendations and provide their responses which we would very much welcome.

1. DECC should work with industry to establish a System Architect role to achieve a whole systems approach.
2. Government/industry stakeholder groups should explore and address effective interactions between engineering, market and regulatory aspects to determine changes needed.
3. DECC/Ofgem should develop the regulatory arrangements that will enable demand response and distributed storage to participate in maximising whole system synergies and the mitigation of risks
4. Network companies should together determine how to address the impact of a data rich environment, including the mechanisms for improved internal and external data exchange.
5. Network companies' procurement arrangements should facilitate greater access for specialist providers to bring benefits in smart grids, demand management and new customer services.
6. Network companies, the IET, and other interested parties should work out how to address the requirements for increasing engineering, commercial and business complexity, including the means to access skills and research and test facilities, and the sharing of knowledge.

What is changing and why is it so disruptive?

The British power grid underpins our daily life. It is a great national asset that connects power stations large and small with industry, businesses, essential services and homes.

Until recently the electricity grid has been characterised as connecting small numbers of big and controllable power plants, feeding electrical power largely 'one way' through the high voltage transmission networks and the lower voltage distribution networks, to us all as end consumers. We are essentially 'passive' users in that we take what we need when we need it, and have no interaction with the power delivery system, other than paying our bills.

This picture is starting to change and within a few years the current system will look remarkably outdated given the transitions that are now underway in the generation and consumption of electrical power. This is a trend that can be observed internationally.

The panel below outlines the major changes and the challenges that each creates.

Five Power Network Challenges

1. **Renewable Generation sources:**
   The challenge is that in many cases the output of these generators is both variable and uncertain. These variations in output require additional balancing actions.

2. **Distributed Generation sources:**
   These can connect in large numbers to the distribution networks, right down to the level of individual homes, and result in two-way power flows which the networks have not been designed to accommodate.

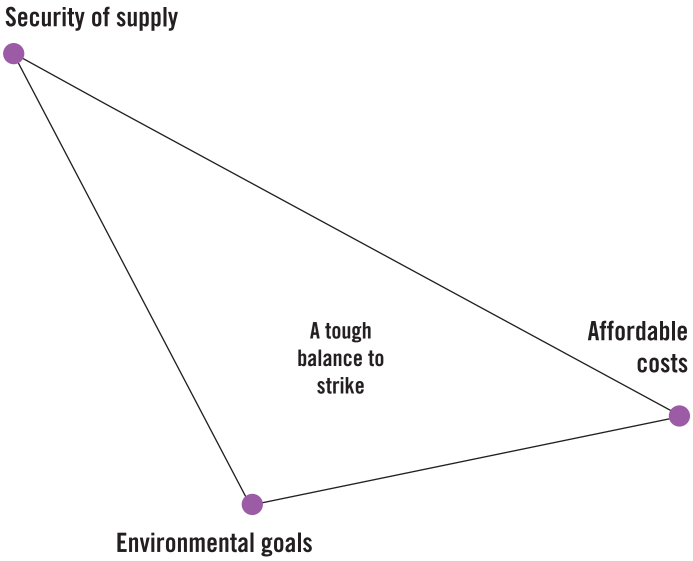
3. **New Demands for electricity:**
   These include heat pumps for low-carbon home heating and charging for low-carbon electric vehicles. Both are capable of increasing the electrical power needed by consumers, substantially exceeding traditional levels of network safe maximum capacity.

4. **Demand Response by consumers:**
   This offers consumers better value if they are willing to use their smart appliances to vary the time of day that they use electricity, for example to align more closely with output from intermittent generation. It can also be very beneficial to alleviating network overloading. However, it creates 'active' consumers, whose actions will at times summate to have impact on the national power system at transmission level. Managing this effectively will require a whole systems approach, spanning both the distribution and transmission networks.

5. **Modern Control & Automation:**
   These and other advanced techniques can provide solutions to enable more power to be carried by the existing networks, and to limit when and where new investment is needed. However, fast signalling and control must always be highly coordinated and integrated across the system to avoid adverse interactions.

The lights are on, so can't we leave well alone?

Development of the national power system requires a careful balance between potentially conflicting requirements. These can be described as the 'Trilemma' shown in the diagram below:



Security of Supply describes the resilience of a power network and its ability to 'keep the lights on' in the event of equipment breakdown, storms and downtime for planned maintenance.

