# SO Submission to Cap and Floor

**June 2017**

nationalgrid

# Contents

# 1 Executive Summary

The aim of this report is to provide an assessment on a range of ancillary services that new interconnector projects may provide and the potential financial benefits for the end consumer.
The interconnectors assessed in this paper are Gridlink, Neu Connect, and North Connect all of whom have applied to the Cap and Floor regime in window 2. In addition, Aquind Interconnector, which has chosen the exemption route, has also been included for comparative purposes.

## 1.1 Scope of this paper

***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 adjacent TSOs to ensure that neighbouring networks can support the provisions of services described.***

The technology used in the design of existing and future Interconnectors is based on Voltage Source Converter (VSC) technology which will allow for the provision of some of the new services which are required for future system operability.[1]

Three Interconnector projects have been shortlisted for consideration under the Cap and Floor framework. These are:

| Project Name | Interconnected Country | Transmission Entry Capacity (TEC) (MW) |
|---|---|---|
| Gridlink | France | 1500 |
| Neu Connect | Germany | 1400 |
| North Connect | Norway | 1400 |

TEC is maximum amount of power a generator or interconnector is permitted to export onto the transmission system. Discussions have taken place regarding a potential reduction of the TEC of Gridlink, however this assessment is based on a 1500MW TEC.
Aquind Interconnector from France to GB (2000MW Transmission Entry Capacity) has been analysed for comparative purposes despite Aquind Limited’s election to pursue the merchant exemption route. All four interconnectors are due to connect in 2022.

The assessments cover the monetary benefit which may be experienced by the SO by contracting with the interconnectors rather than alternative sources. The assessments will cover the following areas:-

- Frequency response
  - The real-time difference between system demand and total generation results in continuous changes to the system frequency. The SO must ensure that sufficient response from various sources such as generation, demand, or interconnector is held to manage the system frequency.
- Black start
  - Black Start services are procured from various sources across the network as a reserve which interconnectors can contribute to at a lower cost. In the event of a black out, these sources must be available to reenergise the network.
- Reactive response

[1] See Ofgem – Benefits of Interconnectors for more information on technologies used

    - The reactive demand seen on the transmission system is falling. Closure and lower utilisation of conventional power plants on the system reduces the potential reactive response available at optimum locations. Interconnectors can alleviate reactive support capital expenditure by providing reactive compensation
- Constraint management (operational cost implications)
    - When a network constraint occurs, the SO takes actions in the market to increase and decrease the amount of electricity at different locations on the network to ensure network boundary limitations are not exceeded. Additional interconnector flow in an area can alleviate or contribute to network restrictions and impact on the constraint costs.

The analysis has been based on a high benefit scenario and a low benefit scenario to demonstrate the range of benefits. The high benefit scenario is a selected Future Energy Scenario (FES) where it is expected that the interconnectors generate the highest benefit to consumers. The high scenario selected for the assessment is Consumer Power. Consumer Power is the scenario where there is a high level of prosperity and less focus on the green ambition. The high levels of prosperity allow for high investment and innovation. New technologies are prevalent.

Low scenario is a selected FES where it is expected that the interconnectors generate the lowest benefit to consumers. No Progression has been selected as the low scenario where there is less prosperity and a low focus on the green environment. This is a world where business as usual activities prevail and traditional sources of gas and electricity continue to dominate.

In order to provide a trend in the results, three spot years have been analysed for each area, 2022, 2026 and 2032. Each interconnector has been studied independently with all Cap and Floor Window 1 interconnectors in the background.

## 1.2 Confidentiality

The assessments in this report were based on price sensitive information. The release of this information could compromise the ability of the System Operator to obtain these services at the most competitive rates. All information within this report should be kept confidential at all times. A public version of this report will be published with all confidential information omitted.

## 1.3 Outputs

It should be noted that the benefits and costs identified in this report are based on costs which may be incurred based on current practices for ancillary services. It is assumed that the utilisation of multiple HVDC Interconnectors to provide ancillary services in a competitive environment, may significantly reduce the costs incurred by the system operator to procure these services however competition has not been factored into the analysis.

### 1.3.1 Key Findings

In summary, the assessments carried out for this report do identify monetary benefits from services that the Window 2 projects and Aquind could provide which in turn will benefit the GB consumer. However, due to the high level of potential interconnection forecasted as a result of Window One, the monetary benefit of Window 2 projects is less than what was forecasted for earlier projects.

### 1.3.2 Overview of the potential benefits

Table 1 presents an overview of the potential monetised benefits which could be generated by the additional interconnectors in one year. It provides the maximum and minimum annual benefits in present value across all the studied years (2022, 2026, and 2032) for each scenario studied; Consumer Power (CP) and No Progression (NP).[2]

Benefits such as frequency response are system wide while others such as reactive response are localised.  Nevertheless, where a local benefit is identified, the financial benefit is to the consumer nationwide in avoided expenditure.

***Table 1: Annual maximum and minimum values of each service, per interconnector and scenario***

| Overall annual value of services (£m) (PV) | Gridlink | | | | Greenage | | | | North Connect | | | | Aquind | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (1500MW) | | | | (1400MW) | | | | (1400MW) | | | | (2000MW) | | | |
| | Kingsnorth | | | | Grain | | | | Peterhead | | | | Lovedean | | | |
| | CP | | NP | | CP | | NP | | CP | | NP | | CP | | NP | |
| | Min | Max | Min | Max | Min | Max | Min | Max | Min | Max | Min | Max | Min | Max | Min | Max |
| Frequency Response Benefit | **Sensitive Information** | | | | | | | | | | | | | | | |
| Black Start | | | | | | | | | | | | | | | | |
| Reactive Response | | | | | | | | | | | | | | | | |

The frequency response analysis concludes the level of frequency response benefit each interconnector could provide and whether the price of this service from an interconnector could displace existing contracts therefore reducing the overall cost to the consumer to procure sufficient frequency response. **From Table 1 it can be seen that all the interconnectors studied will provide some benefit with regards to frequency response.** The range per interconnector is similar as expected due to the similar capability of each interconnector. The differences between the interconnector frequency response benefits are mainly driven by the market flows on the interconnector and the capacity.

**The black start analysis has identified that only North Connect in its defined location, Peterhead, will be able to provide benefit with regards to black start.** To ensure diversity of supply, the contracting strategy allows for only one interconnector to provide black start per zone. Along the south coast where the other three interconnectors plan to connect, there are existing or planned interconnectors which have black start capability, therefore there is no benefit from the additional interconnection. Competition has not been factored into the analysis due to its unpredictability. The financial benefit from North Connect's black start service is very reliant on the assumed cost for black start services, therefore sensitivities have been assessed with an optimistic and pessimistic view of the cost of renewing existing black start contracts. The result is consistent across all FES scenarios.

For the reactive support analysis, power system studies have been completed to identify what the reactive support requirements would be on the network in a case where no additional interconnectors arrived. In order to compensate for the reactive power issues on the network with and without the Cap and Floor interconnectors, a certain level of capital investment would be required. The difference in capital expenditure identifies the benefit of that interconnector with regards to reactive support. The power system studies identified no reactive problems in the South East area of the network where Gridlink and Neu Connect are connecting. Likewise, around Peterhead there are no reactive problems foreseen.

[2] For information on the Future Energy Scenarios (FES) visit http://fes.nationalgrid.com/

Consequently, **Gridlink, Neu Connect and North Connect are not able to provide any additional benefits with regards to reactive power compensation. However, Aquind is able to support the reactive issues** around Lovedean and could save capital expenditure as shown in the table.

***Table 2: Constraint management costs***

| Annual Constraint Costs (PV) (£m) | Gone Green (GG) | | | No Progression (NP) | | |
|---|---|---|---|---|---|---|
| | 2022 | 2026 | 2032 | 2022 | 2026 | 2032 |
| Neu Connect | **Sensitive Information** | | | | | |
| Gridlink | | | | | | |
| North Connect | | | | | | |
| Aquind | | | | | | |

Table 2 shows the annual constraint costs attributable to the interconnectors across all scenarios and spot years studied. As shown, there is a huge variation in the annual constraint costs which is driven mainly by the direction of flow on the interconnector. In earlier years when the interconnector is flowing power into GB, the constraint costs increase as a result of the interconnector. In No Progression (NP) the GB System Marginal Price (SMP) does not fall as quickly and therefore the interconnector will be importing and increase the constraint costs. When the interconnector is exporting the interconnector contributes to alleviating constraints as seen by the negative values in the table. The interaction of the interconnectors makes the correlation between constraint costs and relative GB prices less definitive as power may be transferred from an importing interconnector straight out of GB again on a neighbouring interconnector.

# 2 Introduction

The objective of this paper is to monetise the benefits to GB consumers of the Cap and Floor Window 2 interconnectors. It follows a paper submitted to Ofgem in September 2016 which provides an overview of the range of services interconnectors could provide and future challenges to system operation given the changing nature of generation and demand.

