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IET evidence to the House of Lords Science and Technology Committee

RESILIENCE OF ELECTRICITY INFRASTRUCTURE

EXECUTIVE SUMMARY

1. The UK electricity system has enjoyed high levels of resilience historically, and remains resilient today, but things are changing fast that pose risks to resilience in the short, medium and long term.

2. Resilience is not achieved by picking off and solving individual problems but results from the inter-play of all the multiple inter-related components and factors that form the whole electricity system. The lessons that can be learnt from the last period when electricity resilience was an issue, the 3 day week in the 1970s, are of limited value in the current context because both the underlying issues and the opportunities for resolving them are significantly more diverse.

3. The Government has taken steps to address the short term supply issues through electricity market reform (EMR), but the measures have to work if we are to retain good resilience, and some of the risks are outside direct government control, (for example willingness of investors to invest, and State Aid clearance on new nuclear projects). In the short term, GB will be exposed to lower than historic plant margins from the coming winter until plant procured under EMR provides capacity from 2018.

4. More significant for the medium term (and to a degree the short term) are the transformational changes to the electricity system as a consequence of decarbonisation. These include the introduction of large amounts of self-dispatching renewable generation, the potential electrification of much of transport and space heating, and the rise of the smart consumer and smart home. These, combined with the need to make power networks fit for this new world, vastly increase complexity and require a level of engineering coordination and integration that the current industry structure and market regime does not provide. In turn this increased complexity presents potentially substantially increased vulnerability to cyber threats.

5. The IET recommends the establishment of a System Architect function in the near future to allow these challenges to be addressed effectively.

6. A System Architect function will allow coherent engineering solutions to be developed and implemented such that resilience is ensured, whilst also optimising costs to consumers as the transformation implied by decarbonisation is delivered.

RESPONSES TO QUESTIONS

Short term (to 2020)

QUESTION 1: How resilient is the UK's electricity system to peaks in consumer demand and sudden shocks? How well developed is the underpinning evidence base?

7. We outline below the broad range of aspects which need to be considered in order to answer this question.

Capacity margin

8. The GB electricity system is currently able to meet reasonably foreseeable consumer demand peaks with a margin to allow some generation to be out of service for maintenance or through breakdowns. Since privatisation, for a variety of reasons, the GB electricity system has enjoyed a generous margin of capacity over peak demand, but this has been eroded in recent years as the rate of plant closures has been faster than the rate of new dispatchable[1] capacity being built.

9. The picture has become more complex since large amounts of variable renewable energy capacity (wind and solar) has been added in recent years, because whilst this provides substantial amounts of energy over the course of a year, its contribution to dependable capacity at times of peak demand is relatively limited.

10. If generation is marginally insufficient to meet demand (something not seen in GB since the 1960s), National Grid, as the national electricity system operator, has options such as contracting for peak demand reduction from industrial users, and managed voltage reductions, to allow supplies to be maintained to all consumers. Whilst these measures are rational engineering and commercial responses to managing supply and demand, it is of course possible that they might attract adverse press comment should they be implemented. It is noteworthy that of all the many large power projects currently in construction, only the new gas fired plant at Carrington will give a high level of additional capacity reliability at peak demand, and this will be 1 GW, compared to the 7 GW of coal and oil fired plant closed in the last two years.

11. The power system in Northern Ireland is essentially independent from GB, and has in recent years been fully integrated with that in the Republic of Ireland, something which will have generally increased its resilience. However the overall Irish system is deploying large amounts of variable renewable generation, and will tend to experience the same issues as the GB system.

System Stability

12. New sources of generation such as wind and solar also have lower levels of inertia than the conventional power stations they displace. This means they transfer less energy to the system under fault conditions or sudden losses of generation, resulting in more rapid falls in system frequency and more severe voltage dips. This can in turn cause the growing fleet of small generators embedded in distribution networks to disconnect thereby exacerbating the problem. The industry is aware of this problem and is developing solutions, notably through the Grid Code and Distribution Code Review Panels.

Fuel supply

13. Both the GB and all Ireland electricity systems enjoy a mix of fuel sources and are thus relatively resilient to fuel supply shocks, though there remains exposure to fuel price volatility, particularly gas.

[1] Dispatchable capacity means capacity whose output can be set at will (subject to technical limitations), rather than capacity whose output is determined by uncontrollable factors such as local wind speed.

