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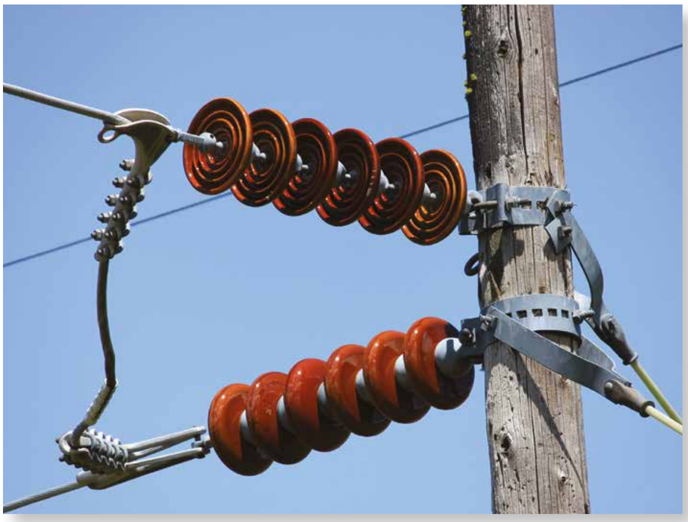
Electricity **Networks**

Handling a Shock to the System

IET technical report on the **whole system challenges** facing Britain's electricity network



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This IET Technical Report developed in collaboration through the IET Energy Sector and Energy Policy Panel informed a Position Statement published by the IET Power Network Joint Vision expert group, which is also available on the IET website.

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Executive Summary

Britain's electricity sector is grappling with the triple challenge 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 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 a Position Statement and this 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.

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.

Part 1: Power Network Joint Vision - Overview

Introduction

Fundamental changes to Britain's electricity power system are already starting to take place and manifesting themselves in ways which had not been anticipated only a few years ago. Moreover, the pace of change is expected to accelerate and it is the IET's considered view that if not addressed by timely and coordinated action on the part of government, industry, and a wide range of stakeholders, these changes will become increasingly disruptive to the secure and cost-effective operation of the national electricity power network.

The inevitable consequence of inaction would be that Britain's electricity supplies will become less secure and unaffordable. A further casualty of inaction will be the decreasing ability of the grid to accommodate the new low carbon electricity production, transport and heat technologies necessary for Britain to realise its ultimate ambition to decarbonise electricity production and achieve its legally binding commitments to reducing carbon emissions.

The changing character of the power network

The currently observed changes to the behaviour of power networks are adverse and are primarily a consequence of the early stages of sector decarbonisation, in particular the introduction of new low carbon electricity production technologies which are gradually displacing conventional fossil-fuelled generation and first-generation nuclear plant; however they are also due to changing electricity demand patterns. The observed characteristics of these changes are in terms of wider variations in transmission system voltages, particularly overnight where in some parts of Britain voltages are now rising to levels beyond the design parameters of the installed transmission voltage (and reactive power) management systems; and in terms of less stable system frequency, which can be observed particularly during abnormal system events.

In terms of the new generation technologies coming on stream, new nuclear, albeit less flexible in its operation, can be considered a low carbon alternative to conventional fossil-fuelled generation (as well as a direct replacement for first-generation nuclear) in that it will be directly connected to Britain's transmission system and will continue to be centrally dispatched. Although the management of large (typically 1800MW) nuclear plant brings some new challenges in terms of managing system frequency (for example maintaining stable operation following an unexpected loss of one of these large units to the system) new nuclear stations do not generally give rise to significant changes in the approach to managing the electricity power network.

However, much of the new low carbon generation now coming on stream, and set to expand significantly over the next decade, is in the form of renewables, in particular wind and solar PV. Renewable generation has the potential to make a significant and effective contribution to decarbonising Britain's electricity sector but, unlike the conventional 'synchronous' generating plant found in nuclear, coal and combined-cycle gas turbine (CCGT) stations, wind and solar PV generation is, by its nature, intermittent and therefore a less dependable source of electrical energy for system balancing (i.e. matching electricity production to demand in real time). Moreover, wind and solar PV generation is often either widely dispersed deep within the electricity distribution grids (so-called 'distributed' or 'embedded' generation) or sited in remote and/or offshore locations, and connected only indirectly to the transmission system via direct current (DC) connectors.

Due to the 'decoupled' nature of these technologies, solar PV, wind generators and interconnectors do not contribute to 'system inertia' which is an essential component of maintaining a stable electricity power system that can be depended upon to operate reliably, within acceptable limits of frequency variation, and able to withstand shocks to the system (for example due to sudden changes in demand or loss of generation, or due to transmission faults).

New demands on the distribution networks

There is a further emerging challenge to the electricity power system due to electrification of heat and transport which is a key plank of the UK Carbon Plan and to delivering on our national obligation towards reduced carbon emissions. Whilst the level of take-up of electric vehicles and heat pumps is currently below some earlier expectations, comprehensive modelling undertaken by the network companies in conjunction with academia illustrates clearly that electricity consumption and, in particular, peak demand (which ultimately drives the need for both generation and network capacity) has the potential to increase significantly above the design limits adopted when the existing electricity distribution networks were installed.

On the other hand, there is scope for these new categories of electrical demand to be operated flexibly, particularly private electric vehicles which, as with other forms of private transport, are typically stationary for over 90% of time. Not only can this be helpful in terms of avoiding excessive growth in peak demand, there is the potential to flex the timing of electric vehicle charging so as to align more closely in real time with the output from intermittent renewable generation. This in turn points to an important characteristic of 'smart grids': i.e. consumer participation. The willing engagement by consumers of all categories (business and domestic) will in future provide a vital new tool for power system management. Innovative contracts for providing ancillary services such as system balancing, or new tariffs enabled by smart meters, have the potential to make a real contribution to whole system optimisation and hence the objective of secure, affordable, low carbon electricity.

Innovation already taking place

The anticipated increase in distributed generation, and levels of adoption of electric vehicles and heat pumps, has been the main driver in Britain for the development of 'smart grid' technologies. It is beyond the scope of this report to catalogue the many smart grid trials that have been (and are continuing to be) conducted by the Distribution Network Operators (DNOs) in conjunction with a wide range of industry stakeholders (including but not limited to: established manufacturers and smaller entrepreneurial organisations, energy suppliers and intermediaries, academia, and not least participating customers). Suffice to say that, as a result of concerted action by the industry and its stakeholders in developing and deploying innovative new technologies and commercial contracts with customers, Britain can now legitimately claim to be European leaders in terms of deployment of a wide range of credible smart grid solutions which have the potential to provide economically viable (and far less disruptive) alternatives to investment in conventional network capacity. Our European position is demonstrated in a recent EU report.[1]

The IET expert group

In recognition of these changes and forthcoming challenges (and opportunities), the IET has called on the deep source of industry expertise that exists within its membership (including expertise from transmission and distribution companies, smart grid specialists, consultants and academia, together with advice from Ofgem and DECC) to give careful consideration to these challenges and to draw up recommendations as to the actions that need to be put in hand in order to ensure the continued integrity of Britain's electricity power system in the face of the demands we can expect to be placed on it over the next two decades and beyond. The challenges identified are matters of significance and the expert group has set out the lines of action needed to achieve solutions in a timely way.

The approach to this critical work, on which we report in this document, has been to establish three distinct work-streams, each tasked with one of three clearly defined objectives which the overall working group identified as being core to creating the necessary foundation for the recommendations of this report to be taken forward. These three objectives were:

- **Understanding and Explaining the Overall Problems:** undertaking a full SWOT analysis (see Appendix 1A) of the challenges facing the whole electricity power system (partly in order to inform the other two work-streams) and developing an IET Position Statement (see below);

- **Power Network Investment Planning:** identifying the necessary changes in the approaches to planning and designing the Great Britain (GB) electricity power network that will secure the most effective outcomes from a whole system perspective in terms of addressing the anticipated challenges; and
- **Operating the Power Network:** identifying the necessary changes in our approach to operating the electricity power network in light of the anticipated challenges so as to maximise its future effectiveness from a whole system perspective.

In terms of reporting the outcome of this study, the IET has been conscious of the different audiences that the conclusions and recommendations need to reach, and hence the style of communication that is most likely to be effective.

Documents now available
As a result of these deliberations, the working group has produced two key documents:

- **An IET Position Statement** which is aimed primarily at policy makers and other informed professionals; and
- **A Technical Report** (this document) aimed particularly at industry professionals

Together, these documents provide a solid foundation for key industry stakeholders (including: network and system operators, the overall industry supply chain, energy suppliers and intermediaries, generators and consumers, government bodies and policy makers) to make the necessary transition to whole system design, planning and operation which the IET believes is essential to avoiding future major disruptive effects to the electricity power system which the nation has (and will increasingly) become dependent upon for delivering secure, affordable, low carbon supplies of electrical energy.

Moreover, the IET believes that by adopting the recommendations in this report and taking the necessary next steps, Britain will be well placed to establish a high level of internationally transferrable expertise in the whole system design, operation and management of electricity power networks, and hence will be well placed to leverage its competitive advantage in securing both inward investment and export opportunities for the benefit of jobs and the wider UK economy.

References for Part 1

[1] http://ses.jrc.ec.europa.eu/sites/ses.jrc.ec.europa.eu/files/documents/ld-na-25815-en-n_final_online_version_april_15_smart_grid_projects_in_europe_-_lessons_learned_and_current_developments_-2012_update.pdf

Part 2: Power System Investment Planning

Introduction

This part of the report examines significant issues relating to a whole system approach to power system investment planning. Much of the emerging challenge stems from the changes to generation background (specifically low carbon technology, location, scale and number including embedded generation) and both active and reactive power demand trends. The strains associated with these changes are already evident to network planners and operators who are aware that these are likely to increase as the transition to a low carbon electricity supply and the roll-out of smart grids gathers pace.

The overall architectural blueprint for power networks in GB is being set by individual network companies as they respond directly to the decisions and choices that customers make. That said there is already a degree of cooperation and joint vision through the GB Smart Grid Vision and Route Map[1], the Electricity Networks Strategy Group (ENSG)[2] and the Smart Grid Forum (SGF)[3]. The focus in this document is on how to do planning, rather than on the shape of the overall plan, vision or blueprint for GB power networks.

An electrical power system includes generation plant and a network of electrical circuits that are operated to deliver electrical energy efficiently and reliably to consumers. The equipment for both generation and network transport is sophisticated, expensive and is expected to do its job for as much as 50 to 60 years in some cases. Electrical power system planning is the on-going process of making investment decisions to install or replace power system equipment in line with an overall architecture. When power system planning is done effectively, the right components are installed in the right places at the right time to deliver a reliable, efficient and cost effective power system that provides the essential links between generation and consumers of electrical energy.

Decisions to invest in electricity production and develop the electricity production system in GB are made by independent private companies in response to market and legislative signals. These decisions involve the selection of generating technology, scale and location to provide the best value to the generating companies and therefore to the investors in electricity production.

Decisions relating to the development of power networks follow a different approach from that for electricity production. The GB power network companies are natural monopolies and are regulated to deliver both efficient investment and operation of the power networks. The power network planning process starts with information about the existing power network and then looks into the future to anticipate coming needs and identifies and analyses the most effective changes to the power network to meet the expected needs in the best way.

There are now a number of significant changes to power systems and power networks that have a bearing on both what power network should be developed and also the associated power network planning process. The IET PNJV has made it a priority to identify these challenges, identifying the most important issues for power system operation and recommending actions to address the challenges.

This part of the report focuses on the area of power network planning and draws on GB power network planning knowledge and experience to explore three issues of high importance:

- Electricity Demand Change and Information Sharing
- Active Distribution Networks
- Network Planning Tools

Each of these areas presents a significant challenge to undertaking the power network planning task efficiently and effectively. Three appendices develop each issue in some detail and propose various ways to tackle the problems and set out recommendations to tackle the challenges posed. The recommendations are intended to inform the process of policy making, coordination between participants in the power system planning process and the supporting tools required. The findings of this report will be of interest to policy makers, regulators, power industry leaders and network planning engineers.

This part has been prepared by the Network Investment Planning Work Stream (WS) B of the IET PNJV expert group which includes transmission, distribution, academic and other specialist planning participants. WSB identified the issues tackled in this report through informal consultation with leading industry experts and representatives of the major power network companies in GB. A long list of issues was discussed extensively, developed and reduced to the three issues covered in this part which are viewed as crucial to effective power system planning. This part is structured to provide a brief background and explanation of the challenge and possible solutions with a way forward recommended for each of the three topics.

Background

Power network planning is a complex, time consuming and challenging task and the processes deployed in GB involve many different sub-processes, participants and sources of information. This section provides an overview of power network planning in GB but is in no way to be seen as entirely comprehensive, as the task goes deeper and wider than this report allows. The key artefacts of the power network planning process will be highlighted to enable a reader to follow up in greater depth.

There are three transmission network licensees and fourteen distribution network licensees (with distribution service areas) in GB and these companies own the networks and operate them under licence from the national government (managed by the regulator Ofgem). Licence conditions include the investment in and operation of a secure, efficient (including an obligation to develop networks in an efficiently coordinated manner) and safe power network, so planning the development of their networks is a central licence requirement.

The transmission and distribution network companies bring forward their proposals to invest in the development of their networks under the price control mechanisms that regulate their natural monopoly activities. One of the planning time horizons is therefore the 5 to 8 year period of regulatory settlements[4]. Things are not quite that simple, since meeting the licence requirement to plan and develop an efficient power network requires a longer view of possible requirements for power networks.

A 10-year planning horizon is adopted in the main publicly available transmission network planning document, the Electricity Ten Year Statement (ETYS)[5]. Likewise a 10-year planning horizon is adopted in the distribution company Long Term Development Statements (LTDS) although the format and depth are different[6]. Power network planning needs to take a long-term view but it also needs to adapt to shorter-term changes.

While the existing regulatory mechanisms encourage long-term thinking they also provide for short-term decisions to respond to the emerging needs to develop the power networks. For example, unexpected trends and decisions taken by individual users of the network (e.g. external stakeholders such as generators seeking connection to the network) would need a faster response than either the 5 to 8 year regulatory period or the 10-year planning horizon of the ETYS and LTDS. In fact, the power network planning process is complex, bringing together short term requirements and longer term thinking.

Gaining investment approval for power networks is also flexible to long-term and short-term needs with mechanisms to approve an overall investment strategy through the regulatory settlement sitting alongside adjustment mechanisms and charge-backs to users of the network that trigger network investment for their sole use. There are also important internal investment approval processes within the network owners so that good governance and robust investment decision making are promoted.

Other external stakeholders have an important part to play in the planning process and probably foremost among these is the planning permission process where the public at large, local government, national government and the judicial system (in public enquiries) can influence the development of the power network.

The existing approach to power network planning could be viewed as more reactive to short-term needs rather than long-term strategic. While the ETYS and LTDS documents set out longer term network development intent, this is done with increasing uncertainty as the planning horizon rolls out. The ETYS and LTDS documents have greatest certainty in the approved plans for the coming few (e.g. 2 to 4) years where network development plans have been put in place to meet specific needs from demand or generation development. It is important to note that the ETYS also takes a 20-year view of possible scenarios for the development of generation and demand to provide longer-term anchor points that act to direct decisions taken in the short-term.

At the transmission level the ENSG brings together key network company, government, regulatory and other network stakeholders to develop plans to meet the greater strategic challenges faced by the GB power networks. This has led to the development of significant plans to reinforce the transmission system to meet the renewable energy challenge (amongst other things) and many of these have received regulatory approval and have moved into construction (the Beauly – Denny 400kV line in Scotland is a good example of this). The work of the ENSG provides coordination of the transmission planning process among the transmission licensees and their stakeholders.

At the distribution network level, the development of network planning policy to address the emerging challenges is coordinated across the distribution licensees through the SGF. The work of the SGF was stimulated by the challenges of low carbon technology roll-out in distribution networks but also addresses the requirements to harness the power of Information and Communication Technology (ICT) to build and operate more efficient and higher performing distribution networks. The outcomes of the work of SGF have been rolled into the distribution licensee business plans that are under regulatory review at the time of writing.

Some coordination of transmission and distribution network planning is done through a Joint Planning Committee where data is shared and where planning problems that affect both transmission networks and distribution networks are tackled.

The data and information required by network companies to form their network development plans comes from numerous sources. The ENSG took a view on the possible renewable generation development futures in proposing a long-term plan for transmission system development. The ETYS takes a 20-year view of generation and demand through scenarios.

One important source of information used by the National Electricity Transmission System Operator (NETSO) in long-term transmission network planning is data provided annually by the distribution companies. The Grid Code[7] requires the DNOs to make a 10-year forecast of demand and generation in their network under each grid supply point and provide this to the NETSO for analysis of future power flows in the transmission network. This is known as the ‘week-24 return’ and the corresponding outcome of the analysis is provided back to the DNOs from the NETSO as the ‘week-48 return’.

A suite of power system analysis tools is used by transmission and distribution network planners to assess issues with future uses of the networks and possible challenges to their adequacy to do their job. The growing challenges of low carbon technology (e.g. intermittent renewable generation at all scales), active distribution networks (e.g. distributed generation, responsive demand and autonomous control) and new data sources (e.g. smart meters) present new analytical challenges to power system planners as they attempt to generate a view on the requirements and possible investments in power networks.