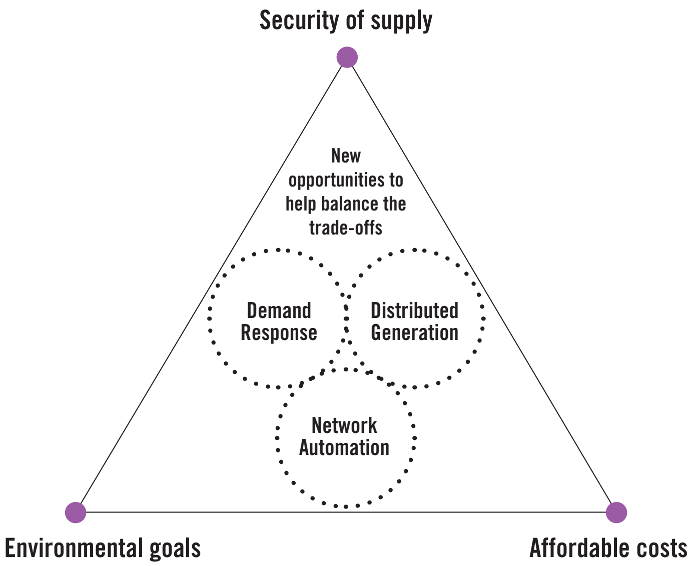
The *Environmental Goals* refers to facilitating government objectives for reducing carbon emissions, such as connecting renewable energy sources and supporting electrification of heat and transport.

Affordable Costs not only refers to the importance of minimising bills to homes and businesses, but also seeking solutions to assist fuel poverty and vulnerable customers.

Security of supply is paramount. If costs were no object, it would be simpler to achieve supply security by building more physical assets, or environmental goals by holding large and expensive 'reserves' of traditional generation to off-set wind and solar variability. However the costs to consumers of such solutions would be unacceptably high.

The electricity industry strives to find the optimum solutions to striking the balance described above – and indeed is regulated by mechanisms that encourage this, as it is very much in the interests of all consumers. Recent work in Britain and elsewhere in the world is developing new ways of designing and operating power networks to help strike the best balance – these networks are commonly referred to as 'Smart Grids'.

Smart Grids make use of a wide range of new developments such as digital systems, data communications, sensors, automation, and power electronics. These enable modernisation of the networks, particularly the distribution systems, which in the future will increasingly have the characteristics that today we associate with transmission grids – such as accommodating two way power flows and managing generation sources. A summary is shown in the diagram:

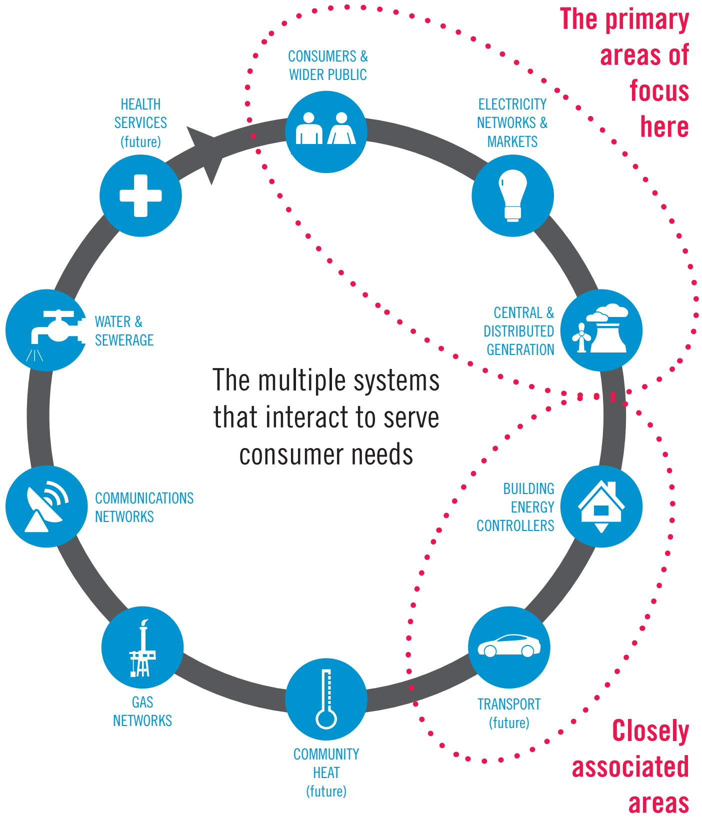


Here the Trilemma triangle is shown as bringing the three corners closer into balance through the use of Demand Response, Distributed Generation, and Network Automation. These are three examples of new smart grid solutions, but it is important to note that they are not simply plug-in additions to today's power network – they change the nature of the system and require new approaches to electricity network design and operation. In engineering terms this is described as requiring a 'whole systems approach'.

Other promising solutions that could be added to help balance the triangle include electricity storage (at domestic and community scale), integration of electricity and community heating, and use of advanced materials such as carbon fibres and superconductors.

What do you mean by a 'Systems Approach'?