Other ‘sudden shock’ events

14. Other “sudden shock” risks, such as type faults on equipment (i.e. faults in design or manufacture that will affect batches of, or potentially all, equipment of that type), severe weather and/or terrorist attacks on key infrastructure such as major transmission lines are managed through a diversified plant base, and a meshed transmission network with high levels of attention given to operational resilience. Thus the impacts of such events would tend generally to be limited in their geographic spread. However the risk does remain that a concerted successful attack by an efficient organisation informed by deep knowledge of the power system, on a number of unprotected and geographically dispersed assets (transmission line towers or possibly major substations) simultaneously could cause a widespread if temporary disruption to power supplies.

15. Distribution systems are less resilient to extreme weather and, as has been seen recently, localised damage can occur that results in groups of consumers being off supply for some days, particularly in rural areas. This has been the subject of Parliamentary inquiry early in 2014, and measures are being put in place to improve emergency response arrangements. Steps have been taken by the distribution companies to increase resilience to severe weather events, including flood mitigation, use of insulated overhead line conductors, rebuilding lines to a heavier construction specification, increasing lightning surge withstand capability, and automated switching to isolate faults and restore supplies. Resilience could be further improved by even greater levels of investment (with resulting increases in consumer prices which Ofgem’s consumer surveys have indicated would not be supported) but, whilst such events are highly inconvenient for those consumers affected, they do not threaten the integrity of the electricity system as a whole.

Interdependencies

16. The electricity system is dependent on the successful operation of other infrastructures including gas transmission, telecommunications, highways (so staff can reach sites to repair faults), railways (for coal transport). Major outages of these systems could impact electricity system resilience. Fortunately the UK enjoys good resilience amongst these individual systems at present, though interdependency with the communication system involving a potential cascade of failure needs to be planned for.

17. The use of cell phones to co-ordinate maintenance by some electricity companies creates a critical inter-dependency as service would be lost from the current cellphone networks in a widespread power outage. (Whilst macro cells do have backup power they would be swamped when the lower tiers of cells with minimal or no backup shut down). Clearly loss of terrestrial communications could severely hamper network recovery. However, back-up systems are available; for example larger distribution substations are equipped with PSTN land lines and Satellite or UHF based SCADA (supervisory control and data acquisition) systems which have voice communications capability, either of which would enable repair teams to maintain voice communications with control rooms and dispatch centres in emergency conditions. The current procurement for a new “blue light” emergency services network could result in one or more of the existing cellular networks being hardened against power failure of reasonable (24 to 72 hour) duration. This could represent a major opportunity to build a firebreak in the interdependency between power and communications.

Conclusion

18. In conclusion, it is possible today to say that the current UK electricity infrastructure is highly resilient. However this picture is changing quite rapidly – in the short term as plant closes and demand begins to recover following the recession, and long term as the UK moves further into its energy transformation. This will create new resilience challenges which are discussed further in our response to subsequent questions.

The evidence base

19. In terms of the evidence base for the above comments: precisely because we have yet to experience the scale of the impact of peaks in consumer demand and sudden shocks to the system that we predict, our evidence is necessarily based on modelling and analyses. National Grid's Electricity Ten Year Statement describes some of the outputs of such modelling (for example system strength and system inertia and their respective future impact on system stability, power quality and electrical power system protection). These and other issues will be subject to more regular and detailed studies under National Grid's new System Operability Framework. Meanwhile, the Smart Grid Forum has undertaken, and is continuing to undertake through its various workstreams, studies to evaluate the impact of future electricity system challenges and their potential solutions.

QUESTION 2: What measures are being taken to improve the resilience of the UK's electricity system until 2020? Will this be sufficient to 'keep the lights on'?

20. In the short term (to 2020), the main challenges to system resilience are:

(a) Capacity and its technical characteristics:

- The risk of the market not bringing forward sufficient new dispatchable generating capacity to replace older capacity being retired. As well as coal fired power stations, recent retirements have included significant numbers of gas fired stations, caused by low coal and carbon prices limiting their operation, and their owners seeing the inflexibility of many 1990s era plants as inappropriate to future requirements;
- The intention is that the EMR capacity mechanism along with new measures proposed by the electricity system operator such as Supplementary Balancing Reserve and Demand Side Balancing Reserve will reduce the risk of plant capacity shortfalls. Supplementary Balancing Reserve is largely dependent on sufficient existing large plant being contracted to remain connected rather than be shut down by its owners, as this timescale is insufficient to allow new plant to be consented and built on a large scale;
- A reduction in fuel diversity caused by the closure of many coal fired power stations, giving greater exposure to gas price volatility for dispatchable capacity;
- The dynamic response of existing dispatchable capacity not being adequate for the very different duties it will be called upon to perform compared to its design duty;
- Falling system strength and inertia due to new generation types, which will make it more difficult to maintain system stability at times of system stress;
- A possible lack of willingness by the private sector to invest large amounts in what has become a politically "hot" sector of the economy;
- The extent to which the operation of the EMR Capacity Mechanism might hamper the wider use of demand response to manage peaks (since contracting under the Capacity Mechanism precludes the option to supply reserve services from the same source of demand response).