Overall Power Network Planning Challenges

This investigation of power network planning in GB, in particular the two case studies in Appendices 2A and 2B, have raised some of the areas of future concern for network planners such as the need for a more coordinated and strategic view of the coming network challenges:

1. Renewable generation has the potential to make a significant and effective contribution to decarbonising Britain’s electricity sector but, unlike the conventional ‘synchronous’ generating plant found in nuclear, coal and CCGT stations, wind and solar PV generation is, by its nature, intermittent and therefore a less dependable source of electrical energy for system balancing (i.e. matching electricity production to demand in real time). The challenge is that in many cases these generators cannot be scheduled or controlled so are unable to assist in the balancing of supply and demand.

2. A key issue for transmission network planning is the net demand change at grid supply points as a result of general demand changes and the growth of distributed generation (i.e. smaller scale generation connected to the distribution

networks) and the inadequacy of existing processes for collecting and sharing data. Transmission planners in the NETSO expect peak demand not to grow substantially in the coming years as a result of efficiency measures and the economic situation but do expect distributed generation to grow and so change the peak, trough and profile demand to be met through grid supply points. Expected growth of this generation is set to alter substantially the power flows through grid supply points and cause two way power flows through distribution networks which have not been designed to accommodate them.

3. The network planning task is likely to present a number of new analytical challenges as new data sources are accessed and utilised, as new planning options are considered and as greater uncertainties and commercial necessities are encountered. In particular there are real challenges to analysing the whole system effects at the network planning stage. In many cases the planning uncertainties are rising along with the operational implications of variable output from low carbon technologies, and the effect of active controls such as demand response and Active Network Management (ANM). Managing this effectively will require a whole-systems approach, spanning both the distribution and transmission networks for both planning and operational purposes.

4. ANM has prospective benefits and needs to be considered as a real alternative to more conventional reinforcement options in network planning. The costs and benefits of ANM are very different to the cost-benefit characteristics of more conventional network planning alternatives, because the longevity of ANM solutions is likely to be quite different. In addition, the modelling and analysis of active networks and ANM solutions is at an early stage as is the understanding of the commercial implications of ANM. An important issue is the need for analysis of multiple post-fault conditions in current network planning approaches and the additional complexity of many more network conditions to be considered in active networks. Such 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, this type of control must always be highly coordinated and integrated across the system to avoid adverse interactions.

Particular Key Planning Challenges

In addition, there are issues concerning the need for further coordination, particularly in the area of planning data and information, the overall architecture and design of power networks and of the analytical tools for modelling complex power systems. More specifically, these issues are explored in some detail in three appendices to this part of the report with the following particular key challenges emerging:

1. Collating the wide range of data from multiple sources required to undertake effective power network planning. This is especially challenging at a time of rapid change in the wider power system in terms of new generation technology, demand technology and issues of scale, location and operating modes for both generation and demand;

2. Effective sharing and access to essential power network planning data;

3. Uncertainty in future electrical demand technology including active and reactive demand profiles and responses under network emergency conditions;

4. The need for a range of planning models, standards and processes to address the emergence of active distribution networks;

5. Cross-cutting issues in active distribution networks for transmission companies and distribution companies such as analytical models, operating regimes, commercial arrangements and service provision;

6. The need for new techniques and tools for network planning to address the new challenges;

7. Cooperative approach to specifying, developing, validating and using new network planning techniques, tools and models;

8. The need for overall coordination of strategic direction and supporting activities in transmission network and distribution network planning and the development of a whole system approach to this.

Recommendations and Next Steps

This part of the report has examined the background and emerging context for power network planning and brings forward recommendations to address the issues and challenges foreseen.

The recommendations are:

1. Development of a specification and governance approach for a GB network planning data repository;
2. Review of the long term planning data submission ('week-24 data') from DNOs to the NETSO to make it more efficient and effective;
3. Commission a study (perhaps starting with meta-analysis) on emerging and future demand types;
4. Development of the scenario planning based approach now adopted by the NETSO in the ETYS to enhance robustness and track trends and observations in the sector;
5. Develop planning models, standards and processes for the treatment of active distribution networks;
6. Establish a transmission and distribution network company working group on active distribution networks to tackle the cross-cutting issues;
7. Develop requirements and specifications for techniques and tools for network planning to address the new challenges and provide the launch pad for diverse stakeholders to contribute;
8. Establish a steering group to lead, oversee and approve tools and models for network planning in GB.

The recommendations above are diverse but would profit from a single point of coordination to ensure that processes, models, tools, data, working groups etc. work to a common vision for power networks and the task of power network planning. It has been suggested that a revitalisation of the Joint Planning Groups to take on this task could achieve this. That joint planning group would have responsibilities to include diverse stakeholders as required and could usefully adopt working methods from the ENSG and SGF. A more effective way to achieve the necessary coordination of network planning efforts and provide a single focus of responsibility and authority would be to establish some form of strategic network architect role in GB. *A power network architect role would take responsibility for the overall network architecture and network development trajectory and would also identify the needs for and then commission, assimilate and exploit supporting activities on network planning data, network planning processes and network planning tools. It is considered that DECC should work with industry to establish this System Architect role to achieve a whole systems approach.*

The first two particular key challenges and the first two recommendations listed above lead to the expectation that Network companies need to determine together how to address the impact of a data rich environment, including the mechanisms for improved internal and external data exchange.

The next steps foreseen are to discuss these proposals and recommendations with a wide industry stakeholder group to test and refine their rationale and then write terms of reference for and convene a network planning coordination group to consider the proposals in some detail and recommend the most appropriate way to achieve the coordination and whole system approach pointed at by this report.

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[2] https://www.gov.uk/government/policy-advisory-groups/electricity-networks-strategy-group

[3] https://www.ofgem.gov.uk/electricity/distribution-networks/forums-seminars-and-working-groups/decc-and-ofgem-smart-grid-forum

[4] Note that the 5-year planning horizon for Distribution Network Operators and the previous 7-year planning horizon for Transmission Network Operators are transitioning to a standard 8-year planning horizon under the RIIO regulatory mechanism (see Ofgem RIIO web space: https://www.ofgem.gov.uk/network-regulation-%E2%80%93-riio-model)

[5] http://www.nationalgrid.com/uk/electricity/ten-year-statement/

[6] http://webarchive.nationalarchives.gov.uk/20130402174434/http://www.ofgem.gov.uk/Networks/Techn/NetwrkSupp/LongTermDS/Pages/LTDevSttmnts.aspx

[7] http://www.nationalgrid.com/uk/Electricity/Codes/gridcode/

Part 3: Operating the Power Network

Introduction and Background

This part of the report examines the operational challenges that either exist now or are likely to develop in the foreseeable future within the context of the whole system design that has been noted elsewhere in this report. The task has been executed using a methodology of bilateral interviews with members of the IET PNJV Work Stream (WS) C to elicit their knowledge, views and insights into the challenges that need attention, the possible solutions, and the areas required for further work to allow a whole systems engineering perspective to be delivered. The questionnaire used in this approach is attached in Appendix 3C with responses in Appendix 3D. There has been dialogue between the various work streams to ensure aligned effort and non-duplication of content. The findings are documented in summary in this section and further detail can be found in the Appendices 3A to 3D. From the findings, three key issues (Information Flows, Resilience and Security) have been identified and have been supplemented by an evidence base from Cardiff University in the form of two case studies which have been developed; “GB Electricity Network Operation - Information Flows - Now and Next” and “Will an increase in Information and Communication Technology (ICT) and embedded intelligence cause a decrease in resilience of the transmission and distribution network?” these can be found in Appendix 3A and 3B.

Overall Power Network Operating Challenges

This investigation of power network operations in GB has raised some of the areas of future concern for network operators such as the need for a more coordinated and strategic view of the new types of generation and demand, and their characteristics and parameters, that are, and will increasingly become, a substantial proportion of transmission and distribution connected facilities:

1. One of the main issues that needs to be addressed for power network operations looking forward to the future is the balancing of the whole system with intermittent renewable generation, uncontrollable output from distributed generation, demand responding to various call-offs, and masked demand from very small scale generation all without unduly inhibiting the development of a low carbon environment. Provision of reserve to cover uncertain renewable generation exacerbates the problem. The challenges are that in many cases these generators cannot be scheduled or controlled so are unable to assist in the balancing of supply and demand and that there can be large numbers in the distribution networks leading to uncontrolled two way power flows for which the networks were not designed.

2. The “peakiness” of heating requirements with very high demands during a cold snap casts doubt on the wisdom of fully electrifying heat – it would require significant heat pump capacity, as well as network capacity and generating plant, all with a very low load factor. In addition, the simultaneous charging of electric vehicles, particularly as such equipment is unlikely to be evenly distributed throughout the power system but appear in clusters, is likely to exacerbate network capacity requirements on an unpredictable basis. Both heat pumps and electric vehicles are capable of increasing the electrical power needed by consumers, radically exceeding traditional levels of network safe maximum capacity. Further, it creates ‘active’ consumers, whose actions will at times summate to have impact on the national power system at transmission level.

3. Control of DNO systems will become far more active. The scale of their networks means that this will have to be largely automated. Control of smart demand/embedded generation will be a new mechanism that will need to be exploited. There is a new generation of control systems needed at distribution level away from dumb Supervisory Control and Data Acquisition (SCADA) data being displayed on passive displays towards new interactive systems running complex power system modelling. 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, but, fast signalling and control must always be highly coordinated and integrated across the system to avoid adverse interactions.

Particular Key Operating Challenges

The ten key challenges that have been identified from an operational perspective are detailed below. These challenges represent where a consensus of members of WSC agreed at this high level of abstraction about the need for some form of action. The differences of views emerged as the detail of these issues was investigated further. The differences were generally dependent on the part of the supply chain the person was associated with e.g. from Transmission, Distribution, Industrial, Consultant, Academia, etc. and this provided a different lens/context to focus on each of the issues. Each of these challenges is briefly described here. The headings somewhat hide the various contexts that sit behind the detail. The detail of how each of these topics manifested itself for each participant varied mainly by the context that their day-to-day work influenced their perspective. This is not a surprise but highlights another challenge for government which is "whose view is right?" This task does not try to answer that question but highlights the different requirements that will need to be taken into account when considering the possible solutions. There were some very strong views about the need for coordinated action rather than a lot of initiatives delivering outside of a clear framework. The detailed feedback received can be found in Appendix 3D. As the interviews were executed under the Chatham House rule, no attribution of comments or views is provided.

Operational issues tend to reflect a requirement to operate what the planners have provided as the infrastructure. Operational teams have a tendency, therefore, to assume the status quo as the starting position, rather than a radical new world, although some see the need for a step change in thinking if the requirements for flexibility, optimisation and low carbon are to be met.

1. **System optimisation**

   There are many facets to optimising a system as can be seen from the views expressed. The boundaries of the 'System' are the real issue, e.g. when it comes to voltage management it really does include top to bottom of the entire electricity supply, delivery and demand side. On the other hand a sub-station can be optimised as a 'system' but it really is a false optimisation when considering the dynamics in the context of the broader system. System optimisation is usually considered when the power network is in its 'normal' state. As more complex dynamic switching and voltage management strategies are used a 'normal' state (especially at distribution) could lose much of its meaning. Given the scale of the whole system, it is hard to imagine a single "controlling mind" responsible for operations. This creates the issue of how the different "controlling minds' can work together to optimise the operation of the whole system.

2. **System modelling**

   Much of the power system is modelled based on quiescent states. With the advent of greater numbers of variable generation sources being connected to the grid, the ability for many of the old static models to cope is becoming challenging. Further, at distribution there are few models to allow real-time operations modelling to deal with the increasing complexity that is now being proposed, especially at lower voltage levels. Models such as Transform® have been developed to provide planning assistance but the impact on operations is still to be understood. Most assumptions are that the centralised SCADA/Energy Management System (EMS)/Distribution Management System (DMS) that are provided by a single vendor for the majority of the UK infrastructure control will incrementally develop to provide the missing functionality. Is this the right approach? Are there other solutions that provide greater flexibility and/or market opportunities? Will there be sufficient skills and experience to understand the problem – let alone offer solutions? A number of the views expressed concern for how the technical impacts fit into the wider issues of socio-economic impacts and how is this modelled today?

3. **System wide control philosophy/authority**

   As with system modelling there is a need to understand the whole system when considering control philosophy and who is the provider of the authority. From the views expressed here, there is a wide understanding that a rethink is needed as to who is best placed, given possible new market players entering this space, to control/monitor different aspects of the emerging complex end-to-end infrastructure landscape and how these 'spans of control' will combine to provide effective control of the wider system.

4. **Flexibility of the power system**
   The need for the power system to deliver a reliable, secure and economic supply across many different sectors; heat, transport, storage, built environment, etc. requires the operational aspects of each sector (e.g. transmission, distribution) to be re-considered. In order to deliver the required level of flexibility that society is now requiring, many views have been expressed that indicate the Smart Grid (the end-to-end concept rather than the project based activity such as smart metering) is needed to manage these operational challenges. Flexibility of demand will also be key to accepting intermittent generation onto the network and making the most of its output.

5. **Industry structure not fit for purpose**
   The industry and market structure we have today is seen as needing to evolve. This single area is probably the greatest constraint on many of the needed outcomes according to the view of the group.

6. **Information flows**
   Data, rather than information, is becoming abundant. A case study has been compiled to understand the evidence base that exists to inform what data will be important and what relationships exist and will need to exist. The model proposed is not definitive but provides an insight into the current state of understanding. Operationally the ability for this industry to innovate will be key to how information flows are allowed to develop between current and new stakeholders. The Case Study (in Appendix 3B) is evidence of a very hierarchical approach with the Transmission Network Operator (TNO) at the heart of information flows. There is some evidence from the views that have been expressed that other models may be more appropriate such as variants of Smart Grid Architecture Model (SGAM). Smart Grid Forum Work Stream 4 (SGF-WS4) is looking into these as options.

7. **Security (cyber and power system)**
   The increase of ICT use in the power network management has raised the question of cyber security as major risk to the integrity of a critical national infrastructure. It used to be the case that transmission was the medium that impacted many thousands of homes and businesses if compromised. There is now concern that a single broadcast message to millions of Smart Meters (if hacked) may deliver a similar or greater level of impact. As evidence is scarce due to the new nature of these threats a Case Study is attached (in Appendix 3A) to inform the debate on what evidence exists today for being able to make decisions about the future. The majority of evidence relates to centralised SCADA systems rather than millions of distributed units that could be controlled via a wireless connection. The views expressed clearly indicate a level of concern that needs further investigation. The decision on how the system is 'locked down' to prevent these types of issues could have a major bearing on the way that information flows above can deliver operational benefits – or not?

   Power System security is also undermined from the cyber security threat but this is only one element. The ability for the power system to be managed in a coherent manner is continually being challenged by the number and nature of intermittent sources connected at all voltage levels that are not dispatch-able. The advent of mobile loads such as Electric Vehicles (EVs) etc. and mass aggregation of demand are all testing the whole system security architecture. Much more needs to be done to understand the impacts across the various responsibility boundaries; transmission, distribution, built environment and individual customers.

8. **Resilience**
   The resilience of a system is its ability to recover its 'shape and form' after an incident, e.g. a fault, and is closely aligned to security which ensures the design is able to be resilient to attack or disaster. The resilience of the power system is becoming more complex to ensure and, simultaneously, more important as society's dependence on electricity continues to increase. As the discrete parts of the system become further integrated there is increased risk of not clearly understanding the potential impact on the whole system. For instance, as voltage management is fast becoming a major challenge for the optimisation of the power network there is greater risk from the increased tapping operations across the different voltages from Distribution to Transmission to cause failures in equipment that has not been operated in this way before. Increased observability is considered

key to future operation (e.g. monitoring at the 230V level in addition to monitoring at the 11kV level which is the current process), and it may be that this will need to be the minimum increase in monitoring to maintain the status quo. The level of resilience has a large bearing on cost; for instance in some quarters the cost of N-1 is being questioned, and leads to the issue of whether we can afford the reliability we have or whether we need to review how the system will be used in the future. Whatever the question, all agree that the costs of, and requirements for, resilience needs to be built into the consideration of system design now – not added as an afterthought later and this generates the question of who has the responsibility to do this.

9. Consumer engagement

From the initial activities with consumers via Low Carbon Network Fund (LCNF) type projects or from international initiatives the views expressed here are, “the challenge is not whether we need consumers to be involved, it is what is really being asked of consumers”. Behavioural change seems to be the prize, but to date, globally, the ability to get change has been less than impressive for the spend committed. Alternatively, customers may be willing to have some usage, for example charging of EVs, scheduled automatically on their behalf. It would appear that there are different levels of participants (not just consumers anymore) that are either very engaged or not engaged at all. Most effort has been expended on individual engagement, whereas community engagement and action has seen the largest impact of changed engagement. Cities are also becoming much more engaged in their energy destiny. Almost everybody is convinced consumer engagement is important; it is unclear what we are requesting of them; is it to help them cut their energy bills or is it to help run the grid? The market structure seems key to the operations discussion; if the retailers send a signal that generation is cheap and everybody follows this in a cluster and turns everything on, a distribution network constraint is the usual end result! Views vary greatly as to how best to utilise the new demand side; utilities really would like to dispatch consumer demand in a similar way to the way in which control is sent to dispatch generation. From the views expressed there is a lot to be agreed on and coordinated – but the question arises of whose responsibility it is.