Today's electricity networks are part of a complex power system. At a practical level there is no inherent storage in the system, so it must respond to consumers' requirements second by second, dynamically matching generation and demand at all times. Furthermore, the networks must provide a delivery system that meets the predicted needs of consumers and will withstand planned and unplanned 'outages' within the many links that form the end-to-end supply chain. A further changing characteristic of the electricity system is increasing inter-dependencies with other systems such as energy controls within buildings. The diagram below summarises the 'system of systems' that forms our national infrastructure.



We take for granted the reliable services we receive from these systems for the great majority of the time. Breakdowns and failures are relatively rare and we depend on these systems for life as we know it at home, in business and in essential services. How is this achieved? – the answer is in part through excellent 'systems engineering', which is described in the box below:

When, for example, changes are proposed to complex computer systems such as financial systems, or the telecommunications infrastructure that supports mobile phones, or the power supplies that support an aircraft, it is international good practice to appoint a 'Systems Architect'. The role of the Systems Architect is to ensure the 'fully functional whole' described in the box.

Absence of a systems approach is likely to result in serious delays to new projects or, much more seriously, compromise technical or operational integrity, resulting in unexpected interactions within the system that cause malfunctioning. A common experience that most of us are familiar with here is when computers 'crash' and have to be rebooted. This is invariably an unintended outcome, i.e. a systems integration failure.

However, the prospect of a 'systems crash' is of course very much more severe for the national power grid, where a 'reboot' is highly complex and it could take several days before service is restored in full. It is a priority to avoid the societal and business disruption that would ensue.

Systems Engineering is an interdisciplinary field of engineering that focuses on how to design and operate complex engineering systems.

Systems Engineering deals with processes, automation, controls, optimisation methods, and risk management. It overlaps technical and human-centered disciplines such as control engineering, industrial engineering, organisational studies, and project management.

Systems Engineering ensures that all likely aspects of a project or system are considered, and integrated into a fully functional whole. This is regardless of boundaries of geography or commercial ownership within the system.

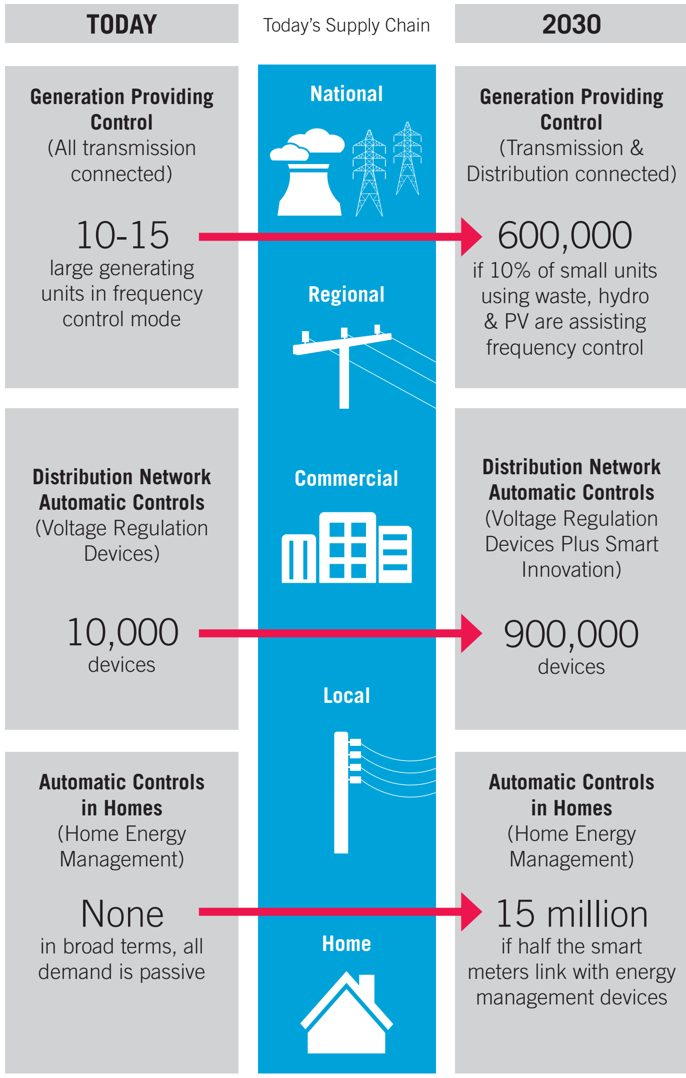
Don't we undertake Systems Engineering already?

Historically the 'systems engineering' of the electricity network has been to a very high standard and it is rare indeed that a systems failure is the cause of loss of supplies. (On the occasions when supplies are interrupted this is commonly due to a very localised fault, to storms or equipment failure – but not a 'systems crash'.)

While this is to the great credit of the engineers who designed the grid originally, we can also observe that their design principles have remained untouched for many years by subsequent developments. Taking a brief engineering example, automatic voltage control is a case in point. This is used to ensure that the voltage which consumers receive (typically 230V) remains within acceptable limits throughout the day. This is seamlessly coordinated by control systems at each of five levels within the GB network which continuously monitor and adjust voltage when it exceeds pre-set tolerances.

