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Benefits of Interconnectors to GB Transmission System

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Executive Summary

The aim of this paper is to provide an overview of the range of ancillary services which interconnectors can facilitate and the potential benefits associated with such services for the end consumer.

To meet carbon reduction targets, the UK needs to introduce significant volumes of low-carbon generation, such as photovoltaic (PV) panels and wind-driven turbines, to replace conventional generation that relies on burning coal and gas. Interconnectors will also play a significant role in meeting the carbon reduction targets. The European Commission set a target of having interconnection capacity of a minimum of 10% of generation capacity by 2020 and proposals to increase this to 15% by 2030. The annual UK Future Energy Scenarios (FES)[1] published by National Grid is designed to provide a credible and plausible analysis of energy scenarios up to 2035 with additional analysis looking to 2050. The key changes for the electricity sector are expected to be in the way electricity is generated as mentioned above and how it is consumed. In terms of consumption, the FES suggests that heat pumps and electric vehicles are likely to create new demand for electricity. These changes create a new electricity system landscape that is very different to what we have been used to managing.

The dynamic operation of the transmission system is largely dependent on the type of generation connected to it, as well as the nature of demand on it. Some of the key impacts of these changes to the system as reported by the System Operability Framework (SOF)[2] are:

- A reduction in system inertia and system strength;
- A greater variability of power flows; and
- The ability to restore the system following a potential blackout.

The ability to deal with the impact of these changes is dependent on the range of products and services available to the NETSO. Our analysis as part of the SOF shows that the GB power system requires new tools for managing these changes in order to ensure economic, efficient and coordinated system operation.

The GB electricity system is classed as an islanded power system with few links (known as interconnection) to other power systems. The GB system currently has around 4GW of interconnection to Ireland (Moyle and East-West; 1GW in total), France (IFA link; 2GW), and to the Netherlands (BritNed; 1GW). These links are currently operating as merchant interconnectors and provide the capability for import/export of energy to different systems. Traditionally interconnectors have been primarily intended to provide capacity for energy flows between different synchronous areas. Interconnectors currently provide a range of services to the System Operator (SO) such as cross-border balancing, trading, and SO-SO trades for network/system support.

[1] http://www2.nationalgrid.com/uk/industry-information/future-of-energy/future-energy-scenarios/
[2] http://www2.nationalgrid.com/uk/industry-information/future-of-energy/System-Operability-Framework

The technology used in the design of existing, and future interconnectors will allow for the provision of some of the new services which are required for future system operability. The services that could be provided by interconnectors include:

- Frequency response and reserve;
- Black start;
- Reactive power reserve;
- Boundary capability; and
- Constraint management.

These benefits are largely dependent on the system conditions, the need for the service in the proximity of the connection point of the interconnector, the technology used by the interconnector, and the arrangements which are in place with the other end of the interconnector to acquire such services.

Scope of the paper

This paper has been produced at the request of Ofgem to provide an overview of the range of services which interconnectors can facilitate and the range of potential benefits to the end consumer. This analysis has been based on the 'Gone Green' scenarios described in the FES for a single year (i.e. 2020), with little consideration, at this stage on potential generation developments in associated markets connected to the 'remote' end of the Interconnectors. For the purpose of this analysis, the social economic welfare and capacity market benefits have not been considered.

To provide robust analysis to support Ofgem with the current Cap & Floor assessments of near term interconnector projects, it will be necessary to significantly extend the present modelling that the NETSO undertakes, to include appropriate European networks. Also to extend the analysis identified in this paper to incorporate the full range of credible scenarios identified in the FES, along with appropriate European scenarios. This type of analysis is not presently undertaken by the NETSO.

This paper focuses on potential consumer benefits and does not consider how developers could extract value in delivering these benefits. It should also be recognised that further discussions are required with the adjacent TSO to ensure that neighbouring networks can support the provisions of services described.