(b) More variable generation and changing demand:

- The possible return of significant year on year growth in electricity demand as the economic recovery gathers pace;
- The increasing deployment of variable renewable generation to much more than the current capacity;
- The possibility of new sources of demand such as electric vehicle charging increasing very quickly should consumer demand for electric cars take off;

- The possible emergence of large amounts of load that is controlled in response to variable tariff signals from energy suppliers, including the potential entry of major consumer brands such as Google or Apple into this market, with corresponding high consumer take-up;
- Limits of distribution network capacity being reached locally, especially in cities, with solutions taking time to implement and hence potentially acting as a brake on economic development;
- The beginnings of sophisticated but non-integrated control responses to all these within networks;
- The implications of the UK leaving the EU in the event of this being the referendum outcome. There is no inherent reason why this should be problematic but this would depend very much on how collaboratively any separation was handled.

(c) Emerging cyber security issues:

- A further concern is that the future system will be much more dynamic and reliant on fast communication and data analysis to ensure technical security and stability. This will reduce the feasibility of manual operation and increase dependence on automation, further exacerbating the potential consequences of cyber attack. For further discussion of Cyber Security issues see paragraphs 38 - 43.

21. Most of these challenges are new and have not had to be addressed before. Whilst the challenges are understood and solutions are being developed, these issues have potential impacts on the whole system which, by definition, are less well understood. The UK, in common with some other countries, is moving into areas of operation where we have little practical experience to guide us.

Measures being taken to improve resilience of the UK's electricity system

22. A number of actions have been taken by government and industry to mitigate the challenges and to develop an increased understanding of the way forward. For example:

- The current Government's Electricity Market Reform includes capacity auctions, which if successful should result in investors gaining the certainty needed to build new dispatchable generation capacity and/or develop demand response and energy storage solutions. Future system resilience is critically dependent on these auctions succeeding.

- The increasing availability of interconnectors between GB and other countries, and to improve connectivity between Scotland and England/Wales. Planned new interconnectors include NEMO (providing a connection to Belgium), and a further GB-France link. It should be noted that because GB is an island, all interconnectors between it and other countries use highly resilient DC technology, rather than conventional AC. This has the benefit of greatly reducing the risk of the cascade failures experienced in the USA and mainland Europe.

- Ofgem and the industry have been innovating through the Innovation Funding Incentive (IFI), Low Carbon Network Fund (LCNF), and Network Innovation Allowance and Competition (NIA/NIC) to explore issues around variable generation and demand on networks and new forms of demand such as electricity vehicle charging and electric heat pumps. However in our view there are a number of as yet unexplored areas in this work. This is primarily due to the focus of LCNF having hitherto been confined to distribution networks whilst the NIA/NIC has been confined the transmission networks. We do not yet have an integrated whole system approach to dealing with these emerging challenges though, from 2015, the Network Innovation Allowance and Competition will allow both DNOs and TNOs to collaborate (or compete) for funding and hence help address this imbalance. The need for such an integrated approach has been the focus for the IET Power Networks Joint Vision activity.

23. The IET has concluded that there needs to be more effective **engineering systems integration** across the electricity system as it embraces these major changes, and has recommended the establishment of a System Architect function to ensure this is delivered. It is not possible to say with certainty when the issues highlighted in this section may all become real, and in some cases this could be after 2020. However given the importance of a resilient electricity supply to social and economic well-being, we believe it to be important that effective systems engineering is undertaken sooner rather than later. Adopting a reactive rather than proactive strategy is likely to lead to inefficient recovery actions and suboptimal investment, and may in any case lead to actual system failures. Comprehensive analysis of the impacts on the electricity system of credible future scenarios should minimise the risk of either stranded or inadequate investment, ensuring timely and optimised investment to deliver an adequate system at the most economic cost.

QUESTION 3: How are the costs and benefits of investing in electricity resilience assessed and how are decisions made?

24. At present there is no single authority responsible for electricity resilience, and little use of consistent metrics to describe it.

- The market is currently left to provide adequate generation capacity. This will change when National Grid runs the first capacity auction mandated by DECC later this year, for capacity to be delivered in 2018/19.
- National Grid is responsible for the safe and secure operation of the GB transmission system within is licence conditions (determined by Ofgem).
- The Transmission and Distribution Network Operators are each responsible for safe and secure operation of the system within their licensed areas according to their licence conditions (vis. to develop and maintain an efficient, co-ordinated and economical system of electricity transmission and distribution).