This paper is written with a chapter for each service which could be provided by each interconnector. The sections include Frequency Response, Black Start, Reactive Power and Constraint Management. Each chapter outlines the methodology used and the range of benefits for each interconnector to the GB consumer.

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 more capable of facilitating the delivery of ancillary services too. These services include 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 voltage source HVDC technology. For more information, the reader is directed to Benefits of Interconnectors 2016. [3]

Voltage Source Converter (VSC) technology is going to be used for all interconnectors in this assessment.

**Frequency Response (Chapter 5)**

The real-time difference between system demand and total generation results in continuous changes to the system frequency. The SO must ensure that sufficient response from various sources such as generation, demand, or interconnector is held to manage the system frequency. In the future, with the changes expected in the energy mix, such as increasing renewables and larger nuclear generation capacity, new measures to control the system frequency will be required. Interconnectors (VSC) have the ability to rapidly change their power output across their full operating range, thus making them a very suitable option for managing the system frequency in the future.

**Black Start Capability (Chapter 6)**

Black Start services are procured from various sources across the network as a reserve. In the event of a black out, these sources must be available to reenergise the network. The costs of procuring the Black Start service is forecasted to increase from 2022 as the existing contracts expire and plants close. The contracting strategy for Black Start is an evolving process which is continually reviewed. It has been identified that interconnectors can provide Black Start capability if they are of HVDC VSC design and sufficient system strength exists behind the interconnected system to provide support. The analysis focuses on identifying the impact and associated benefits that the interconnectors could have on Black Start in 2022, 2026 and 2032 if contracted with. It demonstrates that if interconnectors connect in certain zones, there will be a net economic saving on the overall Black Start procuring costs.

**Reactive Power Response (Chapter 7)**

The reactive demand seen on the transmission system is falling. Closure and lower utilisation of conventional power plants on the system reduces the potential reactive response available at optimum locations. This reduces system capability to control voltage which may result in the need

[3] See Ofgem – Benefits of Interconnectors 2016 for more information on technologies used. https://www.ofgem.gov.uk/ofgem-publications/93802/ngetreporttoofgem-qualitativeinterconnectorbenefits-pdf

for investment in additional reactive compensation. Interconnectors are designed with inherent reactive compensation which can be utilised to generate or absorb reactive power as required without the need for any additional equipment. Interconnectors can also provide additional benefits of dynamic voltage control and system stability.

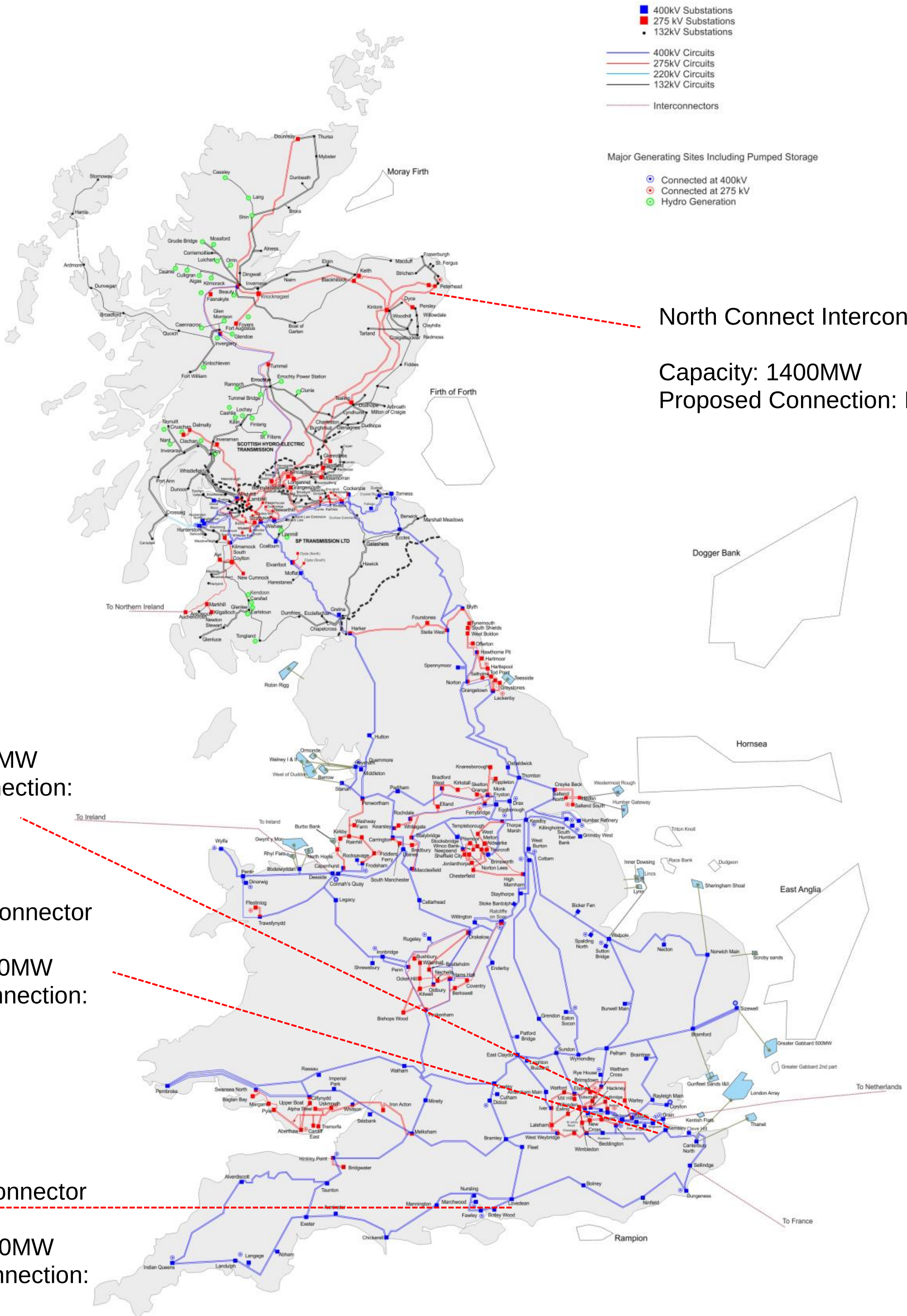
However, unlike system frequency, which is consistent across the network, voltage is a local issue which is uniquely related to the prevailing real and reactive power supply and demand in a local area. The SO must manage voltage levels on a local level, and without the appropriate injections of reactive power at the correct locations, the voltage profile of the transmission system will exceed statutory limits, therefore the benefits an interconnector can provide is dependent on the connection location on the network.

**Constraint Management (Chapter 8)**

When a network constraint occurs, the SO takes actions in the market to increase and decrease the amount of electricity at different locations on the network to ensure network boundary limitations are not exceeded. Interconnectors facilitate the SO by enabling contractual agreements with corresponding SOs in the interconnected markets allowing the transfer of energy from one SO to the other across either solving a system constraint or to aid the balancing of the system. There is a potential that the domestic SO may have to take an action on the interconnector which would result in an additional balancing mechanism cost (constraint cost), however, the interconnector also has the potential to reduce constraint costs on the network during times when there is spare capacity on the interconnector.

Figure 1  below shows the GB transmission network with Gridlink, Neu Connect, North Connect and Aquind, the benefits of which have been assessed in this report.

## GB Transmission Network with Interconnector




North Connect Interconnector

Capacity: 1400MW
Proposed Connection: Peterhead

Neu Connect Interconnector

Capacity: 1400MW
Proposed Connection: Grain

Gridlink Interconnector

Capacity: 1500MW
Proposed Connection: Kingsnorth

Aquind Interconnector

Capacity: 2000MW
Proposed Connection: Lovedean

**Dependency of benefits to the European electricity market**

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.

The Network Code on Electricity Balancing shall set all necessary features to facilitate the development of cross-border exchange of balancing energy, and encourage these to be made possible on every border, within 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 an Interconnector 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.

# 3 Scenario and Spot Year Justification

The analysis has been based on two scenarios for each study area where it is thought that one scenario will show the interconnectors provide the greatest benefit and one will show the least benefit. The rationale for the above is to ensure the best case and the worst case is considered in this analysis. To provide a trend of results, the SO has analysed three different years for both scenarios.

For the Frequency Response analysis, Consumer Power (CP) was expected to show the greatest requirement for additional response and therefore this scenario will show the maximum potential value to the GB consumers of the additional interconnection. In CP there is less conventional plant running and demand is lower, therefore system inertia is at the minimum. This results in greater fluctuations in frequency following an event, therefore a higher level of frequency reserves is needed. In comparison, it was expected that No Progression (NP) will show the least benefit from additional interconnection. This is because there is more synchronous plant on the system and demand is forecasted to remain higher in this scenario. This means voltage fluctuations will be lower and the Rate of Change of Frequency (RoCoF) will also be lower.