1. Introduction

A fully operable power system requires real time control on how electricity is generated, transmitted and supplied. In order to deal with the variable nature of electricity demand, and to ensure security of supply, a number of measures known as "balancing activities" are performed by the NETSO. These activities are intended for either ensuring continuous balance between total power generated and consumed, or for the purpose of ensuring the system performance criteria (i.e. frequency, voltage, thermal) are met.

Interconnectors provide an opportunity for the NETSO to access some of these services (depending on the technology used) from other European transmission systems. They similarly provide the opportunity for GB market participants to offer such service into other European markets.

Existing interconnectors, predominately due to technology choices available at time of development, are currently facilitating limited service to the National Electricity System (NETS), whereas, new interconnectors, are capable of facilitating all of the above services depending on the developers design choices. Given that interconnectors provide access to a wider pool of generation, competition for the provision of these services is increased.

The following sections will review these potential benefits, explore (at a high level) future system requirements, and discuss how interconnectors can help facilitate the provision of these services.

A subsequent paper examining the benefit of future individual interconnectors, and combinations of these, will be produced at a later date. This further paper will seek to monetize the benefits identified in this paper. The objectives of these individual project assessments will be to produce an assessment that can be put into the public domain, however, where confidential data is used, this will be identified and removed as appropriate.

2. Technology overview of Interconnectors

Two power systems can be connected via either High Voltage Alternating Current (HVAC) or High Voltage Direct Current (HVDC) links. Examples of AC links are the overhead transmission lines and cables across the NETS. In Europe, most countries are connected via AC links given the relatively short distance between the connection points which technically and economically make AC connection viable.

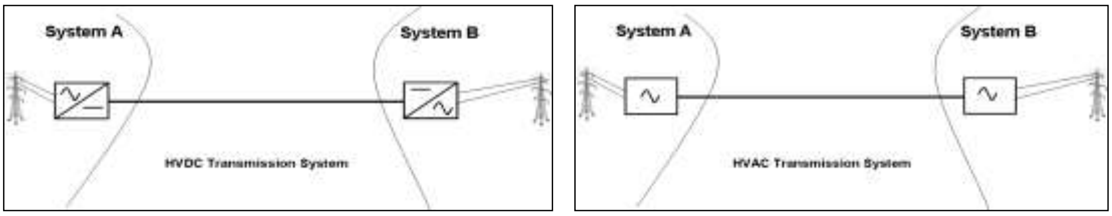

Figure 1: HVDC and HVAC Transmission Systems

The HVDC option, however is often used when there is significant distance between countries (or if they have different nominal frequencies). In the case of interconnection between GB and other countries, because of relatively long distance between the countries, all existing interconnectors are based on HVDC technology. Connecting two systems via HVDC links not only enables flow of energy between the two systems, but also decouples the two systems providing many benefits such as eliminating the effect of disturbances happening at one end from propagating to the other. The technology used in HVDC links also allows various services such as fast power ramp up/ramp down, voltage control, black start, etc. to be provided at a small incremental cost, as they are the inherent capabilities of the HVDC technology.

HVDC links are based on either Current Source Converter (CSC), or Voltage Source Converter (VSC) technology. The latter (being a more recent technology) is also capable of operating within weaker systems, and is less susceptible to disturbances. VSC technology is also more capable of facilitating the delivery of ancillary services which will be explained further later in this paper.

3. Frequency Response & Reserve Service from Interconnectors

3.1 Definition of Service

The real-time difference between system demand and total generation, results in continuous changes to the system frequency. The SO must ensure that sufficient generation and/ or demand is held to manage all credible circumstances that may result in frequency variations – this is termed as Frequency Response. Any additional power sources available to National Grid to manage unforeseen demand increase and/or generation unavailability are referred to as reserve. These comprise a variety of sources, which require different timescales to be ready to deliver the services. By having a range of variety of sources it will facilitate the determination of the optimum system performance and increase competition to allow these services to be delivered at the minimum cost to the end consumer.