25. Hence:

- DECC and Ofgem come to a technical conclusion over how much capacity should be purchased at a capacity auction, though this does not deal with the situation prior to 2018, which is in the hands of the market;
- National Grid procures response and reserve services (such as frequency response, fast reserve, short-term operating reserve, black start capability, voltage and reactive support) and potentially in future other systems services such as inertia via tender, to the extent these are beyond the Grid Code requirements incumbent on generators;
- National Grid works within defined security standards for its transmission system, which it reviews from time to time;
- DNOs work within defined security standards and are also incentivised financially by Ofgem to meet targets for guaranteed standards of service, customer minutes lost and customer interruptions;
- Both transmission and distribution network operators also have to submit full business plans to Ofgem and report annually on outcomes. Network investments are justified to Ofgem on a range of grounds including the various aspects of resilience, including issues such as the impact of flooding resulting from climate change. However the regulatory regime requires companies to demonstrate that all investment is fully justified and this can limit the scope for investment ahead of proven need, especially where there is a risk of the investment becoming stranded.

26. With the arguable exception of the market not signalling a need for new capacity (up to 2018), it will be seen that there are established arrangements in place to build the business cases to deal with many resilience problems, with the arguable exception of cyber security (see our later commentary on this issue). However resilience problems that cross company boundaries, or emerge because of the side effects of the very major changes now occurring to our electricity system as it and the wider energy system decarbonise, are not well captured by the current arrangements – hence the IET's recommendation for a system architect function. There is also no commonly agreed metric for resilience, meaning investment for resilience overall can be difficult to justify.

QUESTION 4: What steps need to be taken by 2020 to ensure that the UK's electricity system is resilient, affordable and on a trajectory to decarbonisation in the following decade? How effective will the Government's current policies be in achieving this?

27. The government's existing policies are designed to ensure the provision of adequate generating capacity (from 2018/9), and (via existing regulatory arrangements governed by Ofgem) the resilience of the transmission and distribution infrastructure against known challenges. They are also effective in fostering innovation in networks on a trial basis.

28. However existing policies do not take account of the scale of the potential impact of decarbonising on the electricity system, combined with consumer market responses to the desire to manage energy well, and potentially to manage supply security locally in some cases. This is by far the largest change the industry will have had to manage in its history.

29. These changes will not produce a resilient and affordable system if they are each treated as bolt-ons to the existing system, and are likely to produce unexpected and costly side effects, constraints to future activity, and risks to stability and hence resilience. Many of the issues to be addressed are currently unquantified, and we cannot be certain that we yet have all the modelling tools necessary to explore them analytically. (See question 7)

30. An electric power system is a complex engineering system, and needs to be treated as such. It is particularly demanding because it is an existing system with inherent legacy characteristics (rather than a new system designed at the outset to cope with the challenges we now foresee) and hence requires us to develop an adaptation strategy that will assure continued security of supplies whilst at the same time undergoing a major technical and operational transformation.

31. It is possible, even likely, that some of the impacts of these changes will not manifest themselves until after 2020; however the costs of putting right the consequences of bad decisions made prior to 2020 as a result of poor engineering systems integration could be very high.

32. The sooner the recommended System Architect function is established, the less severe are the problems likely to be, and the wider the options for managing them. At best, failure to act could cause inefficient investment in short term solutions, make government policy objectives more difficult to achieve, and cause widespread public frustration. At worst, it could ultimately threaten the integrity and security of the whole power system.

33. Prior to 2018, the capacity situation needs to remain under constant review, something Ofgem does on an annual basis. National Grid has plans and arrangements in place to procure capacity and to take other measures if needed, but the rate of plant closures needs to be monitored carefully. Unexpected coincidences of technical issues on what are now very old plant can quickly make a big difference. A very recent example is new incidences of cracking on existing nuclear plant causing all four reactors of similar design to be shut down for inspection and possible rectification, at roughly the same time as unrelated fires shutting two coal fired units, with a total unexpected capacity loss of over 2 GW (compared to a winter transmission system peak demand around 57 GW).

QUESTION 5: Will the next six years provide any insights which will help inform future decisions on investment in electricity infrastructure?