For the Black Start analysis, CP was studied as the scenario with the highest level of benefit from having additional interconnection. This is due to the lower level of conventional plant which is capable of providing black start services. Due to the lack of competition, the prices may be higher than they would be with additional plant competing. Interconnectors will bring additional competition and will, therefore, drive down the price. In comparison, in NP where more conventional plant are still online, there will already be a higher level of competition so the benefit of additional interconnectors would be lower. Principally, this would imply there would be less benefit in the scenario with greater competition. However, due to the unpredictable nature of how competition will impact clearing prices for Black Start this has not been included in the assessment.

For the Reactive Requirements assessment (Voltage Studies), Consumer Power is the scenario where the highest level of transmission connected compensation will be required. As a result, it was expected that CP will show the greatest benefit from having interconnectors available to provide reactive support. No Progression has been used for the low benefit scenario as there is more synchronous plant in this scenario and demand is high. This means higher system inertia and lower levels of lighter demand on the system results in the cables being less capacitive causing less voltage issues. As a result, it was expected that the interconnectors will generate less benefit in No Progression (NP).

For constraint management, the studies have already been carried out as part of the (Connection and Infrastructure Optioneering Note (CION), the results from all four scenarios across the 25 year asset life has been included in the report.

<table>
<tr><td rowspan="2">Year</td><td colspan="5">Ancillary Service</td></tr>
<tr><td>Frequency Response</td><td>Black Start Capability</td><td colspan="2">Reactive Response</td><td>Constraint management</td></tr>
<tr><td>2022</td><td rowspan="3">High – CP<br>Low - NP</td><td rowspan="3">High – CP<br>Low - NP</td><td>2022</td><td rowspan="2">High – CP<br>Low - NP</td><td rowspan="3">All scenarios</td></tr>
<tr><td>2026</td><td>2025</td></tr>
<tr><td>2032</td><td colspan="2">Not studied[4]</td></tr>
</table>

***Table 3: Summary of scenarios and spot years studied***

[4] Reactive Power models are only available up to 10 years into the future due to future uncertainties.

# 4 Interconnectors Assessed

## 4.1 Neu Connect

Neu Connect is a 1400MW interconnector which will connect to Grain on the South East coast of the UK transmission network. The interconnector is contracted to connect in 2022.

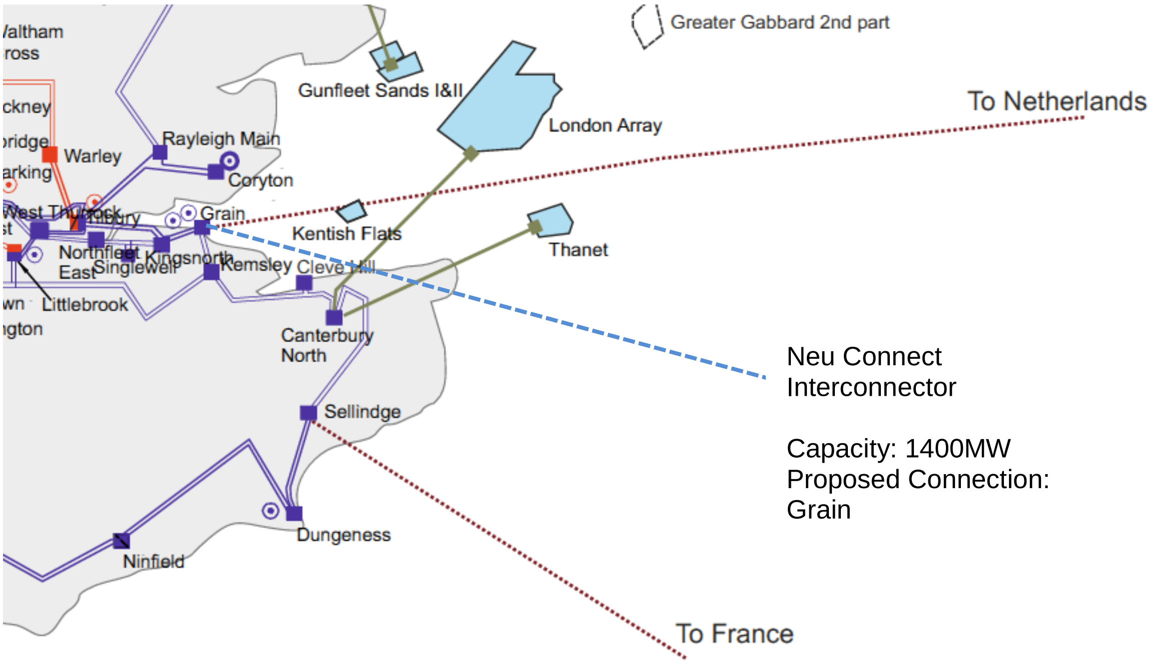



***Figure 2: Neu Connect proposed connection point***

The monetised benefits for the services which Neu Connect Interconnector could provide have been considered and the results can be found in Chapters 5, 6, 7 and 8.

## 4.2 Gridlink

Gridlink is a 1500MW interconnector which will connect to Kingsnorth on the South East coast of the UK transmission network. The interconnector is contracted to connect in 2022.

The monetised benefits for the services which Gridlink Interconnector could provide have been considered and the results can be found in Chapters 5, 6, 7 and 8.

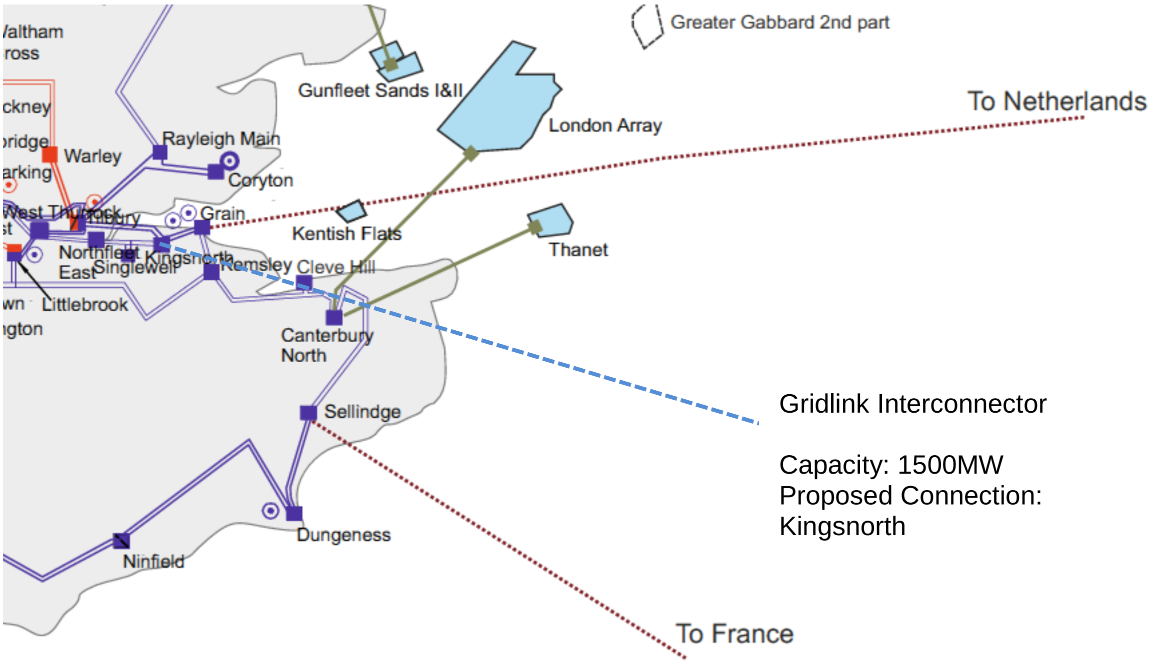



*Figure 3: Gridlink proposed connection point*

## 4.3 North Connect

North Connect is a 1400MW interconnector which will connect at Peterhead which is on the North East coast of the UK transmission network. The interconnector has a contract to connect in 2022.