Traditionally it has been possible to extend the power networks incrementally, to meet new demands or connect new generation, without changing the control frameworks and how they interact across the system.

However, this relative simplicity is starting to change and recent analysis using the Smart Grid Forum's Transform® model now reveals the scale of the challenges that lie ahead. These dramatic changes to system complexity are outlined in the diagram.



The new complexity highlighted in the graphic reveals the evident importance of taking a fresh look at the Systems Engineering for our national power system. Furthermore, the integrity of the system is of such an imperative that its performance must be 'right first time'.

Therefore, as changes take place, it is the IET's view that steps should be taken to **establish the functionality of a "System Architect"**. How this might be fulfilled, whether by an existing party or parties, or by creating a new body modelled on experience from other sectors, remains subject to further consultation and analysis.

Who provides the role of System Architect for the GB power grid?

Since privatisation in 1990, no single party has the responsibility to ensure overall systems integration. Effective work has been led by the Grid Code Review panel and the Distribution Code Review panel in their respective areas. However these bodies, which are constituted and constrained under Licence, are not in a position to address the whole system.

This has not been a concern until now because the changes to the power system have been incremental and have not challenged the underlying 'systems designs'. The evidence is strong that this is no longer a satisfactory situation and the IET has identified, through its expert group, Power Network Joint Vision (PNJV), a range of points to be addressed of which the need for achieving the functionality of System Architect is viewed as a tenet of world-wide good practice and hence an overarching requirement.

What would the functionality of "System Architect" encompass?

The System Architect functionality is envisaged as follows:

- it would be centred on achieving a core accountability for working jointly with industry parties to ensure whole system coordination as the GB power network increases in technical and operational complexity. (The growing complexity of anticipated system interactions between industry parties is shown in Figures 1 and 2 (see pages 14-15))
- it would primarily address engineering systems but it would also encompass aspects of commercial systems that have material interactions, so ensuring a 'fully functional whole' where technical interactions span company ownership boundaries. The interaction between engineering and commercial systems is an important area to consider further if synergies are to be maximised and conflicts avoided. Whilst we could be more specific, we feel it is best to be neither too prescriptive nor restrictive at this stage.

Noting effective outcomes in similar situations in other sectors, it is likely that the System Architect approach would be achieved by utilising Standards and Best Practice Codes as core tools. These would need to be scoped, researched and structured through close stakeholder engagement and feedback from operational experience.

It would be important to establish the System Architect functionality in a way that assigns **clear accountabilities for delivery**. This is important because the integration of design, implementation, and operation of the power network is becoming increasingly critical; without it the secure and stable operation of the system cannot be ensured for the future. This will also support effective balancing of the 'trilemma triangle' described earlier.

There are important roles ahead for innovation, for competitive markets, for new entrants, and for new services. However, there is no complex engineering system in the world that achieves 'integrated control' through market mechanisms or engineering goodwill alone.

One option would be to implement the functionality of a System Architect by establishing a formal body or agency with obligations, duties and the capability to deliver. Alternatively, it might be implemented through existing industry structures. Determining the right approach will require careful analysis and drawing upon lessons from other sectors.

What happens in other sectors?

While not directly comparable, helpful lessons may be drawn from the roles of the GSM Association in the mobile phones industry, from RSSB, the Railways Safety and Standards Board, and from ICAO, the International Civil Aviation Organisation. These agency-style groups work with their sector's stakeholders to develop Codes and Standards, and have a governance role in their implementation.

Lessons learnt also include the difficulties experienced on occasions such as the now defunct Strategic Rail Authority. At risk of over-simplification, this body was intended to ensure a 'whole railway' view when privatisation resulted in multiple parties; however its remit was too broad, it was unable to be 'strategic' in its actions, and it lacked authority to achieve implementation.

Are there pitfalls to be avoided?

The issues raised in this position statement and the actions proposed are varied and in some cases may be demanding. Pitfalls to avoid include:

- Responding only to the short term dimensions of the issues
- Taking too long and extending the period of uncertainty unnecessarily
- Failing to be bold enough, particularly regarding the new System Architect role which must avoid the lessons from the Strategic Rail Authority mentioned earlier
- Losing the gains and opportunities provided by the liberalised markets
- Putting in place new Codes & Standards mechanisms through inflexible structures that fail to address the nature of continual change in the coming years.

What are the big wins here?