34. Yes. We are likely to see sufficient pilot schemes and early commercial deployment of most of the key technologies for decarbonisation within the next 6 years to gain insight into emergent issues. These are likely to include:

- Electric and plug-in hybrid vehicle deployment
- Variable renewables at very large scale
- Heat pumps
- Smart homes and dynamic tariffs, depending on rate of take-up
- Smarter grids at distribution level
- Ultra flexible operation of CCGT plant
- Carbon capture and storage (if deployed in time)
- Community level integrated energy schemes
- Evidence of impact of the smart meter rollout programme

35. The lead times in electricity infrastructure investment can be long, especially for major capital programmes such as large power stations, or for solutions to be deployed widely amongst consumers or on distribution networks. However significant externally driven changes, especially those in the hands of consumers, can take place very quickly. Examples of this would be the speed of market penetration of smart phones, or the rapid uptake of solar photovoltaic panels. One can imagine that the impact of electric vehicles or smart homes and dynamic tariffs could grow very fast if these were to catch on amongst consumers.

36. We will also learn a great deal about operating the system under low margin conditions. The learning will depend on circumstances, but will advance our understanding of how much contingency really exists in the system, or can be contracted, and how to use it. The evolution of demand will also be interesting, especially whether the positive effects of economic growth and take-up of electric vehicles outweigh reductions from increased energy efficiency and declines in energy intensive manufacturing.

37. This means an early need for effective engineering systems integration to ensure policy decisions are subject to an "engineering integrity" test and are able to respond quickly and appropriately to emergent issues. National Grid's new System Operability Framework will support this by providing deeper insights into the technical challenges arising from new types of generation and demand.

ADDITIONAL QUESTION:
What are the main IT and cyber issues affecting resilience and how should they be mitigated?

38. Many aspects of the UK's electricity system depend on computer-based systems. It has been reported that foreign states and others have been detected probing for vulnerabilities in critical infrastructure, so it must be assumed that the UK is also a potential target.

39. Legacy systems were introduced before cybersecurity was recognised as a Tier One national threat.

40. The roll-out of Smart Meters will increase the complexity of the electricity system and the IET has expressed concerns that the design and implementation of the Smart Metering security architecture has not followed best practice for cybersecurity.

41. The costs and benefits of best practice cybersecurity have not been addressed in detail in any DECC documents that the IET has reviewed. The suppliers to the electricity industry are not as familiar with high integrity software development methods as, for example, suppliers to the avionics or nuclear power industries and it seems that this inhibits DECC from requiring the use of modern software assurance methods, for example in the smart metering system.

42. Focused attention needs to be given to assuring the cybersecurity of the specification, design and implementation of critical systems, using mathematically formal specifications and proofs of compliance supported by model-based testing.

43. IT security should be an intrinsic consideration in all energy infrastructure development. One of the roles of the System Architect function recommended by the IET would be to ensure that IT security is at the heart of technical specification of an integrated system.

Medium term (to 2030)

QUESTION 6: What will affect the resilience of the UK's electricity infrastructure in the 2020s? Will new risks to resilience emerge? How will factors such as intermittency and localised generation of electricity affect resilience?

44. Between 2020 and 2030 we would expect to see an evolution of the changes set in place before 2020, bringing:

- renewables on an even greater scale
- the probability of a profound change in how consumers consume, and
- the possibility of massive increases in electricity demand in the event that most transport and space heating becomes electrified.

45. These could be offset to some degree if real progress is made on policies to improve energy efficiency, and change consumer behaviour to either use less energy, or shift more of their energy consumption to times when the system is less stressed. However, the scale of the potential change makes it critically important to gain clarity of likely outcomes sooner rather than later.

46. There could also be a continuing increase in climate volatility, with more flooding, drought and extremes of temperature putting new stresses on electrical equipment and infrastructure generally.

47. This aspect of supply security is receiving particular attention in the USA where recent 'super storms' resulted in severe disruption to the electricity system. A potential solution being explored is the concept of 'micro-grids', where advanced smart grid techniques are deployed to enable buildings, campuses or communities to detach from the national power system and operate as 'power islands' for a period of time. Implementation of this approach has to overcome demanding technical challenges and, should it be contemplated at some stage for enhancing GB supply security, would require a clear long-term migration plan and close integration of technical, commercial and regulatory aspects.

48. Whilst the UK doesn't currently tend to suffer the extreme wind storm conditions that cause severe damage to transmission systems, the position might change in the longer term due to climate change. Moreover, although relatively rare, storms leading to severe ice build-up on overhead conductors have in the past led to the failure of steel pylons. Under the vast majority of severe wind conditions, including hurricanes, the UK transmission and high voltage distribution systems are generally restored rapidly (including through automated switching). By

contrast it is generally damage to the rural low voltage systems that causes extended supply interruptions. Rural micro-grids might be equally susceptible to such storm damage on their local networks, and with possibly fewer resources to call on at times of emergency to effect repairs. Micro-grids would, however, have the benefit of being able to continue operation in the event of a serious loss of generation or transmission capacity due to storm damage or other causes including for example terrorist activity.