10. Whole system design

From the themes above and the views expressed here, there is a clear requirement for leadership and direction when it comes to operational vision. The industry structure we have today relies on market signals, government wishes being interpreted in relation to shareholder value and a multi-party delivery chain acting on these indicators. Whilst this has proved “fit for purpose” to date, greater coordination will be needed in the future. Whilst the industry has bodies responsible for coordination such as the Grid Code Review Panel (GCRP), the Balancing and Settlement Code (BSC) Panel etc., they tend to focus on specific proposals rather than how to respond to fundamental change drivers. Historically, broader changes such as British Electricity Transmission and Trading Arrangements (BETTA), (extending the wholesale market to include Scotland) or the introduction of multiple distribution companies to gas have been dealt with by creating a new code, rather than a series of small amendments. For this to work, a broad consensus of what needs to be achieved would be required. The IET PNJV is starting this debate, but was never intended to be a formal industry body for reaching agreement. The debate will probably need to include the following steps:

- Achieve broad consensus on where changes will be needed to the present frameworks;
- Either bring forward modifications to the present frameworks, or if widespread changes are required, develop a complete replacement framework. This process may require changes to the current remit of existing frameworks or the creation of entirely new frameworks;
- Formal consideration of the proposals leading to adoption.

When considering the relationship with heat, gas, transport, ICT, water, etc. there is a need for coordination when determining how the future design will integrate and provide a coherent and efficient solution. The same is true across the boundaries that exist today between the various market discontinuities (e.g. Network Operators, Metering, Suppliers and Customers). What is clear is that many design decisions are needed across the various boundaries that exist today and it is important that these are considered in a holistic, rather than a piecemeal, manner.

Recommended Steps to do Now
The following recommendations are proposed by the IET PNJV Steering Group for consideration:

1. The majority of the team believes the current industry and market configuration is unlikely to give clarity from a whole systems design perspective on operational requirements for the future. It is, however, noted that some are concerned that the current configuration may just need greater investigation to identify the opportunities to improve the current market configuration. *The IET PNJV has a role to play in bringing this to the attention of those in the industry, regulator and government that need to understand these issues so as to enable government/ industry stakeholder groups to explore and address effective interactions between engineering, market and regulatory aspects to determine changes needed.*

2. Operationally, ten Key Challenges have been identified where further work will be required to ensure that a holistic approach to future operations is considered and prioritised, and that direction is given to the different market stakeholders in order to deliver efficient, cost effective, coherent engineering solutions.

3. Two case studies have been compiled for this report, which provide a good evidence base to inform and further the discussion on both how Information Flows could develop and also the challenges regarding resilience and security of using greater deployment of ICT on power networks.

Within these themes many valid current and possible issues/insights have been identified that should not be lost and it is proposed that any future work should build on this experience. The IET PNJV is providing a platform that has exposed these issues that are not usually documented or highlighted and, since the IET PNJV is not duplicating any other work but is providing an open environment to discuss cross-cutting issues across company and market boundaries, it is recommended that the IET PNJV expert group is continued in order that the issues raised can be driven through to some conclusion.

Recommended Next Steps
In detailing the views of the IET PNJV WSC group it has been difficult to concisely articulate all the views and details provided and ensure that the recommendations proposed represent the entirety of these views. Full reading of these views in Appendix 3D is advised. A clear requirement is to follow up the work started by this group.

This can be divided into two recommendation actions; those that need to be done now (see section above) and those that are longer term.

The impression from the operations experts was that at present we are focused on incremental projects to deal with particular issues. If this continues without a 'bigger picture' in terms of overall design the operational aspects of this approach will become harder to resolve and, probably, less efficient both in terms of best value and flexibility.

Nevertheless some clear messages are apparent and have been highlighted in the responses (Appendix 3D) to the questionnaire listed in Appendix 3C.

1. Skills are, and will increasingly become, an important feature for modelling the power system, maintaining security (both network and cyber) and resilience of the whole system. The question has been raised over whether there will be sufficient skills and experience to understand the problems – let alone offer appropriate solutions. The complexity of the system will result in a need for a higher level of technical expertise in the field, changing the traditional skill requirements of the industry. Also there is a need to recognise a potentially significant future industry skills gap that must be addressed both by curriculum changes and post-graduate training and development priorities. Shortcomings in the availability of skilled people, technology and commercial arrangements could have serious implications for resilience in operations. *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.*

2. Currently, and increasingly, there is lack of end-to-end visibility through the whole system with disparate actors having either insufficient incentive or lack of awareness of the need to share information across commercial and regulatory boundaries. A whole system perspective is not fully reflected in regulatory incentives, pricing mechanisms, or future market development strategies (e.g. future capacity market) leading potentially to lack of coordination, under-exploitation of synergies, suboptimal network investment, and suboptimal market structures (e.g. the potential conflict over the use of demand response tariffs, and storage and demand-side technologies). *DECC/Ofgem should develop the regulatory arrangements that will enable maximising whole system synergies and the mitigation of risks which would include demand response and storage.*

3. There must be adequate incentives and market accessibility for all classes of consumer to participate in demand side management and response and be rewarded appropriately. Traditional sources of balancing and reserve will be inadequate and/or too costly given the increased demand for ancillary services to address intermittency and low system inertia. Further, there is a severe risk of stifled innovation, delayed smart grid progress, and loss of potential competitive advantage over peer nations in terms of developable products and services. Currently, wholesale, retail, balancing, ancillary services markets operate with little evidence of management of conflicts or synergies. *Network companies' procurement arrangements should facilitate greater access for specialist providers to bring benefits in smart grids, demand management and new customer services.*

The ten topics identified as Key Challenges could provide a structure within the whole system design to allow future work to be managed and researched further. It is especially true that Information Flows, Resilience and Security, from an operational perspective, are in need of end-to-end consideration. Barriers to this happening seem to mainly centre on the industry structure not being considered optimally configured for the future. It is therefore recommended that careful consideration be given to this issue before trying to resolve the other issues as this will have a major bearing on the way regulatory, contractual and voluntary policy is implemented.

It was also recognised that it was important that an independent body such as the IET is able to bring experts from across the sectors and different disciplines together and provide a non-vested perspective on these very complex issues. The 'industry' is often seen as just the utility sector by Government and Ofgem and to some extent the public. If we are to embrace many of the changes required many more stakeholders will play a significant role in the decisions to be made. It is therefore important to consider who is responsible or what mechanism is to be used for coordinating this activity as more and more interested parties become involved.

Conclusions

The IET PNJV WSC report has highlighted a number of overall and particular key challenges where there is a need for action. Many of the views expressed have highlighted the fact there is a large diversity on "what is important" within these topic areas. Everyone can agree on high level issues and the risk of doing nothing is seen as unacceptable. There are concerns that some of the rhetoric, both here and elsewhere, could be seen as a call for a return to Central Planning. This is not the intent of those who have been canvassed and it is important that the feedback here is seen in that context.

It is clear that further work will be required to understand the mapping of how all of these issues/ideas/proposals can be captured, prioritised and acted on. The IET PNJV constitutes some of the most senior and respected figures in the industry and has provided a view on the challenges we face in an operational environment. If we are to learn from this experience and knowledge, a much more detailed investigation will be needed.

Appendix to Part 1: Power Network Joint Vision - Overview

Appendix 1A - Assessing the Capability of the Industry to Deliver the Objectives of the Power Network Joint Vision

Extended SWOT analysis

An important early step in the IET PNJV's work was to establish the key strategic objectives to be embraced by the vision; in other words what the outcome would be if the vision for the power network was delivered. This analysis is really at the heart of the vision since it describes the required capabilities and characteristics of the future electricity system if the UK is to meet its strategic objectives for security of energy supplies, decarbonisation of electricity production, electrification of heat and transport, and energy affordability.

The characteristics of the future electricity system have been described and the key messages summarised.

The next step was to determine the principal challenges that the future power network would need to meet if the vision is to be delivered; in other words describing the features of the power network that would enable the electricity system to accommodate the new demands placed on it by renewable and decentralised generation, low carbon technologies such as heat pumps and electric vehicles, and also in terms of ensuring security and availability of power supplies, adequate system stability, and efficient levels of utilisation.

The characteristics of the required power network have been described and, again, the key messages summarised.

Armed with this comprehensive and clearly articulated suite of requirements for the electricity system and the power network's role in delivering it, the next step was to undertake a SWOT analysis.

The purpose of this analysis was to first identify the institutional strengths and characteristic weaknesses inherent in the current industry framework that might facilitate or impede the achievement of the vision - including in terms of its governance, its market and regulatory structure, and its scope for development and deployment of technological and market innovation. This is an important element of the analysis since it identifies strengths that can be leveraged and weaknesses that will need to be addressed in delivering the vision.

The next and final step was to identify the opportunities and threats arising from existing industry and energy sector initiatives, particularly in terms of policy, technology, and market enablers and barriers.

The analysis outlined above is presented in the following pages in tabular form, providing a convenient source of reference for stakeholders - including policy makers, industry and market practitioners, the industry's supply chain for network assets, generators, energy suppliers, investors, innovators, research & development (R&D) establishments and academia.

The analysis has been core to the development of the IET Position Statement and has informed the priorities for the IET PNJV's Work Streams.

Key Strategic Objectives - supported by the vision

Topic	Characteristic	Key Message
A whole system that delivers the Carbon Plan	Affordable, secure and low carbon electricity	The whole system must be planned, designed and operated in a manner which fully utilises available network capacity and low marginal cost/ low carbon generation
A whole system that is sufficiently flexible to support optimum arbitrage between energy vectors	Synergies with both gas and heat production, storage and distribution fully exploited to optimise the whole energy infrastructure	The whole system must be designed to exploit co-generation and heat storage opportunities in order to minimise investment triggered by peak demands and/or network constraints
A whole system that is sufficiently adaptable to support numerous credible future electricity demand scenarios	A system development strategy that embraces and values optionality and flexibility	The future path to low carbon transition is uncertain; the need is to achieve an optimum balance between system asset stranding risk and the risk of inadequate anticipatory investment
A whole system that enables achievement of heat and transport electrification objectives at an acceptable cost	EVs and heat pumps might increase electricity consumption by 20% by 2030	Need to maximise use of existing electricity network capacity and low carbon base-load generation
A whole system able to accommodate high levels of low carbon generation	Electricity production from intermittent wind and solar PV highly dependent on difficult to forecast weather conditions	Need to develop a market that can support adequate reserves of system balancing at economic cost
A whole system and market environment fit to sustain decarbonised electricity production	Typically a generation fleet based on commercially inflexible base-load nuclear and zero marginal cost intermittent wind (and PV)	The market must balance the need to create an environment for investment with the need to avoid excessive spot-price volatility
An integrated power system and market that is proved to be capable of behaving in a predictable and stable manner	There are potentially unforeseen technology-technology, technology-market, and market-market interactions that could give rise to unexpected consequences for system and market stability	Albeit rapid development of both technologies and market mechanisms will be required, robust modelling and end-to-end testing must be applied as far as practicable before mass rollout
An electricity market and system able to balance demand and generation with minimal constraint on either	Electricity demand and generation optimally balanced at all times at minimal marginal cost of electricity production and/or demand curtailment	A key objective must be to ensure that as far as practicable there are no unnecessary barriers to optimum dispatch of generation or profiling of electricity demand
Electricity usage more aligned in real time with low carbon-sourced electricity production	Flexible sources of demand can play a key role in enabling the maximum utilisation of low carbon/ low marginal cost generation and minimising the need for new network capacity and low carbon-merit peaking generation	There must be adequate incentives and market accessibility for all classes of consumer to participate in demand side management and response and be rewarded appropriately

Principal Power System Challenges - in supporting the vision

Topic	Characteristic	Key Message
A power system able to maintain frequency stability despite lower levels of system inertia and increased risk arising from loss of generation events	A system supplied by smaller non-synchronous generators will be more susceptible to disturbances and frequency variations – and to single losses of large (~1.8GW) nuclear sets	Need to enlist alternative sources of frequency response (including storage and demand-side technologies) and maximise ride-through capability of distributed generation protection systems
An electricity distribution system able to accommodate low carbon heat and transport technologies	Large potentially peak-incrementing loads placed on networks designed on minimalist principles with little thermal capacity or voltage bandwidth headroom for step-changes in power flows	Smart gird technologies and smart market mechanisms must be developed to ensure that network load factors are maximised, voltage levels optimised, and latent network capacity fully utilised
An electricity distribution system able to accommodate high levels of micro-generation	Two-way power flows on networks designed for single-way power flows leading to voltage rise issues under light load conditions	Essential to develop smart gird technologies to ensure that network voltage levels can be adequately controlled, along with commercial incentives to encourage natural synergies between point-of-use electricity production and usage
An electricity distribution system able to accommodate high levels of distributed generation	Fault levels exceeding switchgear and/or cable short-time ratings (also make/break ratings for switchgear/circuit breakers)	Need to achieve optimum balance between deployment of smart grid technologies (including fault current limiters and protection systems) and power electronics-based generation decoupling technologies
Electricity storage and flexible 'dispatchable' demand playing a key role in balancing the system and maintaining stability	Traditional sources of balancing and reserve will be inadequate and/or too costly given the increased demand for ancillary services to address intermittency and low system inertia	Rapid-acting Demand Side Response (DSR) (e.g. from industrial and commercial enterprises) can, when deployed as an aggregated portfolio, provide economic sources of reserve near to real time and short notice. Electricity storage can additionally provide effective frequency response
A power system which is able to optimise voltage levels and power flows in real-time and minimise network constraints	Traditional passive network monitoring and control techniques are unable to fully utilise available network capacity	Need for actively managed networks which deploy real-time ratings, state estimation, and voltage and power flow routing optimisation techniques, to maximise capacity headroom
Distribution network protection and control systems designed to minimise loss of network availability in the event of faults	Traditional network protection schemes have only limited scope for discrimination and co-ordination	Higher dependence of low carbon technologies (demand and generation) on electricity capacity and availability leads to a need for more selective isolation and/or automated restoration techniques
A power system designed to optimum levels of redundancy and design security	Levels of design security should be determined through assessment of probability and economic consequences of loss of supply rather than by deterministic standards	Need to review and update current Security & Quality of Supply Standard (SQSS) and Engineering Recommendation (ER) P2/6 security standards – also recognising potential contributions to security from distributed energy resources and DSR
Electricity networks operating at high utilisation and load factors as a consequence of active network management	Real-time thermal ratings and load sharing technologies will lead to networks having less redundancy and hence reduced capability to support outages	Need for careful analysis and planning to understand the risks of reduced outage windows for maintenance and reconstruction
A 'whole-system' management and control philosophy designed to fully integrate transmission and distribution operation	Transmission & Distribution (T&D) networks currently independently designed and operated with only cursory consideration of boundary issues	Need for integrated planning and design, and co-ordinated operation, such that capacity, fault level, protection, voltage and reactive power management, and ancillary support optimisation opportunities are fully exploited

Existing ESI/Institutional Strengths – things we can readily leverage to help achieve the vision

Topic	Characteristic	Key Message
IET PNJV	Industry specialist group with high level of understanding of both the political imperative and the technical challenges of electricity decarbonisation	IET PNJV able to comprehend the deep technical issues arising from decarbonisation of THE electricity sector and identify the most economic solutions / trade-offs – with established communication paths to policy makers
SGF and ENSG	Well informed body of cross-industry and stakeholder representatives able to bring diverse and relevant insights - and manage relevant focused task groups and/or work streams	SGF addressing relevant issues through evolving work stream structure under overall SGF governance and with established communication paths to Government through DECC and Ofgem (ENSG able to support through initiatives such as Cross-Networks project)
Innovation Incentive	Innovation Funding Incentive (IFI) and LCNF (Network Innovation Allowance (NIA) and Network Innovation Competitions (NIC) from 2015) provides for relevant consumer part-funded network innovation - relevance, quality and value-assured through governance and competition structure	Clear evidence of relevant research and experimentation addressing complex issues through both technological and commercial innovation – with well managed dissemination to enable wide-scale learning and rollout of successful solutions
Strong foundation of well-respected UK electricity sector academic institutions underpinned by Engineering & Physical Sciences Research Council (EPSRC) (Hubnet) UK Energy Research Centre (UKERC), Effective Radiated Power (ERP) and Energy Technologies Institute (ETI)	Source of many leading R&D papers (e.g. Conference International de Grand Réseaux Electriques (CIGRE)/ Congrès International des Réseaux Electriques de Distribution (CIRED) generally outperforming EU peers in both quantum and quality	Valuable R&D capability which can be both exploited to support the low carbon transition and developed to create an even more successful UK hub for innovation – leading to potential spin-offs for development of new exportable UK low carbon energy products and services

Current Weaknesses – things we need to address to de-risk achievement of the vision