3.2 Future Challenges

Future changes in the energy mix, such as increasing renewable generation capacity (in particular wind power and larger generators such as the proposed new nuclear plants) will drive the need for additional reserve and frequency response to cater for the variability and intermittency of generation sources. If we continue to utilise the existing process and techniques available for managing primary and high frequency response, the operating cost is anticipated to increase from around £60m per annum to £200m-£250m per annum by 2020. It is therefore important for the SO to access additional tools and services to manage system frequency so as to minimise operating costs.

3.3 Potential Benefits of Interconnectors

Interconnectors can provide both frequency response and reserve. Depending on the technology employed they have a key advantage of being able to rapidly change their power output (Import/Export) across their full operating range, subject to the operating conditions at both ends of the interconnector.

The key benefits from interconnectors providing frequency response and reserve is summarised below:

- Contribution to frequency response: interconnectors provide high speed delivery of response which allows active power to be rapidly delivered or taken from the system to provide frequency response.

- Potential reduction in reserve costs: By allowing the sharing of reserve, and SO to SO trade, interconnectors can reduce long-term capacity requirements and potentially reduce costs for holding system reserve. This is possible as interconnectors can facilitate pooling of reserve resources on a European basis rather than providing the entire service purely from GB. This will not be considered in this paper as it requires specific analysis to take into account the individual characteristics of the connecting system.

In order to evaluate the benefit to the end consumer by providing frequency response, we will undertake quantitative analysis to assess the future frequency response requirements which can be offset by the fast response provided by the interconnectors against the FES.

4. Black Start Capability

4.1 Definition of Service

The Black Start service recovers from a total or partial shutdown of the transmission system which has caused an extensive loss of supplies. The recovery procedure entails isolated power stations being started individually and gradually being reconnected to each other in order to restore an interconnected meshed system.

4.2 Future Challenges

Restoration services or Black Start capability are currently contracted from an array of strategically located thermal, hydro and pumped storage stations at specific locations, which are capable of re-energising the system. The future generation mix is expected to be dominated by non-synchronous generation which is unable to contribute to Black Start[3]. For Synchronous plant, UK nuclear plants have not traditionally been able (technically or from a safety perspective) to support emergency restoration. The reliability of CCGT and coal for emergency restoration tends to be inversely proportional to the time since warmed, and the potential availability of even "cold" synchronous reserves is set to decline to a few modern plant units.

Current system restoration methods have been designed to deal with a total system black out rather than partial, regional black outs as experienced in the past. As system strength and the number of Black Start providers decline, the restoration strategy must be adjusted. Otherwise, re-starting the system becomes dependent on a very small proportion of generation remote from the load, leading to weaker power islands, which are more prone to voltage deviation and a requirement for more reactive power support locally.

Black Start costs are forecast to increase significantly over the next 10 years, with costs anticipated to increase by a 7-10 factor from present prices. Interconnectors could potentially decrease these costs as no additional plant is required for delivering this service (for example installing an auxiliary gas turbine when contracting with a CCGT).

4.3 Potential Benefits of Interconnectors

HVDC interconnectors, based on VSC technology, are capable of providing Black Start capability, as they have the ability to access generators in an area which is not blacked out, and therefore it may provide an opportunity to reduce the cost. . They can also potentially enable quicker restoration times for the transmission system and provide access to a greater diversity of fuel sources improving overall resilience.

The benefit to the system will be location-dependent (at both ends) and the diversity of location of interconnectors to the GB system will be a key factor in achieving the benefit. We are currently in discussions with interconnectors to develop this capability and investigate the potential economics of providing this service.

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[3] System Operability Framework 2014, http://www2.nationalgrid.com/uk/industry-information/future-of-energy/System-Operability-Framework

5. Reactive Response

5.1 Definition of service

The flow of reactive power on the transmission system affects voltage levels. Unlike system frequency, which is consistent across the network, voltage is a local issue which is uniquely related to the prevailing real and reactive power supply and demand in a local area. The SO must manage voltage levels on a local level, and without the appropriate injections of reactive power at the correct locations, the voltage profile of the transmission system will exceed statutory limits.

