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Friday, 8th January 2016

National Infrastructure Commission
1 Horse Guards Road
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Dear Chair of National Infrastructure Commission:

In line with the Commission's call for evidence, I am writing to provide the evidence on how changes to existing market frameworks, increased interconnection and new technologies in demand-side management and energy storage can better balance supply and demand.

1. What changes may need to be made to the electricity market to ensure that supply and demand are balanced, whilst minimising cost to consumers, over the long-term?

- What role can changes to the market framework play to incentivise this outcome:
  - Is there a need for an independent system operator (SO)? How could the incentives faced by the SO be set to minimise long-run balancing costs?

The Independent System Operator or IS0 is the key actor in the various proposals for a deregulated, competitive electric power industry in the World. The IS0 has three major objectives: security maintenance, service quality assurance, and promotion of economic efficiency and equity. When the primary objective is to achieve of economic efficiency and equity of services, this is referred to as Minimized ISO. While the structure of UK's ISO is quite often referred to as Maximised ISO (Max ISO), which covers the objectives of security, service quality and economic efficiency together. In the meantime, National Grid is also the transmission system operator (TSO) in England and Wales. The current mixed ISO/TSO structure is quite often referred to as one of the popular models in the World. It has been known that it is not necessary to move from the current structure to establish fully independent system operator as the case of PJM in USA. We have such an argument because of the following issues associated with the fully separated ISO model:

1) *Efficiency*: Economically establishment of a fully unbundled ISO is not attractive as we will need to set up an independent organisation to perform similar functionalities being carried out by National Grid the moment. And in the meantime, National Grid will still need to keep the relevant departments performing the similar security, operation functionalities. The results of the established the fully separated ISO means that we will need to duplicate the most of the system operation departments that National Grid currently has.
2) *Conflicting operating objectives*: The fully separated ISO will create some technical challenges. The TSOs and ISO would have different objectives and incentives. The objective of ISO is to maximise the power flow transactions while TSOs want to reduce the maintenance costs of their networks.
3) *Risks of security*: In the real-time control and operation of power grid, there needs to a large amount of operational status information flowing between the ISO and the TSOs. This would inevitably affect the control performance of the power grids. In terms of emergency, the coordination between the ISO and the TSOs becomes difficult. These issues would result in potential risks of insecurity with the large scale integration of fluctuating renewable energy sources. Considering the potential cybersecuity issues, a separated ISO structure would create more problems rather than solve them.
4) *The challenges of coordination of planning, maintenance and expansion of the electricity networks*: As mentioned before, there will be duplication departments within the ISO and the TSOs, and this eventually brings inefficiencies of the investments. And in case there are disputes, the delayed engineering projects are very much expected.
5) *The barrier of innovations*: As the ISO and the TSOs may have conflicting operating objectives. The efficiency means different things for different entities. The costly disputes on innovative projects and contracts may create barriers for innovations in the system operations and investments. But I am sure that this fully separated ISO structure would create excellent job opportunities for lawyers and this means that significant payment to lawyers will be created!

Now actually the question becomes how to monitor and regulate the system operator's business in most efficient and effective ways rather than establishment of a duplicated entity ISO.

- To what extent can demand-side management measures and embedded generation be used to increase the flexibility of the electricity system?

The current assessment on the capability demand-side management measures and embedded generation to be used to increase the flexibility of the electricity system is very limited. Most of the studies were based on simple simulations with reduced order models of national electricity system. Although the demand-side management and embedded generation are in principle useful to increase the flexibility of the electricity transmission system in particular, and sometime the electricity distribution systems too, these distributed energy sources in the meantime may create unaccepted voltage profiles and power flow congestion in the electricity distribution networks. The current electricity distribution networks may not have the sufficient control resources to accommodate large amounts of distributed energy sources such as wind turbines, PV panels, electric vehicles and energy storage systems [1].

[1] X.-P. Zhang, et al, "Distribution Power & Energy Internet: From Virtual Power Plants to Virtual Power Systems", *Proceedings of Chinese Society for Electrical Engineering*, vol. 35 no. 14, 2015, pp. 3532-3540 DOI: 10.13334/j.0258-8013.pcsee.2015.14.007

2. What are the barriers to the deployment of energy storage capacity?

- Are there specific market failures/barriers that prevent investment in energy storage that are not faced by other 'balancing' technologies? How might these be overcome?