Topic	Characteristic	Relevance
No established forum for ensuring energy related Government policy decisions adequately pre-informed by industry experts	Energy/carbon policy potentially insufficiently informed regarding implications for T&D costs and future system stability	Significant technical issues might be overlooked – such as system inertia (and hence dynamic and transient stability) which may have significant cost and/or reliability implications – potential risk to achievement of government ambition
Established 'conservative' UK Electricity Supply Industry (ESI) innovation culture - lack of central laboratories and major manufacturers with specialist engineering departments	Geared more towards incremental rather than radical innovation precluding breakaway from status quo and a potential barrier to product development by vendors	Risk of stifled innovation, delayed smart grid progress, and loss of potential competitive advantage over peer nations in terms of developable products and services
Fragmented industry structure (1)	T&D (more accurately 'system' and 'distribution') historically regarded as separate (inseparable?) entities notwithstanding some evolution of boundary over the years	New paradigm suggests wider requirement for system balancing at distribution level exploiting Distribution Energy Resources (DERs) and flexible demand – hence need to decide future responsibilities and accountabilities between parties and establish, and then embed, the principle of 'system architect'
Fragmented industry structure (2)	Established Supplier Hub with responsibility for consumer interface with respect to energy contracts/tariffs	Difficult for DNO/Distribution System Operator (DSO) to access DSR as an economic alternative to investment in capacity to address network constraints
Fragmented industry structure (3)	Lack of end-to-end visibility through the whole system with disparate players having either insufficient incentive or lack of awareness of need to share information across commercial and regulatory boundaries	End-to-end system visibility is key to optimising both planning timescale and real-time decisions to ensure the most economic and stable way of operating the whole system
UK tendency towards isolationism	Industry not as well linked-in to EU as mainland EU network companies (partly as a consequence of a largely independent interconnected transmission system?)	Limits UKs learning and influencing opportunities within EU – for example EU codes / directives which will ultimately dictate UK obligations and standards
Electricity network-network (T&D), network-market and market-market interdependencies not well considered, understood or reflected	■ T&D network largely independently developed and regulated (notwithstanding joint planning liaison); ■ Cost drivers for networks not reflected in electricity tariff prices; ■ Wholesale, retail, balancing, ancillary services markets operate with little evidence of management of conflicts or synergies	Whole system perspective not fully reflected in regulatory incentives, pricing mechanisms, or future market development strategies (e.g. future capacity market?) leading potentially to: ■ lack of co-ordination; ■ under-exploitation of synergies; ■ suboptimal network investment; ■ suboptimal market structures

Opportunities – things we can use or address to help achieve the vision

Topic	Characteristic	Relevance
Accommodating load growth (economic and/or as a result of heat and transport electrification) by managing load factor and creating flexible demand	Managing/incentivising electricity usage with respect to time of day/year and real-time availability of low cost / low carbon electricity production	Manipulating demand shape could maximise latent capacity of T&D networks (and hence minimise need for new capacity); establish a higher economic threshold for inflexible low carbon base-load generation; and, in future, minimise risk of renewable production curtailment (all reflected in lower prices / spot-price volatility)
Voltage optimisation	Current Electricity, Safety, Quality and Continuity (ESQC) statutory voltage variation limits more onerous than necessary to meet appliance compatibility limits	Wider limits would: ■ avoid unnecessary network capacity or active network management investment (especially with low carbon technology growth); ■ potentially reduce network losses; ■ allow lower overall cost of transition... all whilst having no adverse impact on quality of supply
Energy storage	Potential aid to system balancing Short Term Operating Reserve (STOR) and stability (frequency response but development is slow – still at R&D stage	Limited natural UK hydro resource and interconnector capacity enhances the value of storage – especially with a strong future dependency on intermittent renewables
Energy vector arbitrage	Optimising arbitrage between alternative energy vectors according to price/availability will help optimise the whole energy system	Arbitrage Increasingly valuable given a future high dependency on intermittent renewables - and potential future opportunities from Combined Heat & Power (CHP) and heat networks
Job creation opportunities and development of exportable expertise to further underpin economic growth	Efficient investment in the 'right' infrastructure (T&D but complementary infrastructure such as telecoms)	Supports the business case, creates public sign-on and ensures we embark on the right track to our 2030 vision
Ofgem Integrated Transmission Planning & Regulation (ITPR) and ENSG Cross Electricity Networks Project	Seeking to exploit potential synergies arising from integrated offshore transmission, onshore transmission, and onshore distribution network development	More efficient overall whole system
Smart metering rollout programme	Provides a potential catalyst for consumer engagement and product development – which may include work done by new market entrants	A foundation of Informed and interested consumers is a major enabler of low carbon transition
Extoling consumer benefits	Consumers stand to benefit from a 'joint vision' through lower (than otherwise) electricity prices; energy security; lower atmospheric carbon emissions; a stronger UK economy; faster development of (and more choice between) tariff products and smart appliances	Articulating well the way in which consumers will benefit will greatly facilitate sign-on and acceptance of policy – and may even generate technology and product development 'pull'.
Potential future cross-time zone energy trading	Solar PV electricity production not always well aligned to demand locally but excesses from abroad potentially exploitable by UK with the right level of future interconnector capacity and appropriate market framework	Potential security and economic benefits in the longer term
Raising energy's profile on the wider political agenda	A clear 2030 vision would help ensure consistency of messaging by a wider body of politicians to a wider audience	Further awareness and understanding by consumers and the general public will help create the right framework for innovation in smart appliances and Demand Side Response (DSR)/ Demand Side Management (DSM) tariff/contract products

Threats – things that could derail the pursuit of the vision

Topic	Characteristic	Key Message
Variability and unpredictability of renewables (wind and solar) will lead to new power supply challenges	Inter and intraday variations and ramp rates in wind generation and solar PV output due to weather variations will lead to difficulties in controlling system frequency and optimising generation dispatch	The challenge of economically controlling a system supplied by high volumes of intermittents is not yet quantified – important to understand the potential role of storage and DSR in managing both predicted and unpredicted variations in output
True cost of electrification of heat and transport yet to be discovered	Levels of socialised incentives necessary to achieve targets for EVs and heat pumps may be unacceptable	Low carbon transition must be delivered within a politically tolerable budget
Need to articulate risk of failure to meet carbon commitments and/or address energy security and/or achieve economic transition if a whole system analysis of the 2030 journey is ignored	Undesirable (dangerous?) economic, environmental and social; consequences	Whole system approach understanding interdependencies and synergies is essential
Many possible future energy scenarios and routes to decarbonisation involving largely independent energy systems	Involves cross-energy vectors (gas, electricity, heat) and potentially disruptive breakthroughs (e.g. fuel cells and/or hydrogen infrastructure) which could undermine confidence in strategy and/or create future U-turns	Need to consider whole energy system and develop positions on heat networks, process industries (e.g. steel) and transport (EVs or hydrogen?) – requires a manageable number of credible scenarios
Inadequate risk management	The journey to 2030 has many possible paths and will undoubtedly throw up a few surprises en-route; this calls for a continuous risk review framework to identify emerging disruptive influences	Risk management framework would help identify future emerging SWOTs and potential mitigation/ exploitation opportunities and hence de-risk the journey
Unexpected interactions between technologies and/or market mechanisms	New technologies and/or market mechanisms introduced without full appreciation of all possible modes of interaction might lead to destabilisation of the market or indeed the grid	Thorough modelling and end-to-end testing must be undertaken to ensure, as far as practicable, that any potential unintended consequences are identified and adequately mitigated before mass rollout
Current lack of exploitation of ICT to de-risk the economic and secure development of the smart grid	Few engineers able to bridge the gap between Power, ICT and Cyber Security	Need to recognise as a potentially significant future industry skill gap to be addressed both by curriculum changes and post-graduate training and development priorities
Smart metering has been designed with smart grid as an afterthought	Useful network information capability which will help focus future D investment and provide valuable experience with Wide Area Network (WAN) and Home Area Network (HAN) telecoms - but Data Communications Company (DCC) model precludes true integration and exploitation of communications systems synergies	Missed opportunities for real-time information to support active network management and/or potential need for duplicated communications infrastructure
The communication challenge – how to articulate the issues in a way that is understandable to non-engineers without losing or over-simplifying the message to the extent that its relevance is underestimated leading to inappropriate complacency	T&D is a more highly complex technical subject than most non-engineers can ever begin to imagine - not least because it appears to the layman to be very reliable and therefore (presumably) easily managed	IET PNJV may need to enlist expertise exploiting meaningful analogies for the informed layman - alongside well written technically articulate papers for industry professionals (both engineers and non-engineers)

Appendices to Part 2: Power System Investment Planning

Appendix 2A - Electricity Demand Change and Information Sharing

Background

The transmission system planning process in GB requires accurate (or at least adequate) demand projections which include real power (P) and reactive power (Q) at each Grid Supply Point (GSP) for each extreme network condition (e.g. peak demand in winter and minimum demand in summer) along with an estimate of the profile or shape of that demand on typical days. This enables the analysis of the whole power system and the identification of technical issues that affect the secure, reliable and economic operation of the whole power system at those extreme times but also the overall performance of the system throughout the year.

The task of forecasting the peak, trough and typical profiles is being made more challenging with developments in economic growth, energy efficiency, changing commercial and industrial demand, embedded generation, and changing load equipment. As low carbon technology uptake (e.g. heat pumps, EVs) and the economic situation change, this problem is expected to grow in the coming years so new approaches to tackling this challenge are required.

In addition, the specific electrical characteristics of equipment connected to the power system are undergoing a period of more rapid change as consumer appliances change in nature (e.g. lighting, consumer electronics, television (TV) types) and as the proliferation of new electrical technologies continues (e.g. the power electronics associated with electrical drives and small scale generation).

This appendix addresses the issue of the general change in aggregate demand characteristics as observed at GSPs and the changes already occurring there and expected to continue to change in coming years.

Explanation of the Problem

The key issue for transmission network planning is the net demand change at grid supply points as a result of general demand changes and the growth of distributed generation (i.e. smaller scale generation connected to the distribution networks) and the inadequacy of existing processes for collecting and sharing data.

Transmission planners in the NETSO expect peak demand not to grow substantially in the coming years as a result of efficiency measures and the economic situation but do expect distributed generation to grow and so change the peak, trough and profile demand to be met through grid supply points. To illustrate this effect, the minimum demand for the whole of GB recorded by National Grid (NG) in summer 2013 was 19.1GW, the lowest since 2007. The minimum reactive power demand also dropped to a record -3GVAr (i.e. injection from distribution networks into the transmission network) and this presents a challenging operational problem for the NETSO as well as a headache for transmission network planners in estimating what to expect in future years.

Embedded and distributed generation exacerbates this problem with the expected growth set to alter substantially the power flows through grid supply points. The NG working group on embedded generation is attempting to address this issue along with several other challenges relating to embedded generation.

The ‘week-24 returns’[1] from DNOs to the NETSO should provide visibility of the demand evolution and embedded generation growth issues. However, the credible sources of data on future demand and generation changes in distribution networks are few and the process of collating the available sources time consuming. As a result the accuracy of GSP net P and Q demand projections is questionable.

Some of the required data exists but is currently confidential to different network stakeholders so the balance between commercial sensitivity for connected customers and need for transparency for whole system ‘optimal’ planning is important. For example, when more than one generation developer enquires about connection to the power network in the same area then commercial confidentiality prevents some information being exchanged between parties that would provide a useful backdrop to coordinated and efficient network planning. The balance at present seems to be towards maintaining commercial confidence with relatively little useful data available in the public domain to aid effective network planning (or research in this area). Finding a workable solution to this problem would require a balance between transparency and confidentiality through providing some safeguards to data providers about access to, and uses of, the data.

Consequences of Doing Nothing
The consequences of doing nothing about the poor visibility of future net active and reactive power demand at grid supply points include a degradation of the performance of network planning in terms of capital investment efficiency, impairment to the timeliness of network developments and operational problems as a result of unanticipated network conditions.

Inadequate planning could be expected in the form of inadequate network capacity for future network operational states or inefficient-investment, for needs that never materialise. Inadequate planning would lead to a situation where a network architecture selected for one set of challenges cannot adequately, efficiently or reliably serve a different set of needs.

Resource inefficiency might also emerge since the 'week-24 process' is already very time intensive with the NETSO spending around 3 person-months to draw all the DNO supplied data together in a common format ready for use in transmission planning and an additional 10 person-months in total to analyse the generation and demand assumptions.

Commercial Implications
The commercial implications of doing nothing are inefficient or inappropriate use of capital expenditure budgets.

Further Work Required to Identify the Problem Better
Further work to explore this problem might involve detailed consultation with 'week-24 data' analysts in both the transmission and distribution companies and an assessment of the transmission network development plans based on the 'week-24 data' to identify the key uncertainties and possible implications.

Engineering versus Commercial Solutions
Some of the potential solutions to the problem of adequately projecting demand and generation (and from that the net demand at GSPs) include measures to involve additional stakeholders (such as enhanced sharing of information relating to generation and demand development by third parties such as private developers or civic planning authorities) in the data capture process and electronic data exchange from DNOs to the NETSO.

An alternative approach could include dealing with inadequate long term planning through more frequent deployment of corrective operational measures such as automation and active network management schemes to manage demand and generation within the available network capacity.

The role of smart meter data that will become available in GB in the coming years may play an important role in the data collection process for network planning and should be borne in mind in the chosen solutions to address this problem.

Further Work Required to Identify the Solutions Better
The cost implications of under-deployment or over-deployment of capital expenditure as a result of poor demand and generation forecasting could be assessed alongside a detailed cost analysis of operational measures to manage the situation of inaccurate planning and the costs of any enhanced data collection, analysis and management processes. This would provide a means of assessing the cost implications of inadequacies in the data capture and exchange processes.

Further Work Required on Preferred Solution
The solution preferred by industry stakeholders is a shared planning data repository that would be developed, maintained and used by distribution network and transmission network planners alike.

The power network planning data repository would need to be explored in further detail to specify and justify clearly the type of data required and the sources of that data. Demand data from metering in distribution networks, generation development data, Feed In Tariff (FIT) Register data, smart meter data, connected user data (e.g.

Distribution Generation (DG), Demand Response (DR), Independent Distribution Network Operators (IDNO), Offshore Transmission Owner (OFTO), etc.) key parameters (e.g. capacity, location, etc.), system operational data (Elexon) and other sources would need to be assessed. The data access and privacy issues involved in some of this data would need to be navigated carefully and the case for the capture and use of this data put forward to relevant stakeholders.

The resource implications of building and managing such a data repository would need to be evaluated. Open access to data would provide the opportunity for enhanced investigation and analysis by independent third parties such as academic researchers.

Commercial Benefits and Opportunities

The potential efficiencies introduced into the 'week-24 process' and the commercial, if not financial, benefits of better planning would be the expected benefits of pursuing the proposed solution.

Conclusions and Recommendations

The recommendation is to explore then pursue the development of a shared planning data repository to provide a focus for the collection, checking, processing, sharing and using of core planning data. The network companies could jointly develop a detailed proposal for the repository. The issues associated with regulator or government approval could be discussed in relevant industry forums in parallel. The issues of use of commercially sensitive or confidential data to enhance power network planning would also need careful consideration with a range of stakeholders as would the credentials of the organisation to administer the data repository.

In addition, serious thought should be given to an alternative 'week-24 process' (including automated process of submission[2]) – likely to be supported by DNOs, TNOs and NETSO.

In addition, work to characterise new demand types and profiles could provide network planners with a valuable resource for planning studies.

References for Appendix 2A

[1] This is documented formally in the Grid Code: Schedules 9 to 11

[2] This could be comparable to electricity market trading data submission which is fully automated.

Appendix 2B - Active Distribution Networks

Background

Distribution networks have been progressively becoming more active in the last decade with developments of low carbon generation and demand technology and customers that are starting to become more active in their management of energy. DNOs have responded by deploying more advanced automation and control; the combined effect is that the distribution networks have become more active in themselves, while the management of the networks has also started to become more active.

Active Network Management (ANM) has prospective benefits and needs to be considered as a real alternative to more conventional reinforcement options in network planning. The costs and benefits of ANM are very different to the cost-benefit characteristics of more conventional network planning alternatives, because the longevity of ANM solutions is likely to be quite different. In addition, the modelling and analysis of active networks and ANM solutions is at an early stage as is the understanding of the commercial implications of ANM. An important issue is the need for analysis of multiple post-fault conditions in current network planning approaches and the additional complexity of many more network conditions to be considered in active networks.

If DNOs plan to deploy ANM to manage resources embedded in the distribution network then this will alter the characteristics of net demand observed at GSPs. Responsibilities and authority at both planning and operational stages needs to be carefully considered by TNOs and DNOs.

Explanation of the Problem

The transition to active distribution networks presents many possibilities for network users in connection, operation and service provision within distribution networks. Active network users may necessitate an ANM paradigm and both active distribution networks and active network users would present challenges to network planners.

Distribution planners need to develop processes and tools to facilitate active networks and to enable the deployment of ANM as a toolset to manage active networks. Addressing the challenges of active networks through ANM has already been proved to provide benefits to network users[1]. However, it is clear that power network planners are nervous about the perceived complexity and risk associated with ANM. More autonomy in network controls presents challenges to the distribution network planner in assessing the suitability of ANM as a solution to network planning challenges.

Evaluating ANM solutions alongside conventional planning options is currently a challenge. ANM schemes can act as an alternative to network reinforcement so identifying the triggers for investment after ANM has been deployed is an issue for distribution network planners. Conducting network analysis to address the specific issues related to demand side, energy storage and generation presents new challenges for distribution network planners.

Transmission network planners already specify scheduling, constraint, inter-trip, automation and other active controls and accept them as a means of resolving difficult network challenges in a cost-effective and risk-managed manner.

The visibility and control of active distribution is a new concern for transmission network planners as this presents a real uncertainty over the state of the transmission-distribution interface. It is easy to imagine concerns over how the active networks will be controlled and what effect this will have on the transmission network and how they would maintain system security while presenting an operable system to their operational colleagues. The interface and coordination issues between transmission and active distribution networks could be challenging even with the small number of active controls. The optimisation of voltage control and flow controls might require a higher volume of planning analysis studies and greater complexity of those studies.

Rate of Change of Frequency (ROCOF) protection relays are a good example of an active control scheme embedded deeply in distribution networks where the operation of the relays in response to system wide events has major system implications[2]. Coordination of active controls to underpin, or at least to not undermine, system security is a real issue.

The active control of generation or other responsive units would have a bearing on the Balancing Mechanism (BM) and use of the BM to operate the system within limits in an economic way. Only BM units participate in active management at the transmission network level now but in future with more responsive demand and small scale generation this approach needs to change. Management of system wide effects of multiple distribution network ANM schemes is an important future task (normally DNO manages but under what circumstances would NETSO use ANM to control small generators that do not fall under the Grid Code?).