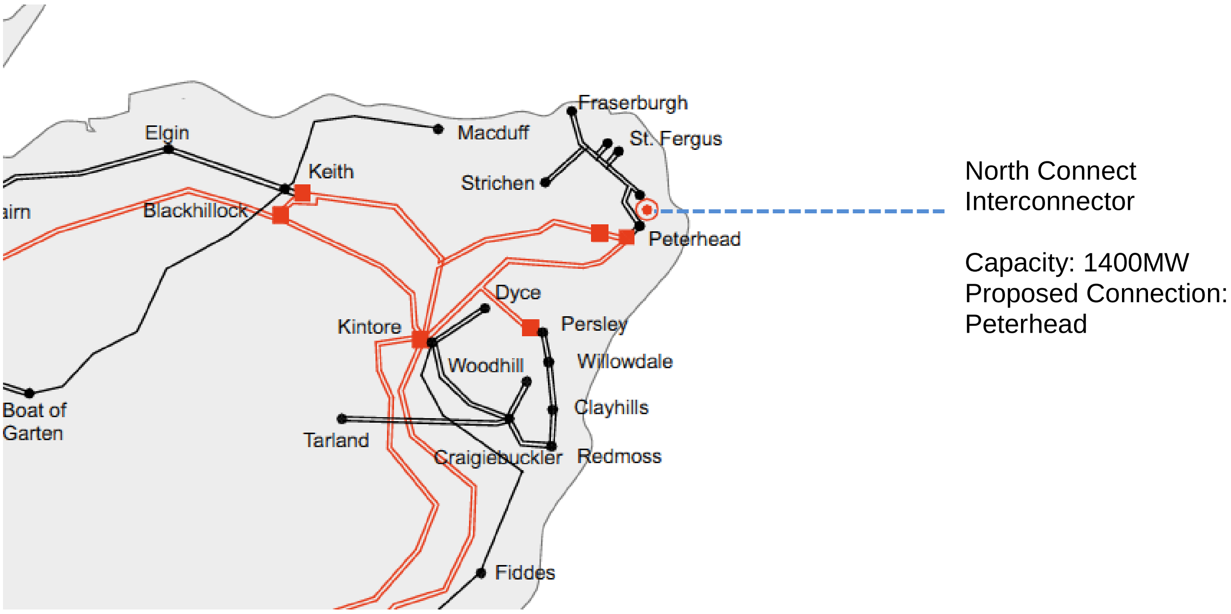



*Figure 4: North Connect proposed connection point*

The monetised benefits for the services which North Connect Interconnector could provide have been considered and the results can be found in Chapters 5, 6, 7 and 8.

## 4.4 Aquind (for comparison only)

Aquind is a 2000MW interconnector which will connect at Lovedean on the South coast of the UK transmission network. The interconnector is contracted to connect in 2022

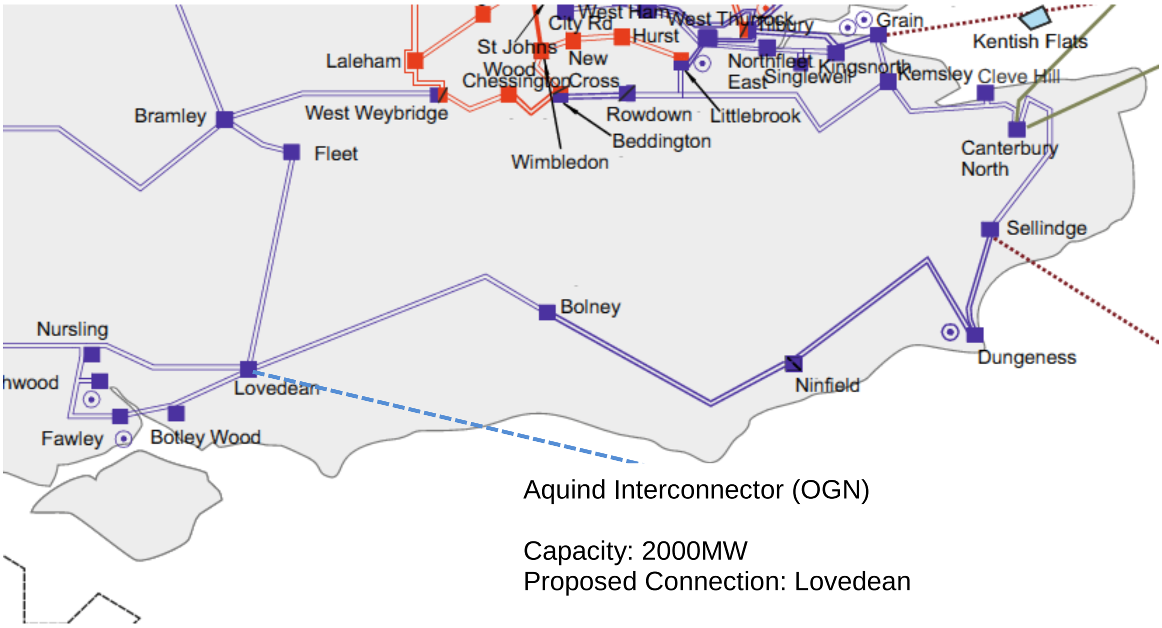



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***Figure 5: Aquind proposed connection point***

The monetised benefits for the services which Aquind Interconnector could provide have been considered and the results can be found in Chapters 5, 6, 7 and 8.

# 5 Frequency Response

## 5.1 Introduction

Interconnectors have the potential to cause various effects on the cost of procuring frequency response. This section quantifies the potential for interconnectors to provide high and low frequency response and displace commercial frequency response.

Interconnectors are able to provide both low and high response. Low response responds to a downward deviation in the frequency (such as when a large in-feed trips) i.e. generation is lost on the system. High response responds to an upwards deviation in frequency (such as when a large out-feed trips) i.e. when a large area of demand is lost.

Interconnectors have the potential to increase the largest in-feed and out-feed loss on the system resulting in additional response requirements. Therefore, it must be noted that there may be additional costs attributable to the interconnector to secure for the higher in-feed or out-feed loss as a result of these interconnectors.

## 5.2 Methodology

When an interconnector is importing it is able to provide high response without the cost of repositioning the interconnector i.e. changing from import to export. Similarly, when an interconnector is exporting it is able to provide low response without the cost of repositioning. Furthermore, when an interconnector is at float (zero output) it can provide both without repositioning. This is technically possible since the current cap & floor assessed interconnectors use VSC technology. For the purpose of this assessment it is assumed that the type of response provided by the interconnectors will be Primary Response (PR) and High Response (HR). Primary response is required when the frequency is low. At this point, additional generation must be available to bring it back up. High response is when the frequency is too high. At this point, generation must be reduced.

Interconnectors could still expect to be paid the mandatory frequency response payment; however, they would displace the more expensive, marginal form of frequency response: commercial frequency response. The savings involved are therefore the difference between the cost of commercial frequency response and mandatory frequency response. This is a difference of roughly 17-20 £/MW/h depending on the type of response being considered. The system need for FR has been considered.

### 5.2.1 Calculating Frequency Response Holding Payment Savings

#### 5.2.1.1 Frequency Response Costs

In order to calculate the potential savings associated with interconnectors being able to provide frequency response without having to reposition, the difference between the average cost of commercial and mandatory frequency response holdings over the last 12 months is taken. These are available from National Grid's Services Reports[6]. Figure 6, below, shows the cost of different frequency response products over the last 12 months. Note that commercial frequency response is not separated out into low and high and therefore we take that as the cost of both low and high commercial frequency response.

[6] See http://www2.nationalgrid.com/UK/Industry-information/Electricity-transmission-operational-data/Report-explorer/Services-Reports/

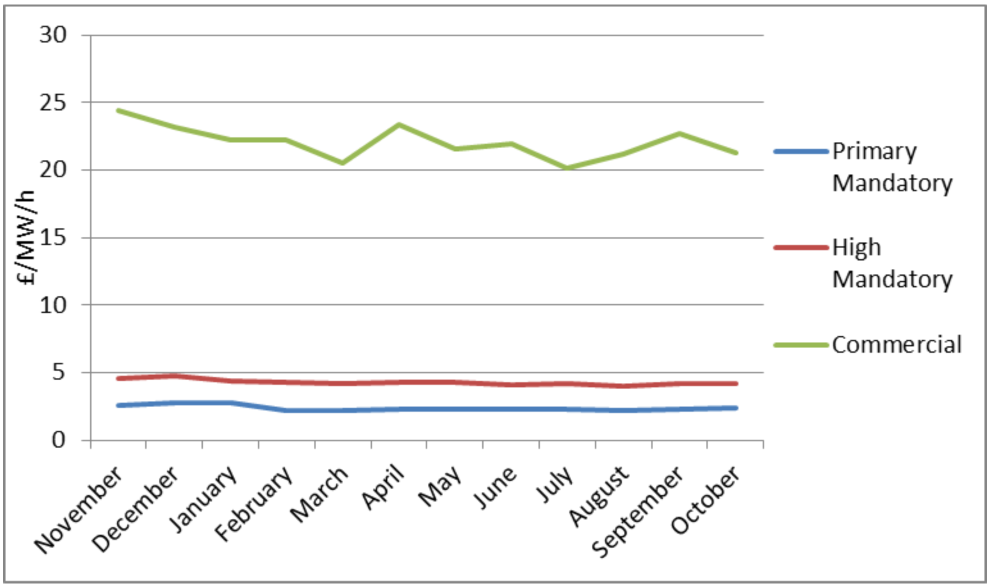


***Figure 6: Average Monthly Frequency Response Holding Prices***

The average prices for primary (mandatory), high (mandatory), and commercial frequency response were £2.4/MW/h, £4.3/MW/h, and £22/MW/h respectively. Therefore, the marginal benefit of interconnectors providing frequency response without repositioning is £19.6/MW/h, and £17.7/MW/h for low and high response respectively.