49. At a more detailed level, changes to network planning and installation practice to accommodate flood risk, as well as remedial measures, are still ongoing, for example, ensuring that substations are adequately protected and that there is ease of access to switching and isolation points on networks to allow work to begin before waters subside.

50. There are likely to be new emergent phenomena as the electricity system is taken even further beyond current (2014) knowledge, and we will need to have the academic and corporate research infrastructure to find the necessary solutions. Many of these challenges are global so this needs to be seen in that context. This has implications in the shorter term for skills development and academic capacity – a teenager choosing STEM options in 2014 could be a useful young researcher in 2024, and a good 2014 engineering graduate choosing an engineering career (say over one in the City) could be leading an industrial research unit in 2030.

51. The need to be “match fit” to address these challenges again points to the urgency of establishing good arrangements for ensuring effective systems engineering of the electricity system sooner rather than later.

QUESTION 7: What does modelling tell us about how to achieve resilient, affordable and low carbon electricity infrastructure by 2030? How reliable are current models and what information is needed to improve models?

52. Modelling provides insights into a range of pathways towards a resilient and low carbon electricity supply by 2030, and this will be more affordable provided sensible systems engineering decisions are taken as to where to prioritise efforts. A range of models are used, typically including sophisticated economic and financial models, whole energy system models, complex iterative simulation models, and a range of technical models relating to the engineering performance of the electricity system.

53. The IET’s focus is on the engineering issues of future system resilience, and hence on the specialist models that allow the dynamic performance of the electricity system to be simulated. The present system is well understood through simulation using mature modelling packages which enable parameters such as: the operation of power stations, power-flows, fault levels, transient and voltage stability, electromagnetic transients, power quality, harmonic distortion, and other important aspects of power system operation to be mathematically modelled. In looking at the energy transformation going forward it will be important not to lose the lessons from past experience embodied in these models and in the experience of engineers in the industry.

54. However as we proceed through the UK’s energy transformation we are faced with new dynamic variables which existing models were not designed to address, as well as new uncertainties that require existing models to be used in new and complex ways. The IET is currently undertaking work for the Council for Science and Technology to explore the modelling capability and identify any gaps. This study will report in December 2014.

55. The study will comment on the current modelling landscape (capability) and outlook (i.e. the need for new or improved models with common underlying datasets).

56. National Grid’s new System Operability Framework (SOF) will provide a framework to enable these modelling needs to be co-ordinated and prioritised at the transmission system

level. However, many aspects of the SOF will have a direct bearing on the design and operation of electricity distribution networks as well as transmission and hence co-ordination across both systems will be essential.

QUESTION 8: What steps need to be taken to ensure that the UK's electricity system is resilient as well as competitively priced and decarbonised by 2030? How effective would current policies be in achieving this?

57. We would argue first for an effective System Architect Role, as stated in our response to a number of your questions. This will be essential in limiting the costs of what will be an inevitably expensive transition to a low carbon resilient electricity infrastructure.

58. In addition we need to move over time to integrating the commercial arrangements for variable renewables (i.e. initially wind and solar but potentially wave and tidal technologies in the longer term) into the wider electricity market. Variable renewables need to be valued for their zero or low marginal cost of low carbon energy, and for any capacity contribution they make. We would suggest they are also charged equitably for system costs incurred for system services provided by other generators and service providers. We need to make similar arrangements to fully integrate and value demand participation. This is a challenging issue with implications for future EU directives on energy; however it is one faced by a range of EU member states.

59. We need also to work harder to deliver greater energy efficiency through a range of measures. This can be key to affordability. Energy efficiency is usually highly cost-effective but a wide range of barriers exist to its systematic adoption.

60. All this depends ultimately on engaged consumers. Government and industry need to continue to work to engage people in their personal energy economy, and both the government and the industry need to act to rebuild lost trust.

QUESTION 9: Is the technology for achieving this market ready? How are further developments in science and technology expected to help reduce the cost of maintaining resilience, whilst addressing greenhouse gas emissions? Are there any game changing technologies which could have a revolutionary impact on electricity infrastructure and its resilience?

61. Most of the technologies required exist but need the experience of deployment at scale in world markets to evolve in function and efficiency and reduce in cost. This comment applies for everything from nuclear power stations to home energy management. It is important that the UK must not develop UK-only standards and practices if it is to benefit from innovation in world markets, and from export opportunities for UK providers.