The application of new preventive and corrective controls to manage a more dynamic system without unduly altering security of supply is a serious challenge. Coordinating the interaction of new controls is an essential task. An example of such coordination is low-frequency demand disconnection relays that have to be coordinated on a GB scale. These are designed to operate when the system finds itself in a condition beyond the planning standards, i.e. as protection under extreme and rare conditions. However, there is no reason why "normal" frequency response cannot be provided in a similar way (e.g. by discharging electric cars for a few seconds, or disconnecting certain classes of demand in a controlled manner, etc.).

Consequences of Doing Nothing

The consequences of not responding adequately to the issue of active distribution networks include not exploiting the advantages of ANM as an efficient solution, not fully understanding the technical implications of operating active networks and so planning ineffectively with the resulting risk of operational problems, and unduly restricting the development of active networks and the advantages for users of distribution networks.

Commercial Implications

The transition to active distribution networks with the accompanying decentralisation of control of active demand, generation and energy storage has implications for the commercial arrangements that would govern the freedom given to active components or otherwise the obligations or restrictions on their operation.

Some work on new commercial arrangements and the transmission-distribution interface is emerging through LCNF projects (e.g. Scottish Power 'Accelerating Renewable Connections' project and the UK Power Networks (UKPN) 'Flexible Plug and Play Project'). However, the need for cross-industry development and agreement of the commercial arrangements to govern the development and operation of active distribution networks will likely require the findings from those projects to be taken further.

Further Work Required to Identify the Problem Better

Additional work to better understand the problems with active distribution networks could include:

- Studies to explore the extent to which active controls be relied upon by network operators (e.g. reliability levels similar to protection);
- Studies to gain confidence in active controls in distribution networks to secure demand and generation connections.

Further exploration of the commercial arrangements and business models that underpin active networks (e.g. network access for users under active network management approaches, financial terms for services provided to support network operation, terms for service provision across the transmission-distribution boundary).

Engineering versus Commercial Solutions

The development and operation of active distribution networks is an area that requires serious engineering and commercial solution development and deployment. The implementation of active distribution networks clearly requires new enabling primary power and secondary control infrastructure architectures but experience to date in GB has shown the central role of the commercial arrangements rather than engineering solutions.

Further Work Required to Identify the Solutions Better

The Smart Grid Forum Work Stream7 (SGF-WS7) have already embarked on an action plan to assess the issues with operating active distribution networks and, while network operations are the focus, it is expected that this work will shed light on important distribution network planning issues and that this should feed into further thinking about distribution, transmission and coordinated transmission and distribution network planning for active networks.

Specific further work should focus on the key areas of assessing the likely scale, scope and uncertainties associated with active networks, modelling active networks, consistency in the treatment of ANM schemes in planning studies, planning triggers for reinforcement post ANM deployment, and GSP flow changes with active distribution networks.

Further Work Required on Preferred Solution

It is clear that active distribution networks[3] are being seriously considered to address system development challenges so the preferred approach from industry stakeholders is to continue to fully explore the engineering and commercial challenges and coordinate the effort and the findings into, for example, good practice guides, new processes and standards.

Further work is required to develop the engineering and commercial solutions to active distribution network challenges and to coordinate this across DNOs as well as coordinate with transmission network companies and the NETSO. Wider industry stakeholders including the users of networks will play an important role in that further developmental and standardisation effort.

Commercial Benefits and Opportunities

The major opportunity associated with active distribution networks is the potential enhanced benefit for network users (e.g. enhanced network access, higher performance and utilisation from distribution networks, better service from the network) so as long as the NETSO can have confidence in or oversight over ANM then there is no reason why it cannot be agreed with DNOs that ANM will be used to defer reinforcement.

Conclusions and Recommendations

It is clear that further analysis is required to assess the current and future impact of active distribution networks on the flows and characteristics at GSPs. The extremes and variability of these flows has important repercussions for both transmission and distribution network planning. The main conclusion is that work should be scoped and commissioned to develop the planning tools, processes, standards and models to underpin full consideration of active networks and active network management in the transmission and distribution network planning task.

In addition, there are considerable interface issues between DNOs and the NETSO in relation to the visibility and controllability of active network components across the transmission-distribution interface and these should be explored and resolved with some urgency to prevent unnecessary restriction of the development of active distribution networks. More generally there is a need to develop a collaborative approach between transmission and distribution network planners on active network issues. This has started through innovation projects[4] but can move forward further with additional effort.

References for Appendix 2B

1. Details of ANM and the many other live and recent low carbon innovation projects can be found at the Energy Networks Association 'Smarter Networks Portal': http://www.smarternetworks.org/Index.aspx?Site=ed
2. The 27th May 2008 system event highlighted such issues. The National Grid report into that event can be found at: http://www.nationalgrid.com/NR/rdonlyres/E19B4740-C056-4795-A567-91725ECF799B/32165/PublicFrequencyDeviationReport.pdf
3. The Business Plans submitted by DNOs in July 2013 under the RIIO-ED1 price control show the expected measures to address active distribution networks and this has been informed by the activities of SGF work stream 3. The RIIO-ED1 business plans can be found at: https://www.ofgem.gov.uk/network-regulation-%E2%80%93-riio-model/riio-ed1-price-control
4. The ScottishPower Energy Networks 'Accelerating Renewable Connections is a good example of a major trial project addressing the transmission/distribution coordination issues: http://www.spenergynetworks.co.uk/innovation/accelerating_renewable_connections.asp?NavID=3&SubNavID=2

Appendix 2C – Network Planning Tools

Background

The new context and set of challenges for power network planning have been articulated by the IET PNJV. The network planning task is likely to present a number of new analytical challenges as new data sources are accessed and utilised, as new planning options are considered and as greater uncertainties and commercial necessities are encountered. In particular there are real challenges to analysing whole system effects at the network planning stage. In many cases the planning uncertainties are rising (e.g. low carbon technology characteristics, location, scale) along with the operational implications (e.g. variable output from low carbon technologies, the effect of active controls such as demand response and active network management). Network planners require analytical techniques and tools to support their network planning task as demands, generation and network solutions become increasingly probabilistic in nature.

Explanation of the Problem

Network planning in a world with a fundamentally higher level of uncertainty is a serious challenge. The network planning task requires a look into the future and the distillation of the uncertainties found to underpin rational decisions about network developments. Uncertainty creates an underlying trend that moves away from today's largely deterministic world, to that having a stochastic nature. In periods of more rapid change it is the current experience that the planning task is becoming more difficult and it is anticipated that this trend will continue. New techniques and tools are required to utilise new sources of data and undertake the analytical task in different ways. However, the industry must be realistic about the level of sophistication of data and tools that could be either developed or assimilated and put to use to plan for a more uncertain future. Perhaps different, more flexible planning options will be preferred as responses to the uncertainties faced.

One challenge is the aggregation of the effects of high volumes of new distribution connected equipment for investment planning in the higher voltage level networks. For example, the combined effect of micro-generation and EVs needs to be understood to plan effectively the transmission network. This is an example of the need to embrace new generation and load technology and project (with uncertainties fully transparent) the combined effect on net demand as well as altered profiles for demand. It is expected that statistical and probabilistic techniques will be required to address problems such as these.

The electrical characteristics of new generation and load technology must also be built into new network planning tools. The flexibility that these new technologies have in responding to network and system events is a key issue. Taking the electric vehicle example, not only does the demand volume, shape and location need to be considered but the effect of power electronic chargers and their ability to contribute to system operation must be explored and built into planning assumptions and models.

Active distribution networks are an emerging new area of network control but they are also a planning option for network operators. The tools and models to assess ANM solutions and appropriately select and deploy them present requirements for new analysis techniques and tools. There are many other examples of the emerging challenges for network planning in the area of techniques, tools and models. There are issues to address in the source of new planning tools as well as on the capabilities of the tools themselves.

Consequences of Doing Nothing

The consequences of not developing the tools required to support network planners in the more challenging task they need to undertake will be unduly restrictive and conservative approaches to planning that will not serve well the needs of network users or society. The development of the low carbon energy system will be inhibited through conservative planning or else risks may be taken inappropriately and without good understanding through analysis.

In the more complex planning tasks the time taken to conduct analysis with inadequate or outdated tools may result in a loss of productivity by valuable but scarce network planners.

Without planning tools capable of assessing new technological options then the uptake of beneficial low carbon, smart or economic solutions to network development problems may be delayed or opportunities missed altogether.

Commercial Implications
Without appropriate planning tools to support the commercial decisions required in network planning then the most effective and efficient options will not be adopted with potential implications for network companies within their regulatory settlement. Incentive and output targets might be missed with accompanying financial implications.

There are commercial implications for the producers of analytical tools as well since the development effort in generating new analytical tools is significant and the payback potentially unclear and uncertain. Some collective direction from the sector on the tools required would provide greater clarity for analytical tool developers. Potential for joint development and Intellectual Property Rights (IPR) sharing might also be explored. The Smart Grid Forum Work Stream 3 (SGF-WS3) sponsored development of the Transform Model[1] is a notable recent example of a collective effort in setting the requirements for a new analytical tool and sponsoring the subsequent development.

Further Work Required to Identify the Problem Better
The work required in this area includes:

- Collating published studies of new generation and load technology electrical characteristics;
- Reviewing recent work on new analytical techniques for power system analysis that address the identified emerging challenges;
- Establish a vehicle for power network planners to engage with analytical tool vendors and other contributors (e.g. academia) to jointly develop requirements and specifications for new tools and techniques in network planning

Engineering versus Commercial Solutions
Engineering specifications for new network planning tools are required and commercial vehicles for contributors to address the requirements and bring forward tools and techniques play equally important roles in encouraging the development of the required network planning tools.

Further Work Required to Identify the Solutions Better
The challenges in techniques, tools and models can be addressed by scoping the problem effectively (through jointly agreed requirements and specifications) and the subsequent contributing activities to address those challenges would need to be coordinated to derive timely and well-formed contributions for network planning practitioners to use.

Further Work Required on Preferred Solution
The development of new models and the processes for cooperative model development and approval is an essential area of investigation for the electricity industry. Models for new low carbon technologies, models of controls and converters, models for active networks (as described in the previous section) and models of new responsive demand are among those that need to be explored.

Analytical tools need to manage new and large data sources and provide ranges of results to reflect the variable operating conditions and the inherent uncertainties in the future power system.

Tools that have the capability to assess system security and performance under the new conditions could play a major role in identifying the best power network development plans. This would have to include representations of the new types of controls for generation, demand and the network itself as preventive and corrective controls will likely become more sophisticated and complex across the networks and the connected components.

Future planning tools are likely to become more sophisticated and will rely on a broader range of data to develop network designs. Care must be taken to develop tools and design processes that maintain a practical balance between software complexity and the time and expertise required to apply it. In other words, a very complex, data-hungry tool will be of little practical use unless a design engineer with a reasonable amount of experience can apply it with relative ease to produce feasible network designs in reasonable time scales. Building on previous work by the IET and emerging state of the art from network company projects, academic research and the power system analysis vendor community, a collective effort to capture requirements and specify a set of next generation network planning tools is required.

Commercial Benefits and Opportunities

Developing collective requirements and specifications for network planning tools would underpin the focused development of the right techniques and tools to address the planning challenges. A range of benefits to network planning outcomes could be expected which would include planning effectiveness, timeliness and planner productivity when the scale of the task is trending upwards.

Conclusions and Recommendations

As a result of electricity demand technology and usage changes, the low carbon transition, the move towards active distribution networks and the additional information required to plan effectively in this new world, new tools and models are required also.

The development of models and the development of cooperative approaches within the power network companies and out to academics and suppliers are all seen as important requirements.

The work required to generate new analytical tools is substantial and new data and computational methods will be required. The task of developing the tools is not urgent at present so there is time to employ an innovative approach to securing the development, testing and commissioning of the required tools. In light of these issues the recommendation made here is that the requirements and specifications for new tools should be prepared and put into public domain for researchers and technology developers to work against. An industry steering group with specific goals and governance methods would lead and oversee the development of the required new analytical tools.

Reference for Appendix 2C

[1] http://www.eatechnology.com/key-projects/transform

Appendices to Part 3: Operating the Power Network

Appendix 3A - Will an Increase in ICT and Embedded Intelligence cause a Decrease in Resilience of the Transmission and Distribution Network?

Introduction
Increased use of Information and Communication Technology (ICT) in electrical power systems is seen as a way to improve asset utilisation, allow more connection of renewable generation and provide consumers with a cost effective and reliable service. However, there is concern that complexity, arising from the increased use of embedded intelligence, ICT and control systems, will make power networks less predictable and less manageable. There is uncertainty around how embedded controllers and ICT will interact in all situations.

Transmission and distribution networks are surrounded by control systems which rely on ICT, whose purpose is to acquire, store, process and distribute information by electronic means across the power network. System operators can cope more effectively with a potential risk when the real-time decision-making is supported by advanced security applications, monitoring and visualisation means. Moreover, advanced automatic schemes enable the reliable operation of power systems and contribute to the prevention, or to the mitigation of the impact, of large power system blackouts.

However, questions have been raised about the negative impact that this increasing reliance on ICT and embedded intelligence might have on the resilience of the transmission and distribution network. Major incidents, both in the transmission and distribution network, have reported malfunctions or inadequacies in the control and ICT systems. A failure in these systems can have a catastrophic impact on power system reliability, as it can affect operators' situation awareness and the reliable implementation of both manual and automatic actions and can ultimately lead to blackouts. There are also concerns about the impact that hacking or cyber-attacks might have on the continuity of the electricity supply. Higher voltage systems are more actively managed and hence there is more scope for ICT and embedded intelligence to cause problems. Several blackouts in the last decade demonstrated that the growing application of complex control systems and ICT increases the exposure of the entire infrastructure to information failures. It is therefore important to understand the mechanisms through which failures and inadequacies in the control systems and ICT infrastructure of a power network may jeopardise the system resilience.

Factors Causing a Decrease in Resilience of the Power System

ICT Failure
The implementation of the modern ICT-based monitoring and control functions in the power network relies on chains of hardware and software components and systems and some level of human intervention. The failure of any element of such a chain makes the function fail and reduces system reliability.

- The North America blackout of August 2003 demonstrated the impact of deterioration *in the state of ICT systems on operators' situation awareness and performance*. Even though the initiating event was an electrical outage, multiple ICT failures resulted in inadequate situation awareness, leading to delayed reactions from the operators. This contributed to the development of the blackout[1].

  Based on the North American Electric Reliability Council (NERC) investigation[1], there were significant reactive power supply problems in the states of Indiana and Ohio. At the same time, the Midwest Independent System Operator (MISO) state estimator (SE) and real time contingency analysis (RTCA) software were not functioning properly due to software problems. This prevented the MISO from performing proper assessments of the system as the events were unfolding. At the FirstEnergy (FE) control centre, a number of

computer software failures occurred on their Energy Management System (EMS) software. This prevented FE from having adequate knowledge of the events taking place on its own system. This contributed to inadequate situational awareness at FE and thus proper operational actions were not taken.
- The Irish disturbance of August 2005 demonstrated the *effect of ICT reliability on the reliable operation of automatic actions, such as System Integrity Protection Schemes (SIPS)*. In this case, the malfunction of an ICT component triggered the unnecessary operation of the system separation detection scheme, resulting in loss of supply to 326,000 customers in the Republic of Ireland and further 74,000 customers in Northern Ireland[2].

An increased reliance on ICT and embedded intelligence systems increases the exposure and vulnerability of the whole power network to information failures and limitations. So, the state of the ICT infrastructure and the level of operators' situation awareness must be taken into account in power systems reliability assessment, as they can significantly affect system reliability and its robustness to widespread disturbances.

Technical remedial measures to prevent or mitigate the impacts of such cascading blackouts include[3]:

- Increase the reliability of the electronic components of the system (sensors, relays and communication devices);
- Increase the reliability and robustness of the control centre base software and the application software;
- Improve operator and reliability coordinator training;
- Understanding interdependencies and cascading effects of ICT faults and scenarios;
- Evaluate reactive power and voltage control practices;
- Improve system protection to slow or limit the spread of future cascading outages;
- Implementing smarter wide-area protection in the form of schemes with a more adaptive nature to tackle operational and coordination complexities associated with SIPS;
- Clarify reliability coordinator and control area functions, responsibilities, capabilities and authorities;
- Establish guidelines for real-time operating tools;
- Evaluate lessons learned during system restoration;
- Install additional time-synchronized recording devices as needed;
- Re-evaluate system design, planning and operating criteria;
- Improve system modelling data and data exchange practices

The information infrastructure must not only be reliable, it must also be adequate for the operator to be able to assess the threats faced by the electrical system. As the degree of interdependence between control areas or between national transmission networks increases, the operator must gain access to information covering an ever-widening area, understand the state of the system and choose the best control actions.

Cyber-attack

The power system uses SCADA systems for monitoring, control, and operation. On top of the power infrastructure reside layers of control systems and ICT. The ICT and power infrastructures together constitute a large, complex cyber-physical system. ICT on power systems has evolved from isolated structures into a networked system, often based on Transmission Control Protocol/Internet Protocol (TCP/IP) and Ethernet.

Commonly used systems based on this technology have been shown to be vulnerable to cyber-attack. Some examples of disruptions of SCADA has been faced in other industries; a dissatisfied former employee of a chemical company was detected while trying to disable some controls of the plants; a gas processing plant from a US petroleum company was hacked by a plant's supplier sabotaging the plant, resulting in losses and 6 month of investigations.