The IET recognises that its recommendations for action may be challenging, but it brings these to the attention of government and other parties in the knowledge that the gains will be substantial. These include:

- Improving the balance of the Trilemma triangle to attain *Security of Supply*, together with *Environmental Goals*, and more *Affordable Costs*
- Repositioning the electricity sector to address the new challenges it faces by establishing a 'whole systems' approach that has clarity and accountability
- Upholding and sustaining economic recovery by encouraging investment; making electricity more affordable; lowering prices of manufactured / exportable goods; increasing disposable income
- Creating high value new jobs, Intellectual Property, and export opportunities
- Ensuring concerted action to protect the integrity of critical national infrastructure.

How does Britain compare with other countries?

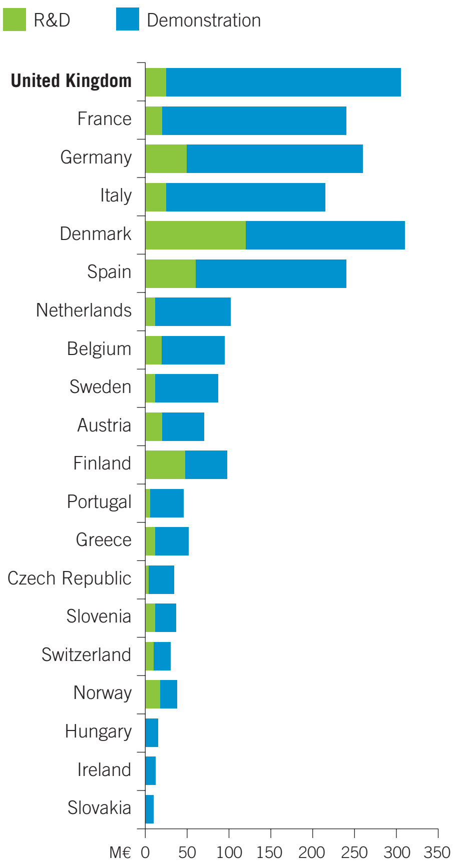
Considering international comparators, Britain has over many years maintained a strong position in power systems developments. In recent years we have not had the scale of investment that can be seen, for example, in China but we have continued to make strong contributions in international bodies such as CIGRE and CIRED, and more recently ENTSO-E.

Over the last ten years we have built a leading position in smart grids, not only through our contributions to European bodies such as the Smart Grid Technology Platform, but importantly through research, development and practical deployment. This has been greatly facilitated by forward thinking from the Government and Regulator that has incentivised innovation in power networks.

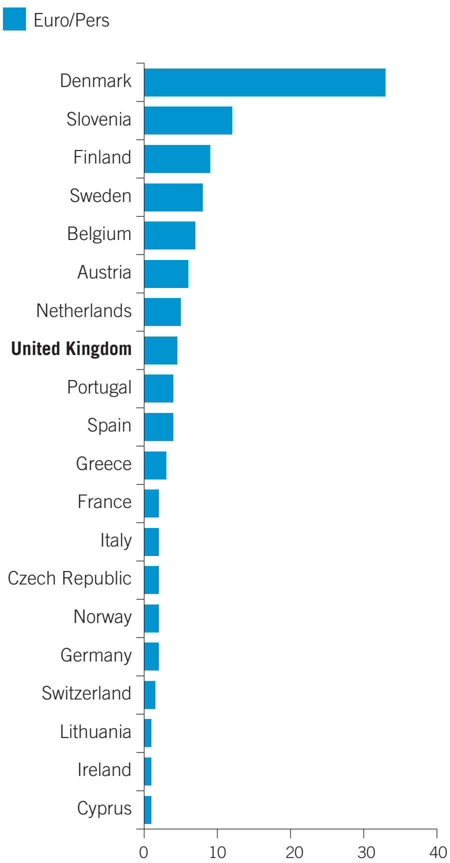
The graphic below demonstrates the UK's leading position in Europe in terms of demonstration projects. Practical deployment is of particular importance for power networks as full simulation in a laboratory setting is not possible.

The range and quality of our deployment projects could be used as a valuable springboard for export growth. The quality and relevance of these projects can be readily examined through the portal at the Energy Networks Association website.

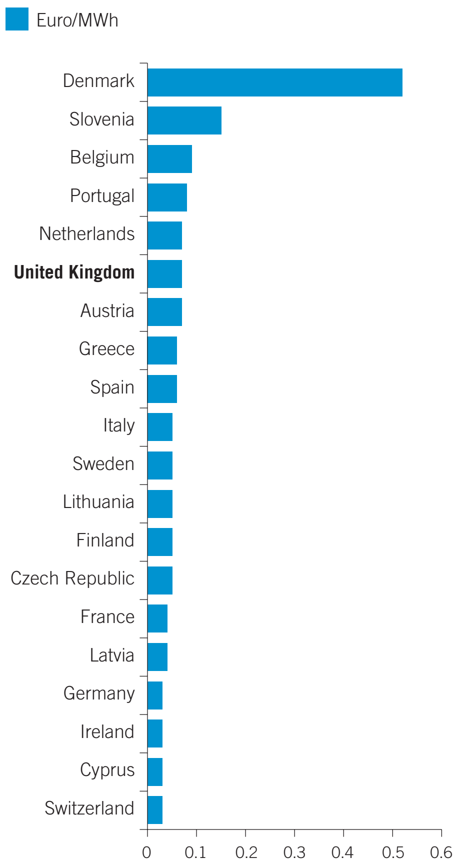
Top 20 investors in Smart Grid R&D and demonstration across Europe 2002-2012