#### 5.2.1.2 Calculating Interconnector Import/Export Profiles

In order to calculate the potential savings associated with interconnectors providing frequency response, an indication of how interconnectors are going to operate is required. We, therefore, take the unconstrained dispatch[7] from National Grid's in-house market model, ELSI[8] for each of the interconnectors in turn, for each of the studied years (2022, 2026, and 2032), and the two FES scenarios under consideration (Consumer Power [CP], and No Progression [NP]).

#### 5.2.1.3 Calculating Frequency Response Requirements

Frequency Response requirements are modelled using National Grid's in-house tool, FRANK. A number of inputs are required to calculate the requirement of FR, the largest loss, system-wide demand and system inertia. With this information, an estimate of the FR system requirements can be found to contain the largest loss risk in the event of a trip.

#### 5.2.1.4 Calculating Frequency Response Requirements

For each interconnector, two loading levels of frequency response are considered, and their financial savings calculated. The levels are a percentage of the total installed capacity of each interconnector and in line with the previous Cap & Floor assessment at 10% and 5% of total installed capacity respectively.

Interconnectors have the ability to provide a higher percentage of response, however, further investigation would need to be conducted to ensure the foreign exporting system can cope with more extensive sudden increases/decrease in demand/generation.

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[7] This is before post gate closure constraint management has taken place. We have taken this over the constrained dispatch since this is a function of the background network, which is currently under review as part of the annual Network Options Assessment (NOA) process.

[8] This is used over the recently acquired BID3 since the original CION assessments were completed using ELSI. We therefore use ELSI for issues of continuity.

## 5.3 Potential Frequency Response Holding Cost Savings

Table 4 through Table 7 below details the potential frequency response savings in Present Value (PV)[9] for each of the Cap & Floor interconnectors in turn. It is assumed interconnectors can provide 5-10% of their capacity for frequency response. Interconnectors have the ability to provide a higher percentage of response, however, further investigation would need to be conducted to ensure the foreign exporting system can cope with more extensive sudden increases/decrease in demand.

It is important to note that this represents a best case scenario where all of the interconnector's potential frequency response holding provision (when needed) displaces commercial frequency response and not lower cost forms such as mandatory frequency response.

***Table 4: Neu Connect***

| Neu Connect | Consumer Power | | | No Progression | | |
|---|---|---|---|---|---|---|
| (PV) £m | 2022 | 2026 | 2032 | 2022 | 2026 | 2032 |
| PR Savings 10% | Sensitive Information | | | | | |
| PR Savings 5% | | | | | | |
| HR Savings 10% | | | | | | |
| HR Savings 5% | | | | | | |
| **Total 10%** | | | | | | |
| **Total 5%** | | | | | | |

***Table 5: Gridlink***

| Gridlink | Consumer Power | | | No Progression | | |
|---|---|---|---|---|---|---|
| (PV) £m | 2022 | 2026 | 2032 | 2022 | 2026 | 2032 |
| PR Savings 10% | Sensitive Information | | | | | |
| PR Savings 5% | | | | | | |
| HR Savings 10% | | | | | | |
| HR Savings 5% | | | | | | |
| **Total 10%** | | | | | | |
| **Total 5%** | | | | | | |

***Table 6: North Connect***

| North Connect | Consumer Power | | | No Progression | | |
|---|---|---|---|---|---|---|
| (PV) £m | 2022 | 2026 | 2032 | 2022 | 2026 | 2032 |
| PR Savings 10% | Sensitive Information | | | | | |
| PR Savings 5% | | | | | | |
| HR Savings 10% | | | | | | |
| HR Savings 5% | | | | | | |
| **Total 10%** | | | | | | |
| **Total 5%** | | | | | | |

***Table 7: Aquind***

[9] The PV is calculated using the Social Time Preference Rate (STPR) of 3.5% which is in line with the Treasury Green Book and based on the current year price (2016/2017).

| Aquind | Consumer Power | | | No Progression | | |
|---|---|---|---|---|---|---|
| (PV) £m | 2022 | 2026 | 2032 | 2022 | 2026 | 2032 |
| PR Savings 10% | Sensitive Information | | | | | |
| PR Savings 5% | | | | | | |
| HR Savings 10% | | | | | | |
| HR Savings 5% | | | | | | |
| **Total 10%** | | | | | | |
| **Total 5%** | | | | | | |

***Figure 7: Geographical representation of Frequency Response Savings***

**Sensitive Information**

- PR Savings 10%
- PR Savings 5%
- HR Savings 10%
- HR Savings 5%

We can observe two general trends in the potential savings attributable to the interconnectors; over time the low response savings increase and high response savings decrease. This is because over time the system marginal price in Great Britain reduces (in both scenarios studied) as a result of increased penetration of low marginal cost generation, such as nuclear, wind, and solar. The interconnectors at first import power as GB prices are generally higher than those abroad, so have the opportunity to provide high frequency response, and then export in the later years, so have the opportunity to provide low response without having to reposition. This pattern is generally observed across all interconnectors studied.

Furthermore, the potential savings are much greater in Consumer Power relative to No Progression. This is principally because of two factors: there are fewer large generators and fewer interconnectors due to connect in NP rarther than in CP. So the largest loss tends to be lower necessitating less frequency response to be held. Secondly there is generally non-synchronous generation in NP and so system inertia tends to be higher leading to lower levels of frequency response holdings being required.

We can also see that frequency response savings are relatively small in the earlier years. This is because in early years the interconnectors tend to import into GB, and so are mostly only able to provide high response. However, there is limited need for high frequency response in these early years. This is because the largest driver for high response is the potential fault of a large interconnector exporting from GB, and therefore behaving like a large demand centre tripping, leading to upwards pressure in the frequency. However, since GB system prices are generally higher than those in prospective interconnected countries there is little export to these countries except in times when either demand patterns or renewable generation profiles diverge between GB and the other country.

Low response is different in that there is a large and increasing need for low response. This is driven by two principal components: firstly the largest in-feed loss risk generally increases over time as large generators and interconnectors connect. Secondly, as increasing amounts of non-synchronous generation connect to the system, this will lead to lower inertia conditions.

Therefore, low response savings are greater in later years than high response savings were in early years. This can be seen as interconnectors begin to export much more in later years and so are able to provide more frequency response.

Past these broad themes the exact values each year’s savings take for each interconnector and scenario are down to the specifics of the market the interconnector is proposing to connect with, and the scenario under consideration.

One notable anomaly is where North Connect creates no savings in frequency response costs in 2026 and 2032 under Consumer Power. This is because in later years it is other Norwegian interconnectors exporting which creates the need for high response. Therefore when high response is needed North Connect is exporting and so unable to provide it without repositioning.

## 5.4 Summary

In this analysis we have shown that the Cap & Floor assessed interconnectors are potentially able to provide a benefit to the system by being able to provide frequency response cheaper than the current marginal form of frequency response (commercial frequency response)[10]. The value of this is intrinsically linked to the interconnector’s generation profile in that during the early years the interconnectors generally import to GB, and so can mainly provide high response (which is mainly needed when the interconnectors are exporting). In later years when the interconnectors begin to export in greater quantities they are able to provide low response, which is needed in significant quantities.

Whilst beyond the scope of this analysis, interconnectors can also displace synchronous generators in the merit order and so reduce system inertia. This would lead to, amongst other things, an increase the amount of frequency response needed to keep the grid stable. The opposite can be true when the interconnectors are exporting, and so increase the amount of synchronous generation on the system, and so system inertia. However, it could also be the case that instead of allowing more synchronous generation onto the system exporting interconnectors could prevent non-synchronous renewables from being curtailed instead, and so not raise system inertia.

[10] Where benefits attributable to an interconnector have been estimated this is with the assumption that the interconnector is able to provide Primary, and High response.

# 6 Black Start

## 6.1 Introduction

Black Start services are currently contracted to reenergise the network in block pieces joining up the sections until the entire network is reenergised. Services are contracted from an array of strategically located generators at specific locations, which are capable of re-energising the system. Black Start costs are forecasted to a cost approximately £Xm per annum by 2026 and kept at similar level till 2032. HVDC Interconnectors are capable of providing Black Start capability, as they have the ability to access generators in an area which is not blacked out.

Interconnectors which use Voltage Source Converter (VSC) technology[11] have the potential to offer Black Start capability and also potentially enable quicker restoration times for the transmission system (given there is no requirement to restore generation) and also provide access to a greater diversity of fuel sources improving overall resilience.