A widely publicised cyber-attack on industrial control systems was the Stuxnet worm; a piece of malware that targeted SCADA systems. The objective was to corrupt a specific type of programmable logic controller (PLC) by rewriting parts of the code and turning it into the attacker's agent. Some media outlets suggested that Stuxnet's targets were nuclear plants. With modifications, it could become a serious threat to power systems.

Security weaknesses have been identified in existing infrastructure. For example, article[4] explains how a system was compromised wirelessly, within 5 minutes, due to the absence of password protection. The example involved attackers driving close to a substation and, using a laptop computer with a wireless Local Area Network (LAN) card, mapping every piece of equipment in the control network. Using software such as Aircrack-ng, an attacker can compromise an IEEE 802.11 network using Wired Equivalent Privacy (WEP) in as little as 15 minutes. After they get the wireless encryption key, they can use a free protocol analyser such as Wireshark to spy on the network. A number of vulnerabilities, such as unintended buffer overflows, have been demonstrated in large power and water infrastructure control systems[5].

- In June 2008, the Hatch nuclear plant in Georgia shut down for two days after an engineer loaded a software update for a business network that also rebooted the plant's power control system;
- In October 2006, the Harrisburg, Pennsylvania water filtration system was compromised and malware was planted;
- In August 2003, the "Slammer" worm infected the Davis Besse nuclear generation power plant in Ohio, causing a five-hour shutdown of computer systems.

A survey of utility companies in the USA revealed that the country's electric grid faces constant assault from hackers, with one power company reporting 10,000 attempted cyber-attacks per month[6].

- More than a dozen utilities reported "daily," "constant," or "frequent" attempted cyber-attacks ranging from phishing to malware infection to unfriendly probes;
- One utility reported that it was the target of approximately 10,000 attempted cyber-attacks each month;
- More than one public power provider reported being under a "constant state of attack from malware and entities seeking to gain access to internal systems";
- A North-eastern power provider said that it was "under constant cyber-attack from cyber criminals including malware and the general threat from the Internet";
- A Midwestern power provider said that it was subject to on-going malicious cyber and physical activity. There were probes on their network looking for vulnerabilities in their systems and applications on a daily basis. Much of this activity was automated and dynamic in nature - able to adapt to what was discovered during its probing process;
- In January 2013, two US electricity production facilities were infected by malware spread by USB drives plugged into critical systems used to control power equipment

In addition to the attacks targeting electricity production, transmission and distribution systems, vulnerabilities have been demonstrated in emerging smart metering systems. For example, a presentation at the 28th Chaos Communication Congress in December 2011 demonstrated the exploitation of commercially deployed smart metering equipment, facilitated by an improperly configured Hypertext Transfer Protocol (HTTPS) server[7]. In this case, the vulnerability allowed the attackers to modify and spoof data which the operator expected to be protected by Secure Socket Layer (SSL).

Procedures considered to protect and secure cyber assets in power networks are discussed in the Federal Energy Regulatory Commission (FERC) Security Standard proposal[8], they include:

- The use of effective password routines that requires periodic password changes, including the replacement of default passwords on newly installed equipment;
- Authorisation and periodic review of computer accounts and physical access rights;
- Disabling unauthorised (invalidated, expired) or unused computer accounts and physical access rights;
- Disabling unused network services and ports;
- Secure dial-up modem connections;
- Implementing Firewall software;
- Implementing intrusion detection processes;
- Enabling security patch management;
- Installation and update of anti-virus software checkers;
- Assuring that communication within a substation automation system and with external networks are secure and protected using encryption and / or message integrity protection;
- Protecting from risks associated with mobile devices such as service laptops or portable media such as USB sticks or CDs that are connected to computers within the control network (only allowing connecting such devices at dedicated points within a dedicated zone);
- Maintaining operator logs, application logs, and intrusion detection logs to check for system anomalies and evidence of suspected unauthorised activity

IEC 62351 Parts 1-7
The scope of the technical standard IEC 62351 series is information security for power system control operations. The primary objective is to undertake the development of standards for security of the communication protocols defined by IEC TC 57, specifically the IEC 60870-5 series, the IEC 60870-6 series, the IEC 61850 series, the IEC 61970 series, and the IEC 61968 series. Another objective is to undertake the development of standards and/or technical reports on end-to-end security issues.[9]

Complexity and Increased Asset Utilisation
Electric power systems have become complex and difficult to operate and protect, as they are composed of hundreds of thousands of components dispersed over a wide geographical area. This makes them subject to numerous sources of failure, which are difficult to accurately predict in the system design. *The complexity of the grid sometimes leads to cascading series of events, from an initial small problem leading to major regional outages; this risk increases as automated control is used to increase system transfers*. In addition, the power system is a highly nonlinear system that operates in a constantly changing environment; loads, generator outputs and key operating parameters change continually. The complexity and size of the ICT, embedded intelligence and control system infrastructure makes it difficult to constantly check if all the electronic components are fully functional. Besides hidden failures in the protection system, there is always some probability that there are software bugs in the large amounts of computer codes used to monitor and control power systems.

There are various challenges as a result of many factors, including the significant growth in demand, the high penetration of renewable energy sources, the use of increasingly interconnected networks and the integration of electricity markets. These factors impose additional stress on the transmission and distribution system, resulting in some lines and other electrical components frequently being operated at or close to their operational limits. *The grid is being operated at its operational limits in more locations and more often because of maximum asset utilisation driven by ICT and embedded intelligence for monitoring, analysing and control*. Hence, the resilience of the system is significantly reduced and might lead to loss of supply.

Control Interactions and Fragility
Implementing a complex electric power system will entail the deployment of control systems that manage grid inputs from both constant and intermittent sources and manage grid outputs to achieve efficiency and economy by intelligently interacting with end user devices. Given the multiple control interactions with which such a grid must cope, the power system becomes fragile and decreases the resiliency of the system. A*s smart grid technologies are added to the grid, especially control at the consumer level, not only will the interactions increase, but also the potential fragility.* These fragilities will impact grid control systems and ultimately the grid itself unless sufficient resilience is designed in.

A key design goal for resilience is a *high level of state awareness* that enables the transformation from reactive to proactive control of electricity production, transmission, and distribution systems.

Future Smart Grids
The electric power grid is evolving from a centrally controlled, vertically integrated grid to a liberalised open electricity market. All these changes and evolutions put extra stress on the power system and new control strategies are being proposed to maintain the desired level of availability. These control strategies are often based on new ICT technologies, such as *open networks (e.g. the Internet), wireless networking, small Intelligent Electronic Devices (IED), Smart Meters etc*. These technologies offer tremendous opportunities but also bring new weaknesses into the power system. Some of the threat scenarios which could endanger the operation of the future smart grid include[10,11,12]:

- During communication between different devices in a Smart Grid, *packets can get lost* or delayed on packet switched networks such as the Internet, due to routers dropping packets when their buffers are full or when packets are corrupted during transmission;
- It is very hard to determine the *reliability and availability of an open communication network* and its dependency on the power system. So, there is a possibility that such communication infrastructures (partially) fail the very moment the power system is in a critical state (e.g. partial blackout) and then the control systems using public networks will have to function in absence of these communications. Also, the heavy data flows caused by a system incident could directly cause the failure;

- Denial of Service (DoS) attacks on control systems by antagonists located on the same network or connected networks;
- Intrusions into centre-substation communication flow and execution of faked commands and data (spoofing attacks/man-in-the-middle attacks);
- Exploitation of standard application layer protocols' vulnerabilities;
- Accidental or malicious infection of substation networks by malware during maintenance;
- Intrusions and malware infections through ICT devices for the primary, secondary and tertiary voltage and frequency regulations of generation power plants

A number of key areas in cyber-security have been identified as an *initial set of research and development challenge* to build a secure, reliable and fully integrated Smart Grid[13]:

- Device level: to devise cost-effective, tamper-resistant architectures for smart meters and other components, which are necessary for systems-level survivability and resiliency and for improving intrusion detection in embedded systems;
- Cryptography and key management: to enable key management on a scale involving, potentially, tens of millions of credentials and keys as well as local cryptographic processing on the sensors such as encryption and authentication;
- Systems level: to design advanced protection architecture that can evolve and can tolerate failures, perhaps of a significant subset of constituents;
- Networking issues: to investigate ways to ensure that commercially available components, public networks like the Internet, or available enterprise systems can be implemented without jeopardizing security or reliability

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Appendix 3B - GB Electricity Network Operation - Information Flows - Now and Next

Figure 1 shows an information flow diagram for today's GB electricity network. It depicts the information that passes between the main actors during operation of the network. It is a macro level diagram, showing only the most important information flows and actors.

Control of the GB electricity network is centralised with the NETSO, presently National Grid Electricity Transmission plc. The NETSO has responsibility for ensuring that supply and demand remains balanced for the total GB system. It achieves this through the Balancing Mechanism – accepting bids and offers to change supply or demand as necessary and using emergency instructions when there are insufficient bids or offers. The NETSO also ensures that flows on transmission circuits, voltages and currents remain within limits and that the system is configured for adequate redundancy. When necessary, switches are operated remotely to reconfigure the network or to switch in reactive compensation.

The DNOs have responsibility for ensuring that distribution voltages and currents remain within limits and for continuity of supply. The DNOs do not have responsibility for maintaining balance between generation and demand (although they may have bilateral arrangements to modify demand or embedded generation for distribution network security purposes. They do have an obligation to: a) provide automatic emergency low frequency demand disconnection (60%* of the total demand in eight stages from 48.8Hz to 47.8Hz); and b) provide a means to manually reduce demand (in four stages at 5% per stage) on instruction from the NETSO[1]. No real time demand and generation information is currently provided by the DNO to the NETSO; the DNO's demand is inferred by the NETSO from Supergrid Transformer metering at the Grid Supply Points.

Automatic control systems in DNO networks include automatic tap changers on transformers at 33kV and above. Remote switching is typically installed on systems at 11kV and above. System reconfiguration is done remotely from centralised control rooms. Typically, this is done to isolate part of the network for maintenance.

DNOs do not interact with consumers for operational purposes, aside from reacting to customers reporting outages and in situations where bilateral arrangements are in place because of local network restrictions. However, generation or demand connected to the distribution network is required to install voltage, current and frequency based protection as a condition of connection. The generic "settings" used for this equipment can aggravate network problems. For instance, distributed generators are required to disconnect from the network when the system frequency suddenly changes (ROCOF protection) – this is intended to prevent islanding. However, ROCOF protection can also exacerbate system instability problems when a large amount of generation is lost (causing the frequency to suddenly drop). A review of ROCOF settings is on-going by the Distribution Code and Grid Code Review Panels (DCRP and GCRP).

Generally, demand does not participate in the balancing of supply. An exception to this is the demand (some at 2GW) contracted with the NETSO to provide short term operating reserve. This contributes to balancing the system for up to four hours at times of shortage of generation. Another exception is the regular demand shifting that takes place due to 'Economy 7' and 'Economy 10' schemes. In these schemes the BBC Radio 4 long wave transmitters are used to send switching signals to storage heaters. The schemes are supplier initiated with limited notification to the NETSO and no notification to DNOs. Additionally, 'Economy 7' and 'Economy 10' are not marketed as strongly as in the 1980s and the number of participating customers is declining.

*40% for DNOs in SPT and SHETL Transmission Areas

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

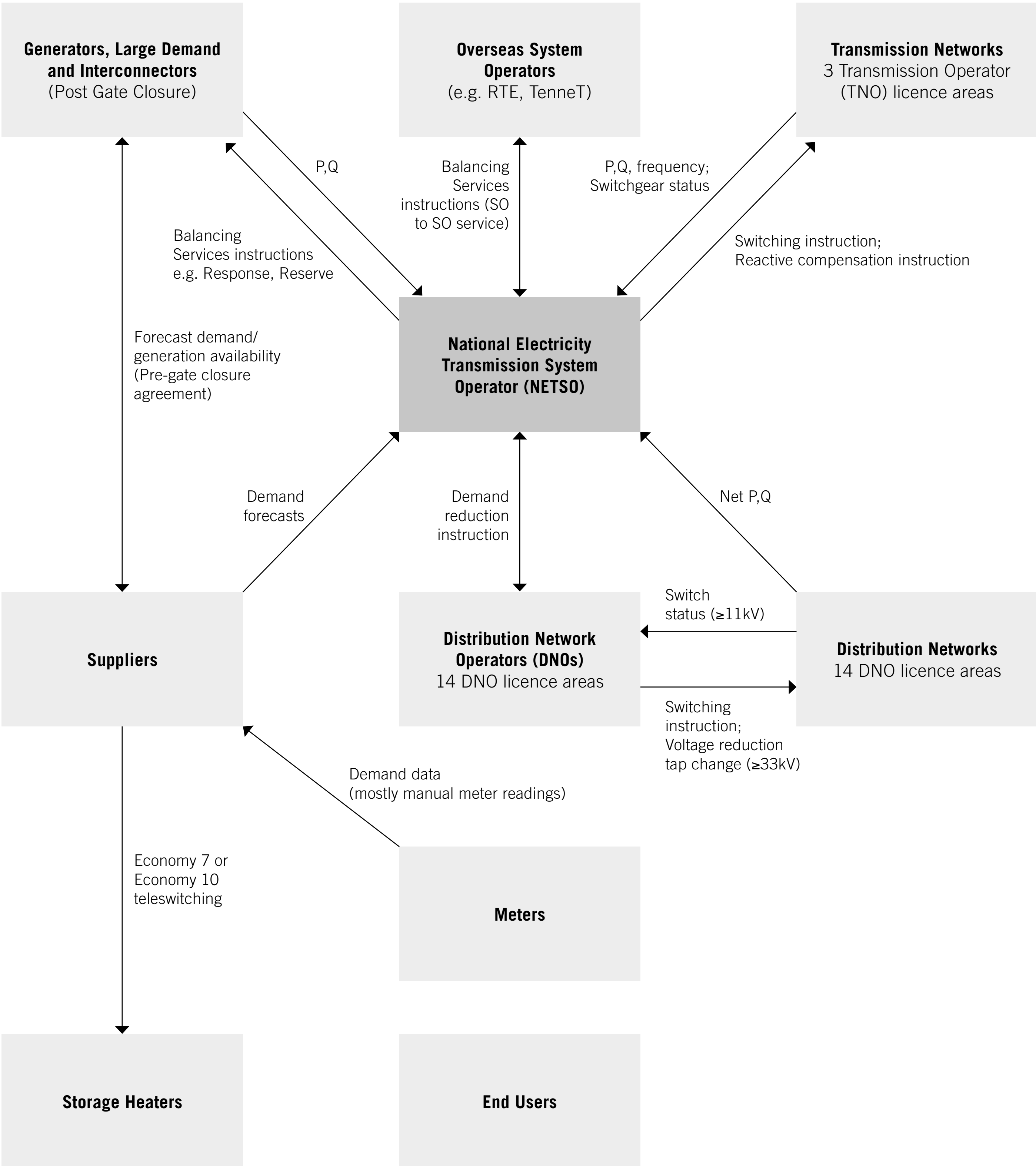

Figure 2 shows a way in which information flows could develop. A major change is the increased information from the demand side as a result of the forthcoming Smart Meter roll out, scheduled to be completed in 2020. This gives rise to new information flows from the customer to suppliers and DNOs. Smart meters also as act as a means of communication of demand response signals (via tariff information) from suppliers, aggregators or DNOs.

It is expected that the smart meter roll out will allow the demand side to more easily participate in system balancing. This is because smart meters will allow customers (or customer's appliances) to receive dynamic pricing signals. As a result, there is an aspiration that Smart Meters will allow customers to better understand their energy use and therefore modify their behaviour (or automate appliance usage) to take advantage of price signals. The evidence for this is open to doubt. Whilst some trials show a reduction in peak usage (e.g. the Irish smart meter trials, where peak usage was reduced by 8.8%[2]), there is concern that such effects will not persist.

Further information flows resulting from smart meters include acquisition of import and export values for those customers that have generators. This will allow the NETSO to become aware of the 'latent demand' – the demand that is hidden by generation in present reporting practices[3]. This data will not be available in real time. However, its use for correcting preceding demand records is feasible – this will improve the accuracy of future demand prediction.

A further potential use of smart meter data is for management of localised constraints on the distribution network. The state (voltages and voltage angles at all points) of the network can be estimated using the previous day's half hourly usage data, supplemented by relatively few real-time measurements within the distribution network[4]. Furthermore, smart meters will be equipped with over/under voltage alarms[5]. This data could be used by DNOs as a basis to understand local constraints and to perform control actions (or influence tariffs).

Communication with smart meters is described as 'regulated' or 'unregulated'. Regulated communication will be overseen by a new licensed body, the DCC and will be sent via the WAN. In contrast, unregulated communication will be sent via the customer's own communications connections and must therefore be separately agreed (and forwarded) by the customer. Which data will be sent via regulated communications, and which must be sent by unregulated communication, is yet to be confirmed. All communication will be routed via communications hubs provided for each premises. These coordinate the 'regulated' external communications (over the WAN) and the communication with the meters, appliances and displays within the premises (over the HAN).

A conflict could arise where different parties want to use demand response tariffs to move demand in opposite directions (e.g. wind generators wishing to encourage demand during high wind and DNOs wishing to limit it due to local constraints). The significance of this problem is not known. A Low Carbon London (LCL) LCNF project is looking at the issue[6].