Top 20 investors in Smart Grid projects by € (Euros) invested per capita



Top 20 investors in Smart Grid projects by € (Euros) invested per MWh consumed



SOURCE: Derived from "Smart Grid Projects in Europe – lessons learned and current developments – 2012 update", European Commission 2013.
(Readers are encouraged to refer to the source material in this informative document.)

How much will all this cost?

The costs will depend on the mechanism adopted to achieve the System Architect role. While there would be some staff and facilities costs associated with establishing an operating body to establish a System Architect role, if that is determined to be the best option, it would not require substantial investment in specialist facilities.

An early next step would be to quantify the costs and benefits, drawing on the experience of the other sectors outlined above.

Compared with the scale of the investment anticipated in the electrical power sector (some £110bn infrastructure investment over the next decade is projected by the government) and the benefits to be secured, the costs are envisaged to be proportionate and will be more than repaid in the risks mitigated and new value created.

What evidence does the IET have for these conclusions?

This Position Statement is informed by a technical review conducted by the IET Power Network Joint Vision expert group. PNJV is a group of industry and academic specialists. Their advice forms the basis of the case put forward in this overview and further information is provided in the associated IET Technical Report.

The historical development of the grid and current trends that are bringing changes are understood, and forecasting tools have been used to inform future expectations. In particular, the Transform® model, co-ordinated by EA Technology on behalf of the Smart Grid Forum, is a comprehensive representation of the electricity distribution network in Great Britain.

Engineers already report changing system performance, on both Transmission and Distribution networks in regard to system inertia and system voltages. There is also conclusive evidence of major challenges to the secure operation of the German network, where many of the drivers acting on the GB network are rather more advanced.

The Council of Science and Technology (CST) which advises the Prime Minister has identified similar concerns and challenges in work led by Professor Sir Mike Sterling.

The group has considered relevant developments taking place in the sector, notably Ofgem's ITPR consultation (on integrated transmission planning and regulation) which concerns a sub-set of the whole system we are discussing.

There is now an impressive portfolio of Low Carbon Network Fund (LCNF) projects looking into innovative ways of managing distribution, transmission networks (individually and in combination). This is evidence that TNOs & DNOs are very aware of the future challenges facing the industry during low carbon transition and taking these challenges very seriously. Many of the large demonstration projects have a 'whole system' context.

The Smart Grid Forum, chaired by DECC and Ofgem, has established a new Workstream, WS7, specifically to undertake wholes system validation for the 2030 networks. The whole systems approach aligns with other sectors and international best practice.

The Secretary of State for Business Investment and Skills, Vince Cable MP, has recently announced a new Catapult 'Energy Systems' to be led by the Technology Strategy Board and we are pleased to note the emphasis on 'systems' as this echoes the need for holistic thinking, as described in this Statement.

Next steps - Who needs to do what?

The IET acknowledges that the regulated frameworks of the privatised sector have delivered many benefits to customers. The action points drawn out in this position statement are intended to work with the grain of the liberalised markets and to facilitate the best opportunities for competitive behaviours, new entrants, and new services.

The next steps recommended by The IET are intentionally high level and closer engagement with key stakeholders is required to refine the questions, build evidence, and develop solutions. Where these potentially affect multiple parties it will be particularly important to undertake open consultation.

Beyond the current industry framework:

1. A Whole-Systems approach is required: other sectors achieve this through the role of a System Architect

We recommend that **DECC** should examine the merits and options for establishing a System Architect role to achieve a whole systems approach to network development and that DECC should consult to establish industry engagement. The IET will welcome a response from DECC.

The IET should consult with its members and identify best practice from other industry sectors.

2. Closer integration is becoming necessary between the Transmission System, Distribution System and End Users

Government and Industry stakeholder groups (e.g. Smart Grid Forum, ENSG) are invited to address effective interactions between engineering, market and regulatory aspects. The IET will welcome a response from these parties.

3. Co-ordination is required for demand response services and to resolve potentially conflicting actions

DECC/Ofgem are invited to consult widely to develop the regulatory, market and operational arrangements for calling-off Demand Response and Distributed Storage participation so as to maximise 'whole system' synergies whilst minimising the risk of conflicting calls on such resources. The IET will welcome a response from DECC/Ofgem.