5.2 Future Challenges

The way we use electricity is changing the reactive demand on the transmission system and in recent years, the reactive demand has been falling[4]. The current annual spend on reactive response is approximately £71m[5]. Closure and lower utilisation of conventional power plants on the system, reduces the system capability to control the voltage, and may result in the need for investment in additional reactive compensation for additional constraint management services described in Section 7. Future interconnectors utilising the right technology could contribute to providing reactive power services to the GB transmission system.

5.3 Potential Benefits of Interconnectors

Interconnectors based on HVDC VSC-technology are designed with inherent reactive compensation plant that can be utilised to generate or absorb reactive power as required without the need for any additional equipment. By locating these links appropriately, there is the opportunity to utilise their reactive power capability to meet the changing needs of the transmission system and to reduce the need to procure reactive services from other sources.

Interconnectors can also provide Dynamic Voltage Control & System Stability depending on the technology employed. The reactive plant can provide continuous voltage control during load variations. HVDC VSC can also respond almost instantaneously to disturbances on the network and thus enhance system stability by maintaining system voltages during large disturbances. It should be noted however, that HVDC VSC technology will be required for dynamic voltage control.

In order to evaluate the value of interconnectors providing this service, we will utilise the FES to form a picture of the future changes in reactive generation and demand. We will then undertake a quantitative analysis to compare provision of the service by interconnectors versus conventional means.

6. Boundary Capability

6.1 Definition of Service

The ability of a transmission network to transfer energy from generation to supply can be described in terms of boundary capability. Each boundary in the transmission network is required to securely enable the maximum expected power transfer.

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[4] Electricity Ten Year Statement 2013, Section 2.4, Demand
[5] Monthly Balancing Services Summary – July 2014, Section 10.2. Voltage constraint costs are also incurred, however these are described in Section 7.

6.2 Future Challenges

Future changes in generation and demand will change the nature of power flows on the transmission system, potentially leading to transmission constraints (Thermal & Voltage) across some boundaries. As part of the annual Electricity Ten Year Statement (ETYS) studies, various options to provide boundary capability will need to be explored to ensure that the system security can be maintained. The location of interconnector connection points to the GB transmission system and the direction of power flow on the interconnector will have an impact on the boundary capability provided to the transmission system.

6.3 Potential Benefits of Interconnectors

Interconnectors could help reduce the need for network investment, by providing boundary capability and reducing constraint management costs. This requires appropriate location of interconnector connection points and depends on the prevailing market conditions between GB and the interconnected market. The objective of this paper is to identify additional benefits which interconnectors can provide to the transmission system, it does not seek to address the optimum connection point to the transmission. The determination of the optimum overall network design is fully considered as part of the Connection Infrastructure Options Note (CION) and is beyond the scope this paper.

In undertaking the CION, it is assumed that the control systems in the HVDC interconnectors are only designed to control the power flow across the interconnectors. Depending on the technology choice for HVDC convertors (i.e. CSC of VSC) and the design of the control system, interconnectors may facilitate either a reduction of transmission investment and/or increase on some boundary capabilities.

In order to evaluate the value of interconnectors providing this service, we will utilise the FES to form a picture of the future changes in the power flows across transmission system boundaries, and we will assess the impact of different technologies and control systems on network performance.

7. Constraint Management

7.1 Definition of Service

A constraint arises where the system is unable to transmit power supplies to the location of demand due to congestion at one or more parts of the transmission network. When a constraint occurs, the SO takes actions in the market to increase or decrease the amount of electricity at different locations on the network.

7.2 Future Challenges

Future changes in generation and demand will change the nature of power flows on the transmission system, potentially leading to transmission constraints (Thermal & Voltage) across some boundaries. The location of an interconnector connection point to the GB transmission system and the direction of power flow on the interconnector will have an impact on transmission constraint costs which currently cost around £220m per annum[6]. Interconnectors can play a significant role in managing future constraint cost. The impact and the potential benefits interconnectors play in constraint management will be assessed as described below.