There are three major issues related to the deployment of energy storage capacity, namely, viability of economics, ownerships, and business models under the market operation environments.

There are a few 'balancing' technologies (**in terms of active power reserve and frequency regulation**) available for the integrated national electricity system provided by:

1. Conventional large power plants
2. Distributed energy sources and demand side response
3. HVDC interconnectors from the other EU countries
4. Energy storage systems

Competiveness of energy storage: Normally we use technologies 1 – 3 with priority as these technologies are cheaper than energy storage systems. However, with the further integration of wind and solar energy into the electricity system, energy storage systems will be needed. Depending on the specific applications, energy storage systems may become profitable now. The viability of energy storage systems are very much related to the incentive schemes and real-time tariff being used. It has been widely accepted that for the time being HVDC interconnectors are more economic than energy storage systems.

A proposal for ownerships of energy storage systems: The very large scale energy systems should normally be connection with transmission networks and hence it would be more reliably and securely operated by TSOs. It is therefore more logic to propose TSOs to be the owners of these very large scale energy storage systems, and obviously such an arrangement would be helpful to ensure the effective use of energy storage systems against system blackouts in terms of emergencies. While the ownerships of middle sized to small sized energy storage systems are flexible, they could be owned by independent energy storage producers, which provide active power reserve for the system.

The current barriers for deployment of energy storage systems

1) there are appropriate strategies available to deploy energy storage systems for transmission networks, distribution networks, homes/buildings;
2) TSOs are excluded from providing energy storage systems, and this is going to adversely affect the development of large scale energy storage systems and subsequently this would delay the implementation of renewable energy integration targets;
3) There are no clear incentive schemes and legal framework available to encourage the penetration of energy storage into the distribution systems and homes/buildings.

- What is the most appropriate scale for future energy storage technologies in the UK? (i.e. transmission network scale, the distributed network or the domestic scale.)

The capacity requirements of energy storage systems should be compatible with capacities of transmission network, distribution network and local network. At transmission network level, the required energy storage capacity could be at the level of GWh/100 MWh, 10 MWh/100 kWh, and 50kWh/10kWh for transmission network, distribution network, and homes/buildings, respectively.

3. What level of electricity interconnection is likely to be in the best interests of consumers?

- Is there a case for building interconnection out to a greater capacity or more rapidly than the current 'cap and floor' regime would allow beyond 2020? If so, why do you think the current arrangements are not sufficient to incentivise this investment?

  Development of large scale HVDC interconnectors with the other EU countries is certainly in line with the policies of European Energy Union. The European Energy Union will ensure **secure, affordable and climate-friendly energy** for citizens and businesses. It will allow a **free flow of energy across borders** and a secure supply in every EU country, for every citizen. Using energy more wisely and fighting **climate change** is not only an investment in our children's future, it will also **create new jobs and growth**. By 2020, each member state should ensure that the interconnection capacity should be at least of 10% of its total installed electricity generation capacity.

  In smart cities, interconnected Gas/Heat/Electricity systems coupled with electrified transport and energy storage systems should be developed. It seems that the current policies for smart cities are mainly focused on ICT developments while the requirements for the effective management of energy demand of smart cities have been overlooked.

At consumers' level, integrated management of Gas/Heat/Electricity/Electrc Vehicles/Energy Storage/Distributed Energy Sources (Wind/Solar) for smart homes/buildings should be developed.

There is a lack of big visions and right strategies in the framework of current energy system developments in terms of coordination and integration of electricity, gas, heat and transport at different levels. Such integrated electricity/gas/heat/transport systems could be better addressed in the framework of 'Global Power & Energy Internet of Everything' proposed by the University of Birmingham in 2011. For your information, I attached the PPT explaining the concept of 'Global Power & Energy Internet of Everything', which is a much broader framework than that of smart grids.

Should you require any further details, please do not hesitate to contact me. We are looking forward to welcoming you at the University of Birmingham.

Sincerely yours,

Professor Xiao-Ping Zhang
Professor of Electrical Power Systems