62. A wide range of new equipment technologies is in development which will create more options for electricity system management over and above those in use today, but will not individually be game changers. Examples of are shown in Table 1.

Table 1: New power system management technologies currently in development

NEW TECHNOLOGY	INFRASTRUCTURE RESILIENCE BENEFIT
Automated and/or autonomous self-reconfiguring networks	Rapid post-fault supply restoration
Dynamic real time thermal equipment ratings	Releases additional capacity from conventional assets
Electrical energy storage in conjunction with power electronic convertors at a range of durations and for a range of scales. (For further explanation see the IET Factfile on Electricity Storage) http://www.theiet.org/factfiles/energy/energy-storage-page.cfm	Can serve multiple needs including network capacity support, operating reserve and frequency response.
Power electronics applications such as static VAR compensators and statcoms	Improved voltage control and efficiency of network power flows
Advanced network monitoring and control systems embracing state estimation and contingency management computation	Assurance of network capability under an increasingly diverse range of credible power flows
Meshed networks employing sophisticated power-flow management techniques, including power electronics devices	Higher network utilisation and/or reduced losses
Adaptive protection systems	Ensure the continued safe operation of transmission and distribution networks under predicted future dynamic changes in system strength (fault levels)
Active management systems which can interface with generator control systems and consumers' energy management systems to dispatch or curtail export and demand	Manage power flows on networks without investment in additional capacity
Phase shifting transformer and power electronics based "soft" open points	Improved load sharing across networks
Series compensators and thyristor switched capacitors	Enhance capacity headroom of transmission networks by optimising voltage levels and improving efficiency of power flows
Voltage source converters interfacing between ac and dc transmission systems	Promises a number of technical and economic benefits over traditional current source technology for connecting dc interconnectors to the GB ac system
Fault current limiters	Enhance capacity headroom in distribution networks to allow additional generation to be connected
Improved designs and materials such as amorphous steel-core transformers	Reduced losses
A wide range of advanced diagnostic techniques (including ultra-sound, infra-red, partial discharge detection, acoustic signature, dissolved gas analysis)	Allow critical asset health indicators to be monitored leading to reduced risk of in-service failure or premature replacement
The exploitation of "synthetic inertia" capability inherent in the speed control system for some generator types used with wind turbines	Help mitigate the overall reducing level of system inertia

Smart metering equipment meeting the requirements of the UK technical specification SMETS2 which will include data transfer via a centrally managed communications system	Provide valuable information on low voltage network power flows and voltage levels, enable better control of voltage to reduce losses, alert network operators to power outages and power quality problems, and also enable the development and use of dynamic tariffs

63. Whilst these technologies each have the potential to make a valuable contribution to future system resilience, this will depend critically on selective application and effective integration, and establishing the necessary business processes that will ensure effective transition from demonstration to business as usual. The engineering integration, even of established technologies into a system with novel topologies and architectures is a non-trivial task that carries risk, and hence will require an engineering systems integration approach (see question 12).

64. Future R&D funding will need to focus on integration of the above (and other) technologies by deploying solutions at scale.

65. A further potential game changer is a much stronger role for community energy rather than large remote energy providers. Community energy is often seen as part of a wider strategy around smart communities, integrating a wide range of consumer's needs to meet as much of them as possible locally. Enablers for smart communities include the big data and communications revolutions we see underway today. The extensive deployment of community energy infrastructure could potentially reduce the need for further capacity investment in transmission networks and the higher voltage parts of distribution networks, such that their role evolves increasingly from providing bulk supply to provision of balancing capacity. In principle, this could enhance system resilience, provided the community energy network is engineered such that it can interact with its local power system when both are operating normally, but continue to operate when disconnected from the wider electricity distribution system (balancing supply and demand within the community). This would occur when supplies from the wider system are disrupted under system fault conditions. However, further work is needed to understand the costs and benefits involved, given the sophisticated network management systems that would be required. The Smart Grid Forum is actively considering any regulatory or commercial barriers that might require attention to promote the economic development of community energy schemes.

66. A further technology under development using largely proven elements is tidal lagoons. The UK has a large potential resource (>10 GW), and costs and environmental impacts would appear to be lower than for large tidal barrage schemes. DECC is currently taking a considerable interest in this technology.

QUESTION 10: Is UK industry in a position to lead in any, or all, technology areas, driving economic growth? Should the UK favour particular technology approaches to maintaining a resilient low carbon energy system?

67. The electricity sector is a worldwide market with a global supply and innovation base. The UK has historically proved an attractive destination for inward investment, as well as for innovative start-up companies. There is plenty of room for UK innovation, export, employment and economic growth, and this is being seen already, for example in Low Carbon Innovation Fund projects, many of which have engaged UK SMEs.