The future generation mix will be dominated by non-synchronous generation which is presently (and for the foreseeable future) unlikely to contribute to Black Start.

## 6.2 Methodology

The current contracting strategy for black start contracts is to have 6 zones with an average of 3 plants per zone. To ensure a diverse supply during black start only allows 1 interconnector per zone can be contracted with. The aim of the strategy is to restart the network in block pieces joining up larger pieces until the entire network is re-energised. For this strategy generation must meet demand in local areas whilst maintaining voltage and frequency requirements, this is where the inherent capability of VSC interconnectors provide a great opportunity.

The analysis assumes the following:-

- Zero additional capital costs for Black Start in VSC interconnectors
- Zonal contracting strategy remains unchanged and three plants per zone is favoured. It assumes that no over contracting is required to achieve this.
- EWIC contract offer used as base for interconnector contract cost components, with ±50% tolerance
    - EWIC (East-West Interconnector) is the only interconnector which offers black start services and is therefore used as an indication of the interconnector contract cost.

Consumer Power (CP) has been studied as the high benefit scenario and No Progression (NP) as the low benefit scenario. An optimistic and pessimistic view of contract costs has been used. The optimistic view assumes all existing black start contracts for plant which exist in the FES are extended at a cost of £Xm p.a. Where there is insufficient black start plant, new contracts are created at a cost of £Xm p.a. The pessimistic view assumes no existing contracts are renewed therefore all contracts are created at a cost of £Xm p.a.

The diagram below shows the zones, current and future interconnectors overlaid on a UK map.

[11] This is not true for Current Source Converters (CSC) type Interconnector

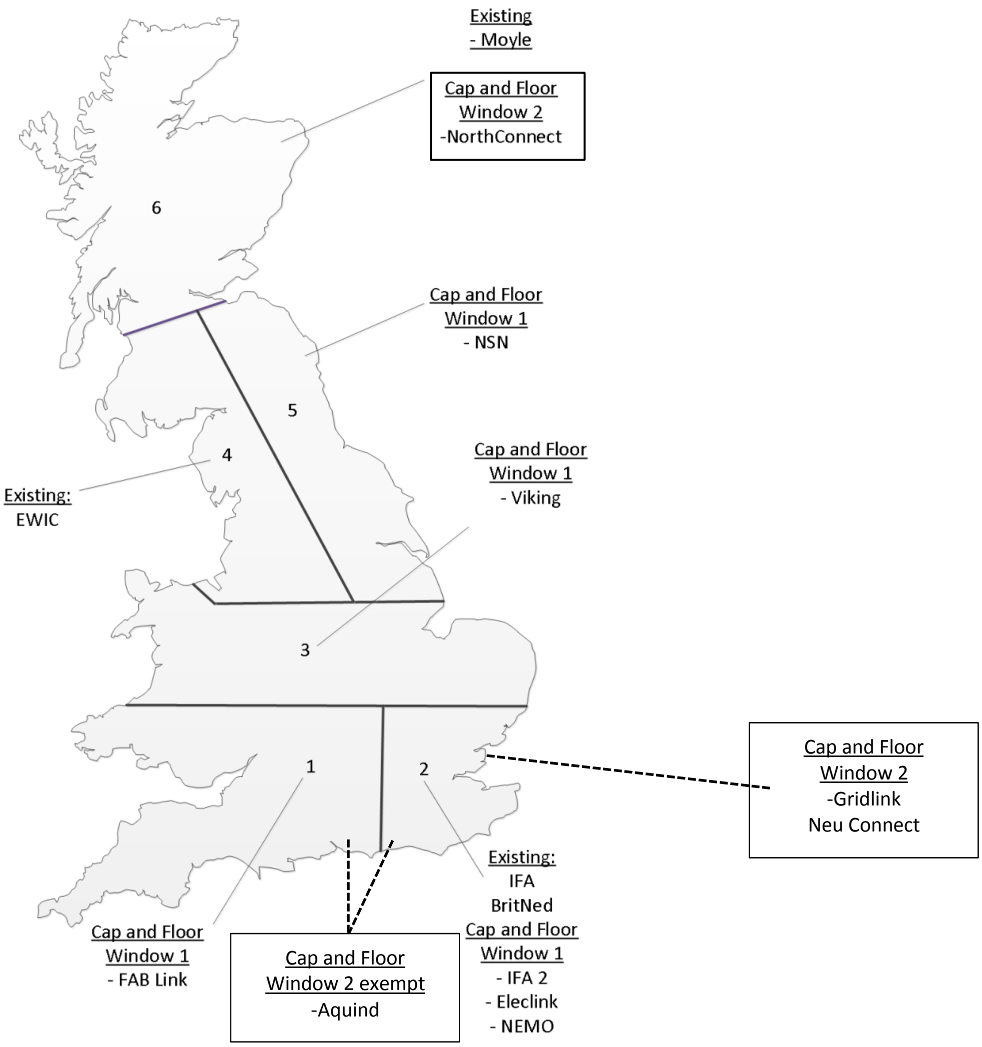


***Figure 8: Geographical representation of current and future interconnectors***

## 6.3 Result – Neu Connect, Gridlink and Aquind

Figure 8 illustrates how interconnectors exist or are planned to exist in Zone 1 and 2[12]. As the analysis assumes only one interconnector can be contracted with for diversity, there will be no benefit from Gridlink, Neu Connect or Aquind which are planned to connect to these zones. The impact of competition is too unpredictable to forecast at this stage so has not been factored into the analysis however one can assume that the additional interconnectors available to provide Black Start in Zone 1 and 2 will drive down the market clearing price of the interconnector contract.

## 6.4 North Connect

**The potential benefit of North Connect providing Black Start capability is within the range £Xm to £Xm as shown in Table 8.** The table demonstrates the benefit of North Connect in an optimistic and pessimistic scenario. The low estimate assumes the cost of a contract with North

[12] Aquind is connecting at Lovedean which is on the border between Zone 1 and 2. Therefore, it can be classified in either zone depending on black start requirements.

Connect is 50% of the cost of EWIC's contract and the high estimate assumes it is 150% of EWIC's contract. In an optimistic scenario the interconector could offer between £Xm - £Xm of benefit. This benefit in future vaule does not vary with time due to contracted plant remaining open across all years in all scenarios, however, due to discounting, the present value will fall over time as shown in Table 9.

| Zone 6 black start contract costs (£m) | Optimistic Scenario | | Pessimistic Scenario | |
|---|---|---|---|---|
| | High Cost Estimate | Low Cost Estimate | High Cost Estimate | Low Cost Estimate |
| Without Interconnector | **Sensitive Information** | | | |
| With Interconnector | | | | |
| **Savings** | | | | |

***Table 8: Black Start Costs and Savings in Zone 6 as a result of North Connect***

The values in Table 8 are based on current prices. Table 9 illustrates the value of North Connect in present value.

| Zone 6 black start savings in PV (£m) | Optimistic Scenario | | Pessimistic Scenario | |
|---|---|---|---|---|
| | High Cost Estimate | Low Cost Estimate | High Cost Estimate | Low Cost Estimate |
| 2022 | **Sensitive Information** | | | |
| 2026 | | | | |
| 2032 | | | | |

***Table 9: Black Start Savings in PV***

## 6.5 Summary

In summary, Neu Connect, Gridlink and Aquind will not have the potential to offer any economic benefit to the GB consumers with regards to Black Start services. This is due to the existing contracts with interconnectors within the same zone. **However, North Connect can offer a potential annual saving of £Xm - £Xm (PV) by offering Black Start services depending on the assumptions made.**

# 7 Reactive Power

## 7.1 Introduction

The voltage-source-converter HVDC technology allows future interconnectors to provide reactive power support to the transmission network without additional installation of shunt capacitors or reactors. In this section, reactive power support capabilities for the proposed interconnectors are investigated.

The reactive power studies have been conducted under two different FES scenarios: Consumer Power and No Progression with respect to the year 2022 and 2025.[13] The studies use summer minimum morning demand data to evaluate the maximum benefits that the proposed interconnectors could provide in terms of reactive power support as the network with minimum load has a tendency for higher system voltages during the summer months. Accordingly, there will be fewer generators running and they will be dispatched as per FES 2016 ranking orders to balance the demand.

To evaluate the reactive power support capabilities of the proposed interconnectors, pre-fault voltage studies are carried out for the base network and the networks with the proposed interconnectors. Each interconnector is studied independently and its reactive power support capability is finally measured by monetary benefits on reactive compensation savings.