Another example of the potential conflict over the use of demand response tariffs can be found after consideration of EVs. Four parties could have an interest in when, and at what rate, EVs are charged; the customer (wants the EV available by a certain time), the supplier (wants to buy electricity at the lowest price), the DNO (wants to manage local constraints) and the NETSO (who may want to use the EVs as a means of system balancing). Again, the significance of this problem is not known.

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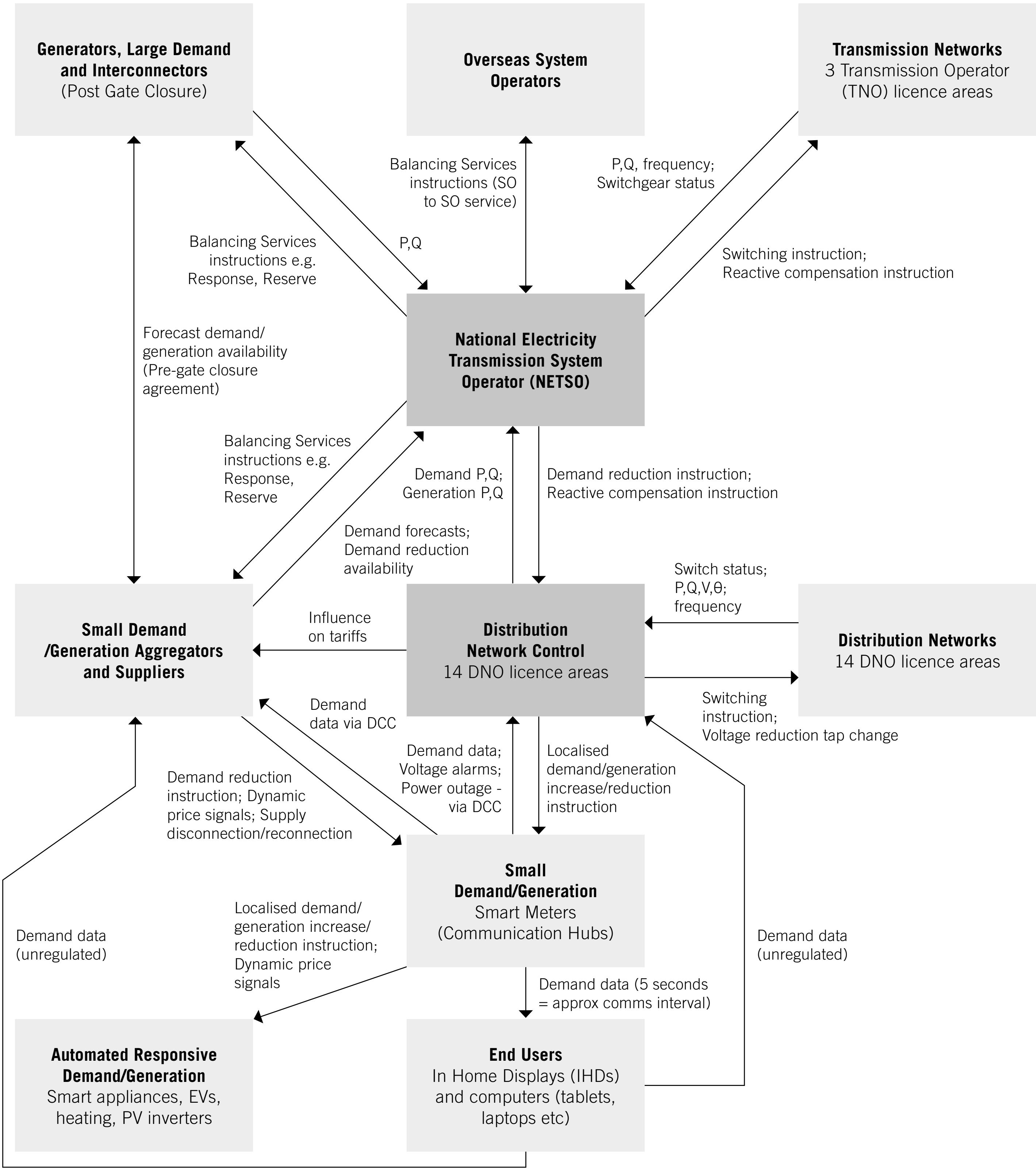
Figure 2 – NEXT – Possible information flows for GB Electricity Network Operation following the Smart Meter Roll Out and increased levels of distributed generation



Appendix 3C – Questionnaire, Interview Questions

Background
The Power Network Joint Vision team have agreed to deliver a report that highlights the cross-cutting issues of the whole systems design and integration for the power system, emphasising the challenges and possible solutions for future network holistic design and operation. WSC has been tasked with the operational aspects of this. You have kindly agreed to be interviewed to ascertain your personal perspective on answers to the questions posed below. Your personal experience will be combined with others on WSC to elicit key messages that arise from the answers given. It is important that you consider the following structure when answering these questions:

- Explanation of the problem
- Consequences of doing nothing
- Commercial Implications
- Further work required to better identify the problem
- Engineering versus commercial solutions
- Further work required to better identify the solutions
- Preferred solution/s and justification
- Further work required on preferred solution
- Commercial benefits and opportunities
- Recommendations

This will allow a consistent method of reporting the issues raised and gives a structure to the interview to ensure we obtain the required information from you. It may help to consider how this work is adding to the knowledge gathering already underway in the Smart Grid Forum, especially SGF-WS3, SGF-WS6 & SGF-WS7. This work is important and will help to shape our industry going forward. *Thank you for your time in advance.*

Questions:
1. What, in your opinion, are the main issues that need to be addressed for Power Network Operations looking forward until 2030?
2. Which of these would you see as the top 3 priorities and why?
3. From an operational perspective – is the market structure today fit for purpose out to 2020 and beyond?
4. If not, what changes are needed to ensure efficient and cost effective whole systems thinking to deliver major benefits not available today?
5. In order to optimise the efficiency of the whole system, what issues need to be addressed and how?
6. From an operational perspective – will the power network configuration have to change from today's technical architectural design, if so how?
7. What are your views on the integration with other vectors such as heat, transport, etc. and what role will old/new technology (such as all forms of storage, automation, home energy management, etc.) need to achieve to maximise flexibility and reduce cost in relation to the network?
8. Given that the Transmission and Distribution network is the theme of this activity what changes do you see will be needed to enable the flexibility now being requested for both generation and demand INTEGRATION (not just connectivity)?
9. What are your views on the impending issues of using greater levels of embedded ICT on the T&D networks of the future?
10. What is your view regarding power network resilience, now and in the future?
11. It is proposed that greater information flows between stakeholders will be needed with increasing data collection (especially from the demand side). What are your views on what will be the critical data that will need to be exchanged, between who and why?
12. Are cyber security and privacy issues an obstacle to data flows?
13. Given the changing mix of generation and system inertia – what are your views on how this should be dealt with from a power network perspective going forward?
14. Are consumers and producers important in whole system design, implementation and operation and why?
15. What in your view should be changed in power system operation to accommodate the new demand side integration of appliances, electric vehicles, heat, etc?
16. How should we deal with real-time control and automation of the power networks in the future?
17. What asset data is important going forward, considering the explosion of devices expected at the lower voltages?
18. What asset data methodologies will be needed to deal with this increase and how will this benefit the operational aspects of the system?
19. What are the major risks and mitigation factors we should consider when proposing a holistic approach to operational delivery in the future?
20. Who needs to act to make all of the above points you have raised actionable?

Appendix 3D – Selection of Responses to Questionnaire

System Optimisation

Question Number	Views expressed
7	The challenge of operational system optimisation is in many ways a result of what policy and planning give to us as a problem. At present there are many views about what may be the best way to go, but in reality the likelihood of any of this materialising is unknown and we are being asked to plan on this basis.
7	An interesting question is should we just accept the generation constraints and continue to build fit-and-forget distribution systems and have a strong transmission grid? Is this an optimal solution? No one seems to have challenged the Smart Grid band wagon to ask if the equation makes sense.
7	We need to be more aware that when integrating technology it is people we are serving, not the system optimisation. We want to let people lead the lives they want to lead, not the lives we wished they would lead. We should optimise our solutions for electricity, heat, transport, etc. based on their needs not ours. EV charging for example – our customers want to reach their destination, they don't want to find out we only wanted them to go half that distance because of a network constraint.
12	Dynamic protection and network monitoring, along with utilising dynamically managed demand and generation to provide ancillary services e.g. frequency responsive demand and controllable Power conversion units on DG.
13	My understanding was that synthetic inertia was being considered as a good alternative for this issue.
17	Device type and location could be achieved by a registration process so that a national inventory of what energy devices are where could be achieved. The data privacy of this would likely cause some people an issue but we already trust many data agencies with address specific information about purchases of household assets.
17	We're too focused about assets on our balance sheet rather than assets that effect the operation of our network. Other assets such as our suppliers and customers may have a much greater impact on the operation in the future.
17	Fit and forget asset registration, over the air interrogation and configuration, benefit obvious, cost not.
17	Mobile electricity demand and supply (EVs) is a new concept moving around the network - this will need considerable thought around system optimisation.
17	We need to concentrate on the large devices. Heat pumps already need permission from the DNO to connect. However, with EV I understand that a DNO is only informed, if at all, after the event. There is also the possibility of charging at another location on a regular basis. The DNO needs to be able to forecast the flows on their network, identify where they need to intervene and then inform the Transmission System Operator (TSO) of what to expect and the flexibility available.
19	We need a more holistic approach to voltage management.
19	Centralised control of smart demand in response to forecast prices creates the risk of step changes in demand. This can be mitigated by making demands "ramp up/down" and making them frequency sensitive.

System Modelling

Question Number	Views expressed
1	Lack of predictive real-time management tools for efficient operation (including predictively and anticipatory nature of problems encountered (i.e. self-learning tools)) Lack of predictive optimal power flow control software and hardware (i.e. smart control), including: ■ New mathematical models and smarter computational tools; ■ State estimation of the grid; ■ Fault location, isolation and restoration; ■ Volt-var-watt control Optimisation; ■ Harmonic detection and mitigation; ■ Coordination of emergency measures; ■ Coordination of intervention teams
5	Whole life cycle efficiency utilising a Total Expenditure (TOTEX) approach, need to account for impacts beyond the network. Current system forces insular efficiency assessment ignoring the wider socio economic impacts, positive and negative.
7	The SGF-WS3 Scenarios are all implausible or extreme. The reality will probably be a lot different. This is a problem of modelling and we need a reality check on these types of market signals. Nobody believes the extremes that have been suggested. It is likely that other outcomes such as the increase in petrol and diesel car efficiencies will modify these scenarios a lot. It is why DECC are unwilling to select a central scenario. The truth will be somewhere within the extremes.
7	We need to have much better understanding from a modelling point of view about how best to balance not just supply with demand but also to add in the network constraint dimension. Our current operational models cannot deal with this.
8	You have to include the generation, transmission, distribution AND the demand side in the system modelling. I know it's complicated but if you don't include end-to-end you will end up with a sub-optimal engineered solution. That then leads on to being able to get the right data to get sensible outputs. This then comes back to the market structure and the way we share data – or don't.

System Wide Control Philosophy/Authority

Question Number	Views expressed
7	While we have a single frequency (50Hz) there will need to be a 'single controlling mind' on all of the networks.
15	No one answer to this, we have centralised and distributed architectures all over the place already, both are viable.
15	This is a key question. Logically, the following drivers will be involved: ■ Customer choice – I'm going out in three hours' time, so I want my car charging whatever the cost; ■ Suppliers will want to be free to purchase electricity at the cheapest times and will then need to communicate this to their customers. Such a system is a cyber-security risk – it could be hacked to get all a suppliers EV to start charging at 1700hrs; ■ DNO loading. If an 11kV/415V transformer is overloaded, there needs to be an automatic device to detect this and some means of communicating to the connected smart demand that it must reduce. This also implies a means of deciding which load to reduce; ■ To protect the whole network, there needs to be a frequency sensitive element to control. This will be especially important if suppliers are switching in response to half hourly price changes and would mitigate the cyber risks associated with supplier systems. It can be thought of as an automatic over-ride to detect when the commercial arrangements were not working and intervene Given that the whole point of the exercise is decarbonisation, we need to ensure that demand is aligned to times of surplus renewable energy.
16	Power networks in the future will rely more on real time data (generally available online) from devices installed at all levels of the network up to consumer end. The control systems will compute all data and use more predictive and stochastic methods to forecast the conditions of the network. Tools should be able to manage predictively and anticipatory nature of problems encountered (i.e. self-learning tools).
16	Nationally agreed design principles, standards and approvals would enable engineering oversight and guidance of the selection of mission critical control and automation technology (or would that prevent diversity and leave the system more vulnerable to common mode problems or event attack?)
16	Control of DNO systems will become far more active. The scale of their networks means that this will have to be largely automated. Control of smart demand/embedded generation will be a new mechanism that will need to be exploited.
16	There is a new generation of control systems needed at distribution level away from dumb SCADA data being displayed on passive displays towards new interactive systems running complex power system modelling.
16	We'll need highly automated control down to every end point (240v) eventually as there is no way a control engineer will have the ability to deal with the number of issues on the network.
19	If we operate a lean, closely managed system, will it be vulnerable to unexpected /extreme events?

Flexibility of the Power System

Question Number	Views expressed
1	Harvesting "surplus" renewable generation to decarbonise heat/transport. Increasing distribution network capacity to allow widespread electrification of heat/ transport. Using Smart Demand as a tool in managing the wider network.
6	The "peakiness" of heat with very high demands during a cold snap casts doubt on the wisdom of fully electrifying heat – it would require lots of heat pump capacity/network capacity/generating plant with a very low load factor. We could use dual-fuelled heating appliances that use low carbon electricity when available and top up by burning gas when there is a shortage of renewable electricity and/or the heat pump/network are fully loaded. Such devices could also provide frequency response, avoiding the need to part load plant.
7	Significant challenges likely to emerge in the electricity system as a result of the requirements for electric heat and transport so the role of new technology in the form of demand response, automated control, energy storage (including thermal) and home energy management would be essential too.
7	Absolutely essential if we are doing all this Smart Grid stuff to reduce carbon as opposed to keeping a large number of people employed for a few years then this is critical. We are a long way from this type of thinking in the UK predominantly as a result of the silos that the UK regulator and market structure has created.
7	In principle, flexible demand from other energy vectors can provide balancing services if planned and operated efficiently. ■ Storing heat: Cooling control actions and comfort level in commercial building; ■ Integrating heat networks with electricity networks? It might be a bit complex to go beyond electricity at this stage?
8	All the above, markets, architectures, whole life assessments, the technology is the last issue.
8	This issue depends on the levels of penetration of smart grid technology. It also depends on the customer participation/engagement levels. Particularly at Distribution levels, there will be a need to plan for a combination of detective/monitoring, corrective and preventing technologies to be implemented.
8	Voltage control Control of smart demand
	Whilst we can lobby on particular points (e.g. EV chargers to be frequency sensitive, or the need for access to interconnector flexibility in real time), I think that we really need to be able to articulate a vision of how all this will pan out. This will then provide a context/justification for our "asks". This vision will need to cover: ■ Where we will get the flexibility to accept high levels of variable renewable generation; ■ How we will "harvest" the surplus renewable energy to decarbonise heat/transport – bearing in mind that it will mainly occur at times of low demand; ■ How we will manage the increased load on the distribution system as heat and transport are decarbonised. From my ball park calculations, smart alone will not deliver this – we will need to bury bigger cables; ■ How we will manage "active demand" to satisfy end customers, suppliers, DNOs, TSO and the need to fully exploit low carbon sources; ■ How we remunerate peak plant to ensure that we continue to enjoy security of supply

Market Structure Not Fit For Purpose

Question Number	Views expressed
1	Markets that support flexible generation, flexible demand and energy storage (in its broadest sense) in particular capable of dealing with localised requirements and capable of providing customers with a level playing field in terms of economic opportunity.
3	The *energy market* as currently exists only seems to provide relatively short run incentives for generation capacity and seems to have few long term signals to bring forward the types of generation plant or the development of demand response or energy storage that might prove highly useful, if not essential, in securing hour by hour supplies in future years. Moreover, the *services market* as operated by the Great Britain System Operator (GBSO) meets existing requirements for services to stabilise and secure the system but this is unlikely to be sufficient towards 2030 in areas such as response, reserve, reactive power, etc.
3	No, in particular in relation to the operation of markets to deal with localised issues, current system is actually designed to prevent geographical differentiation.
3	Need to recognise the current configuration's limitations. Does not take account of local markets at all. The current structure was designed for centralised models not distributed architecture – the market needs to have recognition that this is not the case now.
3	My main concern is that half-hourly pricing will prove to be too blunt a tool for encouraging an effective balance. We already have issues with interconnectors ramping rapidly on the half hour. This will be exacerbated if lots of EV and/or heat pumps switch on the half hour. One solution would be to make EV/PV demand both ramp in/out and respond to system frequency. Hence, if large numbers of EV did come in simultaneously, they would depress the frequency slowly and automatically reduce their energy take. It is not clear to me how the communications to "smart demand" will work. The end customer, supplier, DNO and TSO will all have a legitimate interest in influencing smart appliances. How will this work? How do we avoid having a huge/costly IT system that, should it malfunction, could jeopardise the grid? Voltage control at times of low demand is causing problems. It is likely that TSO, DNOs and embedded generators will need to work together more closely.
3 and 4	No - It will require technology components and solutions to allow electricity consumers to be active participants. This includes smart metering and two-way communication infrastructure between supplier and consumer, as well as smart appliances, demand response, prosumers and aggregators.
4	Electricity Market Reform (EMR) proposals may address some of the energy market issues. Securing the contribution of distribution connected resources aggregated up to meaningful scales for system operation is likely to be required for an effective operation of the system.
4	Mechanism for balancing within settlement periods. Way of reconciling needs of customer/supplier/DNO/TSO controlling smart demand. More holistic approach to voltage control.