Within the current industry framework:

4. Closer Joint Planning for Distribution & Transmission networks is required, with improved internal/external data exchange

Network companies and other interested parties are invited to address the impact of demand profile changes, active consumers, and of industry growing 'data rich' from new sensors, smart meters, etc. The IET will welcome a response from these parties.

Network companies and other interested parties are invited to consider the scope and mechanisms for improved internal/external data exchange. The IET will welcome a response from these parties.

5. Supply chains need to encourage entry of innovative solutions and entrepreneurial services

Network companies and other interested parties are invited to examine procurement and commercial practices to encourage greater access for specialist third-party providers to bring benefit to demand management and new customer services. The IET will welcome a response from these parties.

6. Skills, Research & Test facilities should be developed to match the challenges ahead

Network companies and other interested parties are invited to address how to meet the requirements of increasing engineering, commercial and business complexity, and the UK requirement to access necessary skills and facilities, including knowledge sharing. The IET will welcome a response from these parties.

Further Information

This Position Statement is informed by a technical study conducted by the IET Power Network Joint Vision expert group. The full report entitled "Electricity Networks – Handling a Shock to the System: IET Technical Report on the whole system challenges facing Britain's electricity network", published on 4 December 2013, is available on the IET website.

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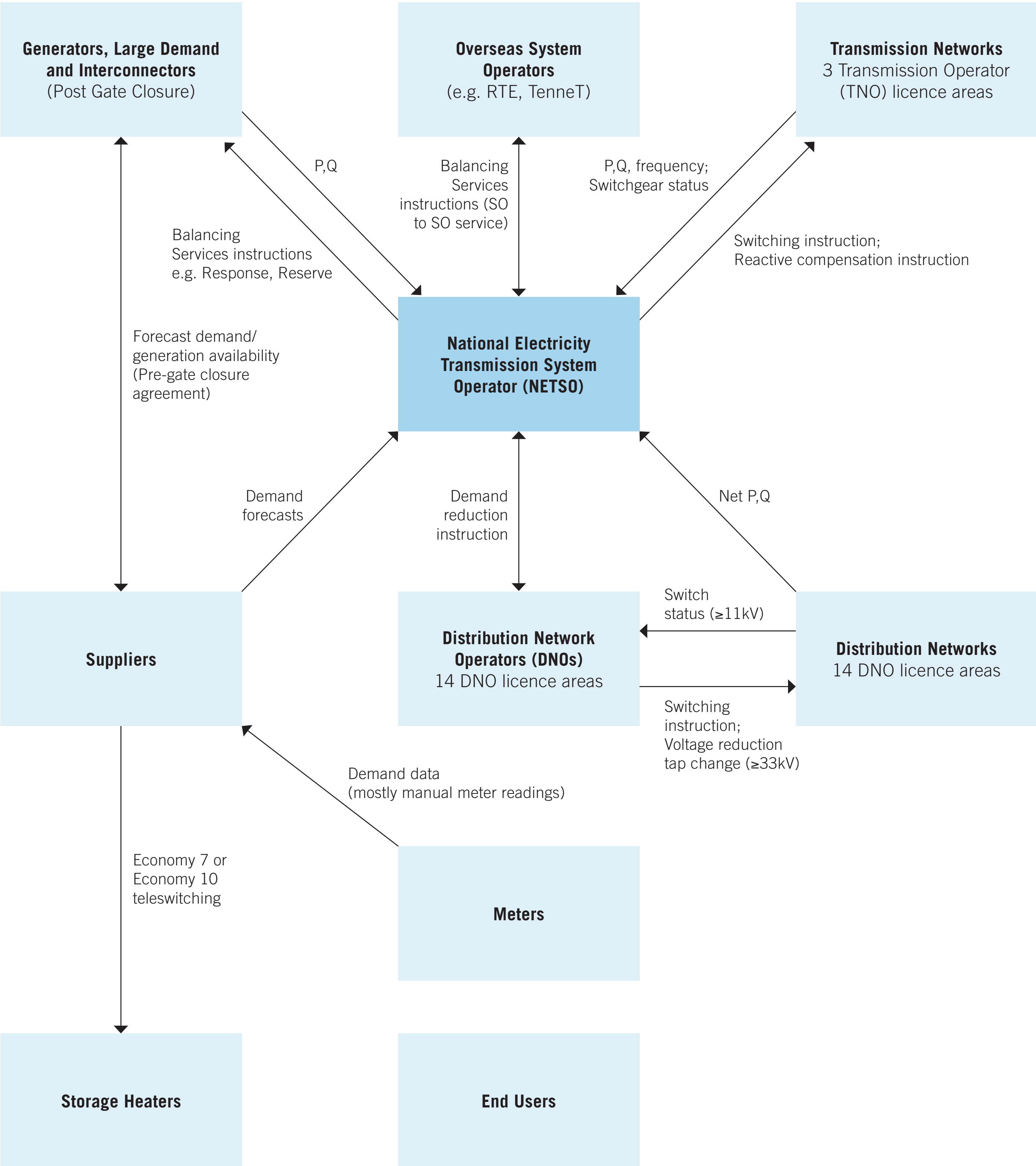
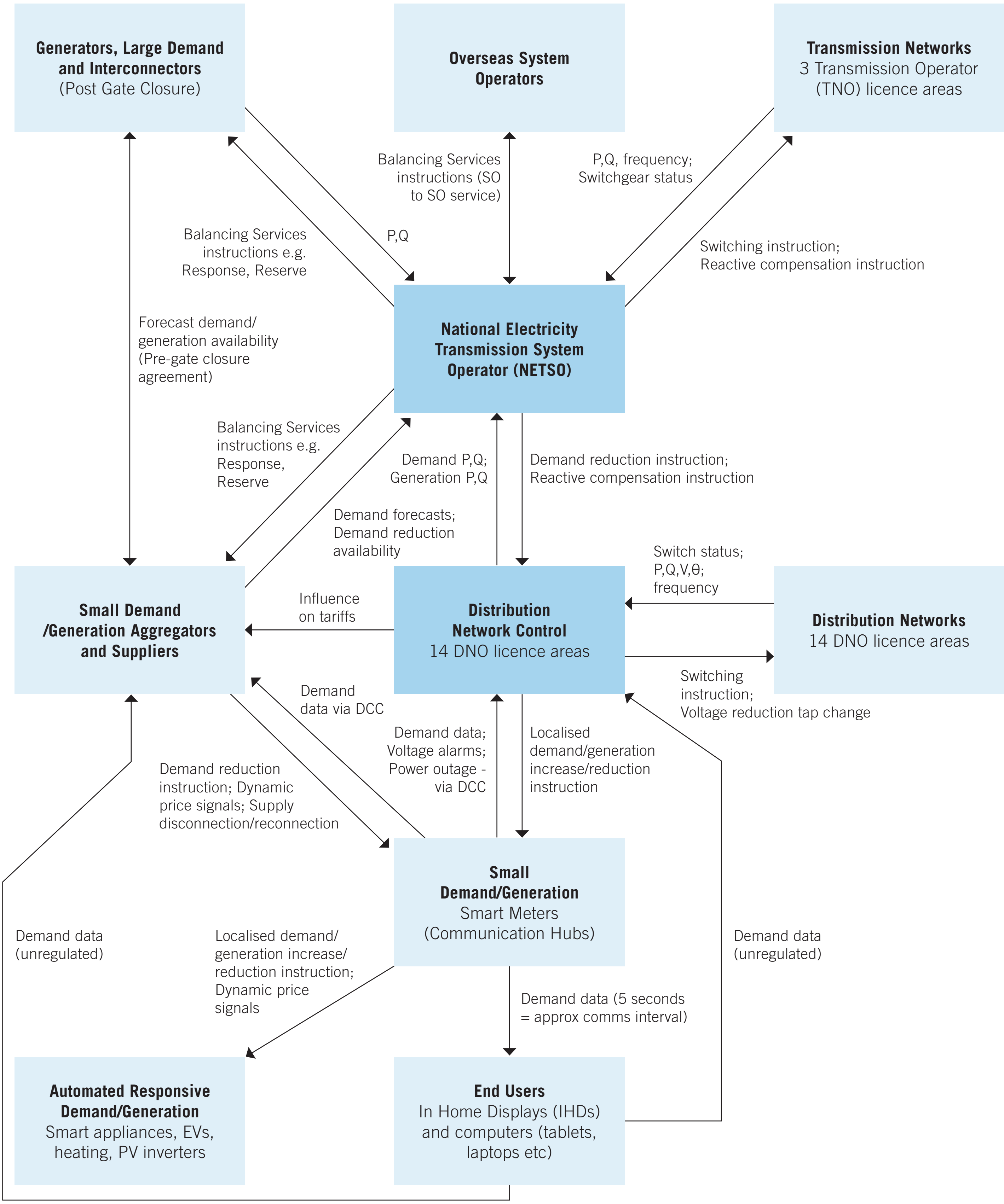
Figure 1 - NOW - Information flows for GB Electricity Network Operation



For explanation of the terms please refer to the Technical Report

Figure 2 – NEXT – Possible information flows for GB Electricity Network Operation following the Smart Meter Roll Out and increased levels of distributed generation



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*Savoy Place will be closed for refurbishment from summer 2013 until autumn 2015. During this time IET's London home will be within the Institution of Mechanical Engineers building at:

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If you are attending an event during this period, please check the venue details carefully.

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