68. A pragmatic view needs to be taken of where support to innovation has a realistic chance to succeed in developing new UK export industries, and it will be key that barriers are not introduced by specifying requirements and solutions unique to the UK that are not aligned to the direction of travel in other world markets.

69. All new technologies carry risk in development, and may not evolve into competitive commercial propositions, so it is wise not to limit technology choices unduly. We would recommend an open and diverse approach to technology, using the energy transition to create an environment to welcome innovation.

70. The Energy Systems Catapult, to be launched in April 2015, can play a key role here in catalysing the development and commercialisation of promising new technologies.

QUESTION 11: Are effective measures in place to enable Government and industry to learn from the outputs of current research and development and demonstration projects?

71. As mentioned above, Ofgem's initiative in introducing first the Innovation Funding Incentive (IFI) in 2005 and subsequently the Low Carbon Network Fund in 2010 (to be superseded by the Network Innovation Allowance and Competition) have provided a strong incentive for transmission and distribution network operators to re-engage in effective research, development and deployment. All network operators have responded positively to the incentive and this has led to the development of many of the technologies referred to in Q10 above.

72. The results of this research is widely and effectively disseminated through regular dissemination events, a smart grid web portal (which is now under further development) and a highly regarded annual conference.

73. Network Operators have also demonstrated that this research is already leading to significant network investment efficiencies, as demonstrated in their Business Plans for the regulatory periods covered by Ofgem's RIIO ET1 and ED1, and are now beginning to systematically adopt these new solutions as business as usual. However, there is much more to be done before we can be confident that we have the capability to effectively integrate these solutions at scale.

74. Going forward, the new Energy Systems Catapult should be effective in 'bringing-on' new technologies, not only for the benefit of UK consumption but also as potential employment growth and export opportunities.

75. The System Architect role would be supported by such on-going effective RD&D and would be in a strong position to leverage the benefits of integrated deployment.

QUESTION 12: Is the current regulatory and policy context in the UK enabling? Will a market-led approach be sufficient to deliver resilience or is greater coordination required and what form would this take?

76. We believe the current approach, which is a mix of market led, regulator led and government led, is missing the key element of **engineering systems integration**. This has been less important historically. The system was changing only slowly and knowledge gained over the last 100 years was enshrined in the industry codes everybody follows.

77. However we are now in the early stages of a period of profound change. We are not yet in a position to forecast where this will ultimately lead or predict all the problems that will emerge. In the absence of a systems integration approach there would be a serious risk of investing heavily in assets that could become stranded, or of losing resilience through poor systems integration. There will be a greatly increased need for new engineering skills in the industry, and greater demands on the engineering competence of companies involved.

78. The IET recommends the establishment of a System Architect role in the near future, to ensure the major changes needed are subject to effective systems engineering. We have

already been exploring this with the industry through the IET's Power Networks Joint Vision expert group. Our first report "Electricity Networks: A Shock to the System[2]" was published in December 2013, and we have been following this up with work funded by Innovate UK (the new name for the Technology Strategy Board) to explore what can be learnt from system architect and systems authority roles in other critical infrastructure sectors. This work will be published in early October[3]. We have also been working on behalf of the Council for Science and Technology on a study to identify the gaps in our modelling capabilities, to be completed in December 2014.

79. We are currently exploring the role of a system architect further with DECC and Ofgem

80. We would be keen to explore these very important issues with the Select Committee in oral evidence.

81. The opportunity exists now to put in place effective systems engineering arrangements for the electricity sector, which will allow a resilient low carbon infrastructure fit for the future to be delivered cost effectively, taking full account of new knowledge and technologies as they evolve.

82. Without this there is a risk that the electricity system will evolve in a piecemeal fashion, at higher costs and with significant risks to its resilience in the future.

83. Beyond electricity, there will be a need for more coordinated local strategic spatial planning in the future to guide the development of electricity, heat and other infrastructure, in a world of increasing local power demand and the long-term transition from natural gas.

About the IET

84. The Institution of Engineering and Technology (IET) is one of the world's leading professional bodies for the engineering and technology community and, as a charity, is technically informed but independent. This submission has been prepared on behalf of the Board of Trustees by the IET's Energy Policy Panel and takes into account input received from the wider membership.

[2] Electricity Networks: A Shock to the System - IET position statement on the whole system challenges facing Britain's electricity network, IET, December 2013

[3] Transforming the Energy System: How other sectors have met the challenge of whole-system integration, IET, October 2014