## 7.2 Methodology

As reactive power is a local problem in its nature, the voltage studies only focus on the local areas where the interconnectors are to be connected. Table 10 lists four studying areas and corresponding substations (all substations within a two-substation range of the connection points) to be considered in the following studies.

| Studying Area | Area 1 | Area 2 | Area 3 | Area 4 |
|---|---|---|---|---|
| **Interconnectors** | **Gridlink** | **Neu Connect** | **North Connect** | **Aquind/OGN** |
| **Connection Points** | Kingsnorth | Grain | Peterhead | Lovedean |
| **Substations in the local areas** | Tilbury | Tilbury | Kintore | Fleet |
| | Grain | Kingsnorth | Blackhillock | Bramley |
| | Singlewell | Kemsley | Persley | Botley Wood |
| | Northfleet East | Singlewell | Craigiebuckler | Chilling |
| | Barking | Northfleet East | Keith | Fawley |
| | Littlebrook | Littlebrook | Tealing | Marchwood |
| | Coryton South | Coryton South | Kincardine | Nursling |
| | Ryleigh Main | Ryleigh Main | Knocknagael | Mannington |
| | Warley | Warley | | Chickerell |
| | Kemsley | Rowdown | | Bolney |
| | | Cleve Hill | | Ninfield |
| | | Canterbury | | |

***Table 10: Definition of studying areas for the interconnectors proposed***

In order to explore the range of reactive power support the interconnector could provide, the interconnectors will be dispatched at 25%, 50% and 100% of their full capacities respectively and compared against the base network without the interconnectors according to the following two steps:

[13] 2032 cannot be analysed due to uncertainty of local configuration of network in the future

1. Calculate the requirements of reactive compensation in Mvar for the local areas around the connection points **without the interconnectors** through pre-fault voltage studies such that all bus bar voltages within a two-substation range of the connection points are maintained within planning limits.
2. Repeat the first step for the networks **with the interconnectors** and determine the differences in additional reactive compensation requirements in Mvar.

The differences of additional reactive compensation required between the base network and the networks with the interconnectors will be covered by the installation of shunt reactors or STATCOMs. In general, shunt reactors cost much less than STATCOMs but the installation capacities of shunt reactor units are fixed and bound by voltage levels (200Mvar for 400kV s/s; 100Mvar for 275kV s/s; 50Mvar for 132kV s/s). This sometimes could cause problems such as under or over compensation. STATCOMs are more flexible as they are available in ±50/100/200Mvar for different voltage levels. And STATCOMS could provide dynamic voltage control which could effectively eliminate over compensation.

Based on the requirements of reactive compensation in Mvar, investment savings on any shunt reactors or STATCOMs are then calculated according to the equipment costs listed in Table 11 and Table 12. These costs are documented in ETYS 2015 Appendix E23 for onshore equipment. It is assumed that the cost for a 275kV 100Mvar shunt reactor is the same as a 220kV 100Mvar shunt reactor listed in Table 11.

| Specifications | Cost(£m) |
|---|---|
| 60Mvar-33kV | 1.5 |
| 100Mvar-220KV | 4.1 |
| 200Mvar-400kV | 4.3 |

***Table 11 : Equipment cost for shunt reactors***

| Specifications | Cost(£m) |
|---|---|
| 50Mvar | 5.6 |
| 100Mvar | 16.5 |
| 200Mvar | 24.4 |

***Table 12 : Equipment cost for STATCOMS***

### 7.2.1 Network Assumptions (Summer Minimum Demand)

With reduced power demand and a tendency for higher system voltages during the summer months, fewer generators will operate and those that do run could do so at a reduced power factor output. Reactive power analysis is therefore usually performed for the summer minimum demand condition as this presents the limiting factors.
The summer minimum voltage studies will be conducted under two different scenarios for the chosen years to evaluate the maximum and minimum benefits that the interconnectors could provide in terms of reactive support. System demand for each scenario/year is listed in the following table:

| | Year 2022 | Year 2025 |
|---|---|---|
| Consumer Power | 14.9GW | 13.6GW |
| No Progression | 16.3GW | 15.7GW |

***Table 13: System demand per year and scenario***

The below is a brief summary regarding the appropriate zones to be studied for voltage constraints.

- **North East** – the area of North East is an area with historically known problems with high voltages. Based on historic data nuclear power plant Hartlepool was contracted to provide reactive support (leading). Note that Hartlepool will be closed in 2023, which means it won't be available for 2025 studies.

- **East Coast** – East Coast is part of the transmission network that had a relatively consistent voltage profile. The units which were contracted to provide reactive support are Spalding and Sutton Bridge.

- **South East –** The unit which keeps the voltage profile in South East area is historically Marchwood.

- **South West –** The voltage profile in South West is supported by Langage

- **South Wales** – Pembroke is generally used for voltage profiling in South Wales

## 7.3 Key assumptions

The demand data used in the studies is listed in Table 14. It is assumed that all generators are dispatched as per FES 2016 data. In addition, availabilities of generators and existing reactive equipment are also considered: a 90% availability scaling factor is applied to all generators across the GB network; a 95% availability scaling factor is applied to all Mechanical Switched Capacitors (MSCs), shunt capacitors and shunt reactors across the GB network; a 90% availability scaling factor is applied to all Static Var Compensators (SVCs) and STATCOMs around the connection points of interconnectors. A standard summer outage pattern is applied to the GB network. Voltage control circuits are also utilised accordingly for voltage profiling.

| | **Consumer Power** | | **No Progression** | |
|---|---|---|---|---|
| | **2022** | **2025** | **2022** | **2025** |
| **Demand (MW)** | 14881 | 13642 | 16311 | 15741 |

***Table 14 : Demand data for GB network***

## 7.4 Base network

Table 15 shows the results of pre-fault voltage studies for the base network **without** the interconnectors proposed. The definitions of the areas can be found in Table 10. It is easy to see from the load flow results that the voltages around Kingsnorth, Grain and Peterhead are consistently within planning limits; hence, no high voltage issues are observed in Area 1, Area 2 and Area 3 in any scenarios/years. This indicates that there is very little or no benefit for Neu Connect, Gridlink and North Connect in reactive support around these areas. In Area 4, high voltages are observed under three different models. Therefore, Aquind has potential in reactive support as the local voltages are considerably high, especially for CP 2025 with the lowest demand of all models.

| | **Consumer Power** | | **No Progression** | |
|---|---|---|---|---|
| | **Year 2022** | **Year 2025** | **Year 2022** | **Year 2025** |
| Area 1 | **Sensitive Information** | | | |
| Area 2 | | | | |
| Area 3 | | | | |
| Area 4 | | | | |

***Table 15: High voltages observed from pre-fault voltage studies***

## 7.5 Neu Connect, Gridlink and North Connect

The networks with these three interconnectors are assessed against the base network in voltage studies. It can be concluded that these three interconnectors have no benefit in reactive support in any scenarios/years with any dispatch values they are assigned for.

## 7.6 Aquind

To resolve the high voltage issues in Bramley and Fleet, additional reactive compensation is required; and Bramley is the most effective substation for voltage control among all substations listed in Area 4 due to its consistent high voltages across different models. Table 16 shows the reactive compensation required in Bramley for the base network and the networks with Aquind at three different dispatch levels.

| | Base network Without Aquind | Aquind dispatch @25% | Aquind dispatch @50% | Aquind dispatch @100% |
|---|---|---|---|---|
| **Year 2022 CP** | Sensitive Information | | | |
| **Year 2022 NP** | | | | |
| **Year 2025 CP** | | | | |
| **Year 2025 NP** | | | | |

***Table 16: Reactive compensation requirements to resolve high voltage issues***

Base on the requirements shown in Table 16, additional investments for shunt reactors or STATCOMs are then calculated respectively in Table 17 and Table 18. The investment savings from Aquind are concluded in Table 19 and Table 20.

| | Base network Without Aquind | Aquind dispatch @25% | Aquind dispatch @50% | Aquind dispatch @100% |
|---|---|---|---|---|
| Year 2022 CP | Sensitive Information | | | |
| Year 2022 NP | | | | |
| Year 2025 CP | | | | |
| Year 2025 NP | | | | |

***Table 17: Additional investment for shunt reactors (£m)***

| | Base network Without Aquind | Aquind dispatch @25% | Aquind dispatch @50% | Aquind dispatch @100% |
|---|---|---|---|---|
| Year 2022 CP | Sensitive Information | | | |
| Year 2022 NP | | | | |
| Year 2025 CP | | | | |
| Year 2025 NP | | | | |

***Table 18: Additional investment for STATCOMs (£m)***

| | Aquind dispatch @25% | Aquind dispatch @50% | Aquind dispatch @100% |
|---|---|---|---|
| Year 2022 CP | Sensitive Information | | |
| Year 2022 NP | | | |
| Year 2025 CP | | | |
| Year 2025 NP | | | |