Information Flows

Question Number	Views expressed
1	Communication difficulties among system operators, consumers and prosumers /aggregators
11	There is no issue with providing the correct level of security, we are doing it already, key point is that customers accept the use of their data to operate the network; this is down to how it is deployed and how it is portrayed to customers.
11	This is likely to be an area where the DNO input to the smart meter roll out design and standards has already thoroughly dealt with the required data for local network operation and system operation.
11	The expectation is that the communications channels would be at least as complex as those depicted in the following link http://energy.gov/sites/prod/files/gcprod/documents/EdisonElectric_Comments_SmartGridDataFlow.pdf
11	The TSO will need greater knowledge of what is happening/planned to happen with the generation and active demand on the DNO network. Of course this can only happen if the DNO already has access to this information. The DNO will need to make decisions about voltage control in the light of Mega Volt Amperes Reactive (MVAr) flows onto/off the transmission system.
11	This needs further investigation as there is no clear understanding of who needs what data and why.
16	Generation/Demand type mix by LV network. The rest can be inferred. Of as much importance are things such as the socio economic characteristics of each neighbourhood.
19	We need to ensure data collected is useful and needed – how will this be turned into information and visualised by the receiver?

Security (Cyber and Power Network)

Question Number	Views expressed
9	With or without embedded ICT, the power system of the future will be more complex and difficult to manage and operate. It is clear that with greater use of (or even dependence on) embedded ICT there are new challenges to be addressed. With the greater complexity of the primary power system then the greater challenge seems to be to operate the system efficiently and securely without ICT rather than with it. If this is true then the key requirement is for sound application of ICT where required from transmission system level all the way down to individual consumer and device. Such sound application requires sound standards and processes, appropriately skilled engineers and rigorously tested technology.
9	A relatively reliable system will become potentially significantly less resilient and more prone to complete collapse, in particular if no thought goes into abnormal operation e.g. storms, and major failures or extremes of weather e.g. 50 year high pressures etc. Also the complexity of the system will result in a need for a higher level of technical expertise in the field, changing the traditional skill requirements of the industry.
12	We need to be clear that generation and the demand is all part of the system we (network operators) need visibility of the security of these stakeholders – e.g. are they matching our own high standards of security? All of these should be seen as critical national infrastructure points of connection that could compromise the whole system.
12	Yes, even if only because the perception is already out there that this is difficult, complex, potentially serious, etc.
12	Cyber security should not be an obstacle to data flows in a smart grid. Data flows are key for deployment of the communication systems necessary for smart grid control. Cyber security measures should be included from the start to ensure the integrity and confidentiality of information and systems. Cyber security should be built-in at architectural level of the smart grid designs, not added on in the future.
12	Cyber security is a real issue for any data flow that affects operational decisions. Privacy issues are a political issue rather than an engineering issue, but need to be resolved none the less.

Resilience

Question Number	Views expressed
1	Resilience against cyber-attack and natural disasters.
2	Ability of new systems to remain resilient and to be capable of rapid restoration post storm event given the introduction of long time constants to the network dynamic along with the mutual interdependence of communications and power infrastructure in a Smart Grid future.
9	Cautious. We need to ensure that: ■ They do not reduce the high level of reliability currently delivered by the "passive" assets employed; ■ The lifetime of the assets and the need to replace them ahead of the main assets is considered; ■ The network does not become too brittle. For example, if a smart network is just able to cope with a cold winter's day, what will happen if an area is off supply for 48-72 hours and is then restored or the gas supply is lost for several days? How do we prevent the network being damaged?
10	There are clearly threats to power system resilience from the generation and demand developments anticipated, such as securing demand from a more variable and uncertain generation mix at every moment as happens now. The application of new technology with adequate operator oversight can play a major role in identifying and executing appropriate control action to secure the system in a broad range of operating modes. The resilience question then boils down to the operator oversight, the sound use of good ICT to support operations and delivery of flexibility of generation, demand and energy storage. Shortcomings in any of these three areas (operators, ICT, flexibility delivery – or in other words skilled people, technology and commercial arrangements) could have serious implications for resilience in operations.
10	In terms of network resilience, being cyber security or weather related, the essential concept is that security should be built-in at architectural level of the smart grid designs, not added on in the future.
10	As heat and transport are electrified the impact of a power outage will increase and hence resilience will become even more important. See comments about restoring load following a long power failure above. We need to be wary of creating IT systems that, if they malfunction, could jeopardise the grid. From a resilience perspective, there is a strong argument for local devolved control that can only affect a small area and using physical measures such as system frequency that cannot "malfunction".

Consumer Engagement

Question Number	Views expressed
1	New offerings and “product” concepts to engage customers.
1	Lack of demand side management technology.
9	Of more importance is the interaction that the customer will have with the system, they are now no longer interested in whether it is just on or off but are interested in a whole range of complex interactions e.g. why is a constraint active, why is DSM on or off, why the value is the value at that point in time etc. This will mean a 100 fold increase in customer interaction with the industry, this has already been seen on Orkney for example where customers are now actively informed of the status of the ANM system as a direct result of the high level of interest of those who are actively part of the scheme.
14	I believe that consumers and prosumers will play a very important role in system design, implementation and operation. For example, high levels of aggregation of prosumers in a certain area will have an impact on how the system is designed and operated. Levels of network reinforcements will need to be implemented by DNOs to allow for this to take place. DSOs will need to take into account the micro-generation forecasts in order to efficiently manage it.
14	Yes, they are central to the whole thing, which is the point about markets being needed to encourage the correct behaviours and support from stakeholders.
14	More important in implementation and operation through their participation since their vested interest in the design and architecture might deflect from the best solutions (although each stakeholder might have such deflecting vested interests).
14	Consumers are important, but cannot be expected to play an active operational role. Hence, their equipment needs to manage their smart loads automatically. Producers who are connected to a smart network may have to accept that one of the control actions on the network is to vary their output/power factor.

Whole System Design

Question Number	Views expressed
1	People with the skills to deliver the Smart Grid, this includes customer engagement and technology skills.
1	Lack of storage devices/interaction with EVs.
1	Balancing the whole system with intermittent renewable generation, uncontrollable output from distributed generation, demand responding to various call-offs and masked demand from very small scale generation all without unduly inhibiting the development of low carbon development. Stabilising the system under dynamic or contingency events with substantially different dynamic response and inertia characteristics including from a multitude of smaller generation, demand and energy storage units. Managing substantial numbers of DER units (and overall capacity) in distribution systems including the interface real and reactive power flows into the transmission system.
1	Provision of reserve to cover uncertain renewable generation. Ensuring that peaking plant remains economic to retain security of supply.
5	We need to take advantage of “smart” demand to make the best use of available generation and network capacity. The issue will be doing this without leaving the customer dis-empowered. Distribution networks will need to be smarter – measuring the loading/temperature of key components and automatically controlling demand to prevent overloads.
5	Projections of the profile of daily electrical demand in 2020-2030 suggest very different energy volumes and peaks from today so efficiency (financial as well as energy) is likely to be a major consideration in system and network (T&D) operation with efficiency being managed more actively than at present if costs to end consumers are to be managed. Scheduling and controlling the flows of energy not just spatially but also temporally and topologically in the power system and between responsive, controllable and storage capable devices will be essential to maintain or improve efficiency when sources and demands will have very different power capacity, energy volume and profile characteristics.
6	The complexity of operating a system with many more active and participating system service providing units and much greater needs for operational data and control flow in real time suggests different architecture for system operation would be necessary.
6	Possibly, all the elements exist now but with the current architecture, the key change will be volumes and complexity and security/reliability considerations. Anyone or organisation that thinks it can define all this now is kidding itself (you could make educated guesses), key will learning from projects underway and working with National Institute of Standards and Technology (NIST) and SGAM to evolve appropriate architectures. It could be argued that markets come first.

Whole System Design cont.

Question Number	Views expressed
6	At distribution level: If levels of DG are high, there might be need to move from Single or Multiple Antenna (i.e. radial, tree/water fall structures) to Meshed and Looped grids. Hybrids are also interesting options. Advantages: ■ Easier to adjust with increases of load and DG, micro-grids, etc; ■ Losses can be decreased; ■ Better voltage profile; ■ Greater flexibility Disadvantages: ■ More complex planning; ■ More complex operation if not automated; ■ The short circuit current can increase (could include the use of current/fault limiters); ■ Protection systems need to reviewed or upgraded
6	I'm not sure that the architecture needs to change. However, the electrification of heat/transport implies a significant increase in network capacity. Hence, this would be an opportune time to review the current architecture.
13	In the first instance we need to relax the ROCOF settings on embedded generation. There will be other stability issue beyond ROCOF settings. It is possible that these can be mitigated using "artificial" inertia created by smart loads or interconnectors. There could also be novel arrangements at power stations, e.g. a clutch to allow the unit to operate as a synchronous compensator when not generating.
13	There is a need to plan the system correctly as operationally there is little that can be done to deal with a lack of inertia on the system, save for a small element of support from power electronics, other than putting more rotational machinery on the system.
18	I'm not sure what to recommend here. However, the system will need to access both "standing data" (e.g. where heat pumps are installed) and "dynamic data" (e.g. energy take by the heat pump over the past 12 months). All this raises one of the big questions: is it better to embrace the complexity of managing a smart distribution system, or would it be better to build a large network and continue to operate a "fit and forget" approach?
19	Communication systems, Network resilience, lack of computational tools.

Annexes to the Whole Report

Acronyms

ANM	Active Network Management
BETTA	British Electricity Transmission and Trading Arrangements
BM	Balancing Mechanism
BSC	Balancing and Settlement Code
CCGT	Combined-Cycle Gas Turbine
CHP	Combined Heat & Power
CIGRE	Conference International de Grand Réseaux Electriques
CIRED	Congrès International des Réseaux Electriques de Distribution
DC	Direct Current
DCC	Data Communications Company
DCRP	Distribution Code Review Panel
DECC	Department of Energy & Climate Change
DER	Distribution Energy Resources
DG	Distribution Generation
DMS	Distribution Management System
DNO	Distribution Network Operator
DoS	Denial of Service
DR	Demand Response
DSM	Demand Side Management
DSO	Distribution System Operator
DSR	Demand Side Response
EMR	Electricity Market Reform
EMS	Energy Management System
ENSG	Electricity Networks Strategy Group
EPSRC	Engineering & Physical Sciences Research Council
ER	Engineering Recommendation
ERP	Effective Radiated Power
ESI	Electricity Supply Industry
ESQC	Electricity, Safety, Quality and Continuity
ETI	Energy Technologies Institute
ETYS	Electricity Ten Year Statement
EV	Electric Vehicle
FE	FirstEnergy
FERC	Federal Energy Regulatory Commission
FIT	Feed In Tariff
GB	Great Britain
GBSO	Great Britain System Operator
GCRP	Grid Code Review Panel
GSP	Grid Supply Point
HAN	Home Area Network
HTTPS	Hypertext Transfer Protocol
ICT	Information and Communication Technology
IDNO	Independent Distribution Network Operators
IED	Intelligent Electronic Devices
IET	Institution of Engineering & Technology
IFI	Innovation Funding Incentive
IHD	In Home Display
IP	Internet Protocol
IPR	Intellectual Property Rights
ITPR	Integrated Transmission Planning & Regulation

kV	Kilo Volt
LAN	Local Area Network
LCL	Low Carbon London
LCNF	Low Carbon Network Fund
LTDS	Long Term Development Statements
MISO	Midwest Independent System Operator
MVAr	Mega Volt Amperes Reactive
NERC	North American Electric Reliability Council
NETSO	National Electricity Transmission System Operator
NG	National Grid
NIA	Network Innovation Allowance
NIC	Network Innovation Competitions
NIST	National Institute of Standards and Technology
Ofgem	The Office of Gas and Electricity Markets
OFTO	Offshore Transmission Owner
PLC	Programmable Logic ontroller
PNJV	Power Network Joint Vision Expert Group
PV	Photovoltaic
R&D	Research and development
ROCOF	Rate of Change of Frequency
RTCA	Real Time Contingency Analysis
RTE	Réseaux de tranport d'électricité
SCADA	Supervisory Control and Data Acquisition
SE	State Estimator
SGAM	Smart Grid Architecture Model
SGF	Smart Grid Forum
SGF-WS3	Smart Grid Forum Work Stream3
SGF-WS4	Smart Grid Forum Work Stream 4
SGF-WS7	Smart Grid Forum Work Stream7
SIPS	System Integrity Protection Schemes
SQSS	Security & Quality of Supply Standard
SSL	Secure Socket Layer
STOR	Short Term Operating Reserve
SWOT	Strengths, Weaknesses, Opportunities and Threats
T&D	Transmission & Distribution
TCP	Transmission Control Protocol
Tennet	NETSO of the Netherlands
TNO	Transmission Network Operator
TOTEX	Total Expenditure
TSO	Transmission System Operator
TV	Television
UK	United Kingdom
UKERC	UK Energy Research Centre
UKPN	UK Power Networks
V	Voltage
WAN	Wide Area Network
WEP	Wired Equivalent Privacy
WS	Work Stream
θ	Voltage Angle

Explanation of Terms

The following explanation of the important terms used in this report is provided for better understanding of them. These explanations are not intended to be formal definitions and may not be consistent with the same or similar terms used in governance documents or internationally. Some alternative terms have been used in the questionnaire and responses in Section 3 of this report, but, as these are appended verbatim, they have not been aligned with the terms used in the main body of the report.

NETSO
National Electricity Transmission System Operator. Responsible for balance and security of the transmission system and overall economic/secure system design. This function is currently carried out by National Grid for GB.

TNO
Transmission Network Operator. Responsible for switching, and design and build of the transmission network. Currently there are three TNOs in GB; National Grid for England and Wales, Scottish Power for South of Scotland and Scottish Hydro Electric (Scottish and Southern Energy) for North of Scotland

DNO
Distribution Network Operator. Responsible for switching, and design and build of the distribution network. Currently there are 14 DNOs in GB, 12 in England and Wales and 2 in Scotland

Whole System
This refers to GB and includes:

- 50Hz transmission network equipment (both off shore and on shore). Generally at voltages of 275kV and above, although in the North of Scotland 132kV is considered as a transmission voltage.
- Interconnection equipment – usually high voltage direct current connections with other utilities.
- 50Hz distribution network equipment
- Customer equipment
- Demand
- Generating plant
- Local and wide area control equipment used for the control of any or all of the above
- SCADA systems

Whilst, in the broadest terms, commercial and market activities may be considered as part of the operation of the system as a whole, these activities are considered and addressed separately within this report.

Transmission System
This includes the transmission network, SCADA systems, and local and wide area control equipment.

Transmission Network
Interconnected power frequency equipment (e.g. lines, cables, transformers, compensation equipment), at transmission voltages. This also includes interconnection equipment which may be high voltage direct current.

Distribution System
This includes the distribution network, SCADA systems, and local and wide area control equipment.

Distribution Network
Interconnected power frequency equipment (e.g. lines, cables, transformers) at distribution voltages. Note: Although the terms ‘System’ and ‘Network’ are generally used in this report in accordance with the above explanations, this is not an inviolable rule and ‘System’ is sometimes used where ‘Network’ would be more accurate. This is unavoidable since formal documents do use ‘System’ where, by the above definitions, ‘Network’ would be more appropriate, e.g. the NETSSQSS talks about ‘transmission system voltages’ where these are actually voltages on the network.

Power Network or Electricity Network
Interconnected power frequency equipment (e.g. lines, cables, transformers) and interconnectors at transmission and/or distribution voltages.

Power System
This includes the power network, SCADA systems, and local and wide area control equipment.

Distributed generation
This generates electricity from small energy sources and can include domestic PV, small wind turbines and small hydro schemes. It is connected to distribution networks at 240V and 11kV voltage levels.

Embedded generation
Generation that is not connected to the transmission network but may have an impact on it.

Intermittent generation
Generation that is not continuously available due to a factor outside direct control. Its output may be predictable (e.g. tidal power) or unpredictable (e.g. wind, solar, and wave power).

Low carbon generation
Generation that produces electrical power using processes that produce substantially lower carbon dioxide emissions than from fossil fuel generation plant. This can include wind, solar, hydro, geothermal and nuclear power. It can also include biomass generation where the biomass is grown in a sustainable manner.

Renewable generation
Generation that produces electrical power from continuously replenishable energy sources such as wind, solar, hydro, tidal and wave power. It can also include biomass generation where the biomass is grown in a sustainable manner, and electrical power produced in waste burning plant.

Conventional generation
Generation that produces electrical power from continuously non-replenish-able energy sources such as coal, oil, gas and nuclear. Large scale hydro power may be regarded as conventional generation but is also renewable generation.

Generation Power Plant
Generally a large scale industrial facility for conventional generation.

Consumer
A person or organisation whose equipment consumes electrical energy.

Customer
A person or organisation who has a contract with a supplier for the supply of electrical energy.

GB Power Networks Industry Groups

- UK Treasury – UK Infrastructure
- Smart Grid Forum (SGF)
- Electricity Network Strategy Group (ENSG)
- Energy Research Partnership (ERP)
- UK Energy Research Council (UKERC)
- IET – Power Network Joint Vision (PNJV)
- Energy Network Association (ENA)
- Technology Strategy Board (TSB) – Energy Systems Catapult

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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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