[6] Monthly Balancing Services Summary – July 2014, Section 10.2

7.3 Potential Benefits of Interconnectors

With regards to constraint management, it may be possible for the SO to enter into a contractual agreement with the corresponding SO in the interconnected market to allow the transfer of energy from one SO to the other across the interconnector for the purpose of either solving a system constraint or to aid the balancing of the system. This SO to SO trade provides a commercial means to deviate from the interconnector scheduled flows and could help to reduce constraint costs particularly during times when there is spare capacity on the interconnector. Additional balancing services, such as SO to SO trades, may contribute to reduced Balancing Services Use of System (BSUoS) charges[7] and hence reduce the costs transferred to the consumer. There is also the potential for European TSOs to coordinate the dispatch of multiple interconnectors to resolve constraints in a European context but this is beyond the scope of this paper.

In order to evaluate the value of interconnectors providing this service, we will assess the incremental boundary capability provided by interconnectors and undertake a Cost Benefit Analysis to quantify the impact on constraint costs.

8. Dependency of benefits to the European electricity market

Exchange and sharing of ancillary services, in particularly balancing resources, is critical both for the integration of increased volumes in renewable energy integration and to enhance the efficient use of available generation capacities. There is currently a great diversity of arrangements for ancillary services throughout Europe. Common rules for cross border exchanges of such services are included within the future Network Code on Electricity Balancing. In the absence of such a code, any homogenous assessment of the value of transmission for exchange of ancillary services remains difficult.

The European Council, Commission and Parliament are currently working together to develop the energy policy required to meet our 2030 energy goals around climate change and energy security. These European legislative bodies have clearly stated how they believe additional European interconnection is a cornerstone of achieving a single European electricity market and removing isolated electrical networks. Further interconnection will facilitate the removal of both physical and market based cross border constraints. This in turn will allow a greater number of providers to participate in a far larger, single market both for the provision of balancing services, as well as energy, which will ultimately provide lower costs for end consumers.

The Network Code on Electricity Balancing shall set all necessary features to facilitate the development of cross-border exchange of balancing energy, and encourage that these are made possible on every border, in the limits defined by the Network Code on Load Frequency Control and Reserve concerning procurement of Ancillary Services. Reservation of cross-border capacity for the purpose of balancing energy is only allowed for cases where TSOs can demonstrate that such reservations would provide socio-economic efficiencies.

The number of benefits associated with interconnectors is dependent on the market environment, and physical characteristics of the system the interconnector is connected to. For example, the provision of frequency response at one end may have an impact on the other system and as such may limit the capability and benefit associated with the interconnector. The technical capability of an interconnector to deliver ancillary services, within various timescales should be carefully evaluated, considering both the technical characteristics of the interconnector and the technical definition of the products in the market:

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[7] The BSUoS charge recovers the cost of day to day operation of the transmission system.

- If at least one of the interconnected markets (such as the GB) has a market-based approach to balancing services, such that the price of balancing services can be sensibly projected over a forecast horizon, then a question of monetisation of balancing services benefits arises.

- If the interconnector connects to one area which has a market-based approach with the remote end connecting to an area which does not have a market-based approach, then great care should be exercised in attempting to quantify the benefits.

In exploring the benefits interconnectors could facilitate, it should be noted that further discussions will be required with the connecting TSO to ensure benefits we have identified are available and that there are no network restrictions or adjacent networks which restrict availability of these services. It should also be noted that it may be difficult for a merchant interconnector to translate these consumer benefits into value which could be assigned to any individual project.

9. Conclusion and Next Steps

The provision of additional HVDC interconnections to the European power network offers a number of potential benefits to GB and the end consumer. The degree of benefit depends in some cases on the location of the interconnector, and the technology employed.

Going forward at the request of Ofgem, we will be undertaking further assessments to quantify the potential benefits and value that interconnectors connecting to the GB transmission system against Gone Green Scenarios. This analysis will help support Ofgem in their assessment of the Cap and Floor regime for near term projects and Ofgem have indicated the combinations of projects for assessment.