***Table 19: Investment savings on shunt reactors (£m)***

| | Aquind dispatch @25% | Aquind dispatch @50% | Aquind dispatch @100% |
|---|---|---|---|
| Year 2022 CP | Sensitive Information | | |
| Year 2022 NP | | | |
| Year 2025 CP | | | |
| Year 2025 NP | | | |

***Table 20: Investment savings on STATCOMs (£m)***

| *Savings (£m) (PV)* | Aquind dispatch @25% | Aquind dispatch @50% | Aquind dispatch @100% |
|---|---|---|---|
| Year 2022 CP | Sensitive Information | | |
| Year 2022 NP | | | |
| Year 2025 CP | | | |
| Year 2025 NP | | | |

***Table 21: Investment savings on shunt reactors in PV (£m)***

| *Savings (£m) (PV)* | Aquind dispatch @25% | Aquind dispatch @50% | Aquind dispatch @100% |
|---|---|---|---|
| Year 2022 CP | Sensitive Information | | |
| Year 2022 NP | | | |
| Year 2025 CP | | | |
| Year 2025 NP | | | |

***Table 22: Investment savings on STATCOMs in PV (£m)***

## 7.7 Summary

Section 7 described the studies that had been carried out for the evaluation of reactive support capabilities of the four interconnectors proposed for Cap and Floor. It was found that Aquind was the only interconnector who potentially could be beneficial for reactive support. The ranges of savings on reactive compensation provided by Aquind are summarised in Table 23.The other three interconnectors, Neu Connect, Gridlink and North Connect, however, were found of no benefit due to better voltage profiles around the local areas of their connection points.

| | Shunt reactors (£m) | STATCOMs (£m) |
|---|---|---|
| **Year 2022 CP** | Sensitive Information | |
| **Year 2022 NP** | | |
| **Year 2025 CP** | | |
| **Year 2025 NP** | | |

***Table 23: Investment savings on reactive compensation installation by Aquind***

# 8 Constraint Management

## 8.1 Introduction

This section outlines the operational constraint cost implications from having an extra interconnector in the relevant areas of the network. Each interconnector has proceeded through the Connection and Infrastructure Optioneering Note (CION) process where the most economic and efficient connection site was identified for the project.

The operational constraint cost implications of a certain interconnector is a function of energy prices in the interconnected markets across Europe and the modelled system marginal price for GB. Therefore, the analysis has been performed for a range of price forecasts for European markets. The central case which is included in this report is based on the base market prices and base constraint costs.

The tables below show the forecasted annual constraint costs for each spot year considered (2022, 2026, 2032) across the Future Energy Scenarios; Gone Green (GG), No Progression (NP), Consumer Power (CP) and Slow Progression (SP). Included in the table are the results when the European prices are 10% higher than the base case and 10% lower than the base case.

Generally, GB prices are lower than Norway, France and Germany in earlier years; however, in later years the GB price increases above European prices. This price differential will impact on the flows across the interconnector as power will tend to flow from a low price area to a high price area. If the price in Europe is reduced by 10%, the price differential will usually increase causing higher flows on the interconnector in earlier years. As a result, this will heighten the impact of the additional interconnection.

## 8.2 Methodology[14]

In order to forecast constraint costs, National Grid used a Microsoft Excel tool, ELSI (Electricity Scenario Illustrator) which uses linear programming to simulate the future operational constraints through optimisation of generation and storage resources to meet consumer demand requirements. This analysis was carried out based on the Future Energy Scenarios 2016.

ELSI models the electricity market in two main steps. The first step looks at the short run marginal cost (SRMC) of each zonal fuel type and dispatches available generation from the cheapest through to the most expensive one until the total level of GB demand is met. This is referred to as the 'unconstrained dispatch'. At this point, the network's (boundaries) are assumed to have infinite capacity.

The model then considers the power flow restrictions on the network and re-dispatches generation where necessary to relieve instances where power transfer is greater than capability. The costs associated with moving away from the economic dispatch of generation is called the operational constraint costs and is calculated using the bid price and offer price (£/MWh).

The Present Value of Constraint Costs attributable to the new connection is calculated by subtracting the system-wide constraint costs without the new connection from the constraint costs with the new connection. The interpretation of a negative number here means that the interconnector reduces constraints on the network whereas positive numbers refer to an attributable constraint cost (red in table below).

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[14] For more information regarding the CION methodology, see interconnector CION documents (4th document down) http://www2.nationalgrid.com/uk/services/electricity-connections/policies-and-guidance/

## 8.3 Neu Connect

| Annual Constraint Costs (PV) (£m) | GG | | | NP | | |
|---|---|---|---|---|---|---|
| | 2022 | 2026 | 2032 | 2022 | 2026 | 2032 |
| -10% European prices | Sensitive Information | | | | | |
| Central Case | | | | | | |
| +10% European prices | | | | | | |

***Table 24: Annual Constraint Costs for Neu Connect (GG, NP)***

| Annual Constraint Costs (PV) (£m) | CP | | | SP | | |
|---|---|---|---|---|---|---|
| | 2022 | 2026 | 2032 | 2022 | 2026 | 2032 |
| -10% European prices | Sensitive Information | | | | | |
| Central Case | | | | | | |
| +10% European prices | | | | | | |

***Table 25: Annual Constraint Costs for Neu Connect (CP, SP)***

In GG, the price difference between Germany and GB alternates from Germany predominately being the cheaper price area to GB in around 2026. The price differential is the main driver for the flows on the interconnector and as the interconnector is exporting to Germany in later years this will alleviate some constraints on B15. Increasing the price in Germany by 10% in later years will reduce the price differential between the 2 countries. In contrast, in the NP scenario, GB always has a higher price than Germany meaning the power will predominantly be flowing into GB causing further constraints on B15, therefore the interconnector will increase the total constraints on the network.

## 8.4 Gridlink

| Annual Constraint Costs (PV) (£m) | GG | | | NP | | |
|---|---|---|---|---|---|---|
| | 2022 | 2026 | 2032 | 2022 | 2026 | 2032 |
| -10% European prices | Sensitive Information | | | | | |
| Central Case | | | | | | |
| +10% European prices | | | | | | |

***Table 26: Annual Constraint Costs for Gridlink (GG, NP)***

| Annual Constraint Costs (PV) (£m) | CP | | | SP | | |
|---|---|---|---|---|---|---|
| | 2022 | 2026 | 2032 | 2022 | 2026 | 2032 |
| -10% European prices | Sensitive Information | | | | | |
| Central Case | | | | | | |
| +10% European prices | | | | | | |

***Table 27: Annual Constraint Costs for Gridlink (CP, SP)***

This table shows that the flow on the interconnector in most years is not heavily impacted by the price in France as there is only a small difference between the annual constraint costs between the price sensitivities. The table above shows that the interconnector power is enabling more expensive plant to be bid off in the GG scenario causing a negative constraint cost attributable to the interconnector. As the flow increases, more power can be displaced by this cheaper power. Similarly to Germany, in NP the price in GB is always higher than the price in France, therefore the interconnector contributes to higher constraints on the network.

## 8.5 North Connect

| Annual Constraint Costs (PV) (£m) | GG | | | NP | | |
|---|---|---|---|---|---|---|
| | 2022 | 2026 | 2032 | 2022 | 2026 | 2032 |
| -10% European prices | | | | | | |
| Central Case | | | Sensitive Information | | | |
| +10% European prices | | | | | | |

***Table 28: Annual Constraint Costs for North Connect (GG, NP)***

| Annual Constraint Costs (PV) (£m) | CP | | | SP | | |
|---|---|---|---|---|---|---|
| | 2022 | 2026 | 2032 | 2022 | 2026 | 2032 |
| -10% European prices | | | | | | |
| Central Case | | | Sensitive Information | | | |
| +10% European prices | | | | | | |

***Table 29: Annual Constraint Costs for North Connect (CP, SP)***

North Connect experiences higher constraint costs when the flow from Norway is greater, i.e. when European prices are lower. With greater flows from North Connect, often the local boundary will cause limitation and generators within merit will need to be bid off, therefore increasing the constraint costs. As the flow decreases from Norway this issue will not arise as much and in later years the interconnector may be exporting to Norway.

## 8.6 Aquind

The CBA for Aquind was carried out using a previous methodology which would not be comparable to the figures provided for the Cap and Floor applicants, therefore the constraint costs will not be provided for Aquind.

## 8.7 Summary

The results above show the diverse range of potential benefits and costs which could be attributable to the interconnector. A key driver is the direction of flow on the interconnector where generally when the interconnector is flowing power into GB the constraint costs increase and when flow is out of GB, this alleviates constraints bringing total constraint costs on the network down. GG provides a scenario where the System Marginal Price (SMP) in GB falls below Europe in later years which demonstrate the driver of the savings attributable to the interconnector. In NP, the GB SMP doesn’t fall below the SMP of some interconnected countries, therefore the constraint costs remain higher as a result of the interconnector.