Moyle Interconnector Capacity Increase

Need Case Update

Date: September 2023

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Executive summary

The Moyle Interconnector is a 500 MW High Voltage Direct Current (HVDC) link between Northern Ireland and Great Britain. It has two submarine HVDC cables operating at 250 kV and dual monopole converters, with a combined capacity on either direction of 500 MW. This interconnector, which was the first HVDC link in the island of Ireland, is owned by Mutual Energy and was commissioned in 2002.

Although the interconnector is technically capable of transferring 500 MW in either direction, it is restricted to 295 MW export and 450 MW import to prevent 110kV overloads on the Ballylumford - Eden circuits and potential voltage excursions at all voltage levels in the east of Northern Ireland. However, the limit on export capacity of Moyle of 295 MW, can be increased to 500 MW if the 110 kV circuits between Castlereagh substation and Carnmoney substation are open and transmission connected batteries are run in voltage control mode. Future planned generation at Ballylumford would however reduce this capacity for voltage stability reasons.

This assessment covers the legal, operational, technical, and economical drivers, to justify a project to address these restrictions.

From the socio-economic assessment, the benefits of deploying a solution that allows the interconnector to operate at its maximum capacity are a reduction of electricity production costs, a decrease of CO2 emissions, an increase of renewable integration and an increase in congestion revenues from increased interconnector activity.

Error! Reference source not found. are presents the annual impacts in NI of increasing the import and export interconnection to 500 MW.

Case ID	Scenario TYNDP2020 Scenario Report	Interconnector		Production cost-benefit [£m][1]	Renewable integration [GWh]	CO_2 emissions [MT]	Congestion revenues [£m][10]
		Import [MW]	Export [MW]				
2	NT	500	400	14.1	307.1	-0.068	9.7
3		500	500	19.7	563.3	0.032	16.4

Table 1 : Annual impacts in NI of increasing the import and export interconnection to 500 MW

[1] Exchange rate on 21st December 2021 : 1GBP = 1.17EUR. Rounded to the 1st decimal case.

1. Introduction

The Moyle interconnector is a 500 MW High Voltage Direct Current (HVDC), linking the transmission networks in Northern Ireland to Great Britain. The interconnector is made of two submarine HVDC cables operating at 250 kV, with a combined capacity on either direction of 500 MW. This interconnector, which was the first HVDC link in the island of Ireland, is owned by Mutual Energy and was commissioned in 2002. Although the interconnector is technically capable of transferring 500 MW in either direction, the connection capacity in Northern Ireland is restricted below the capacity of the link.

Mutual Energy, and the Transmission System Operators (TSOs) on each side of the Irish Sea have sought to remove any limits and increase the power flow through the interconnector to its original limits. SONI in conjunction with National Grid Electricity System Operator (NGESO) carried out an economic assessment of the economic benefits to Great Britain and the island of Ireland of providing the full capacity in 2013. The investments required to enable the increased capacity were also listed. NGESO have now provided a firm connection to allow 500 MW export to Scotland. This has been enabled by investment in the transmission system in the area and also in commercial arrangements in the wider area.

The Transmission Development Plan Northern Ireland 2021-2030 has included for a project to address this restriction on the Northern Ireland side.

This is an update to the original 2019 Needs report. This considers the changes that have occurred since the original 2019 Needs assessment. In particular this update examines alternative methods of operational existing and future batteries as well as planned generation connections at Ballylumford.

2. Moyle Interconnector connection arrangements

The Moyle Interconnector is connected to the transmission system in Northern Ireland at Ballycronan More converter station. Ballycronan More substation was connected in 2002 by diverting one existing Ballylumford – Hannahstown 275 kV circuit into the new substation, see Figure 1 below. This established a Ballylumford – Ballycronan More circuit as well as a Ballycronan More – Hannahstown circuit. These share the same towers as the Ballylumford – Hannahstown circuit.

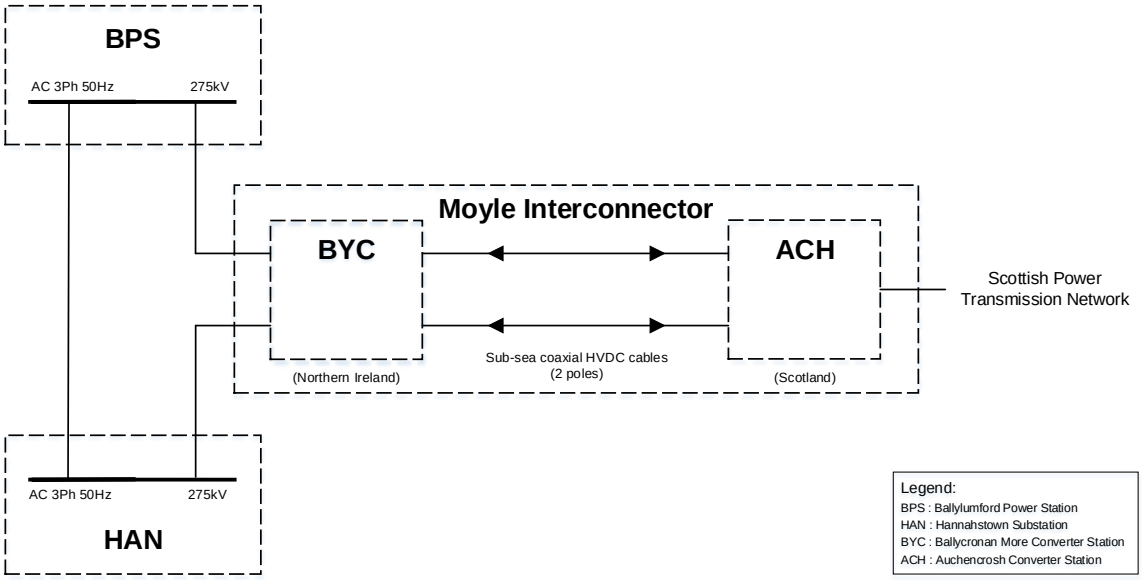

Figure 1 : Integration of the Moyle interconnector in NI's transmission network

Figure 2 presents the configuration of the interconnector and its connection to NI's transmission network. The HVDC configuration is a dual monopole. The Moyle interconnector is self-compensating for reactive power losses with four 59 Mvar capacitor banks at the Ballycronan More converter station with three of these capacitor banks also acting as harmonic filters.

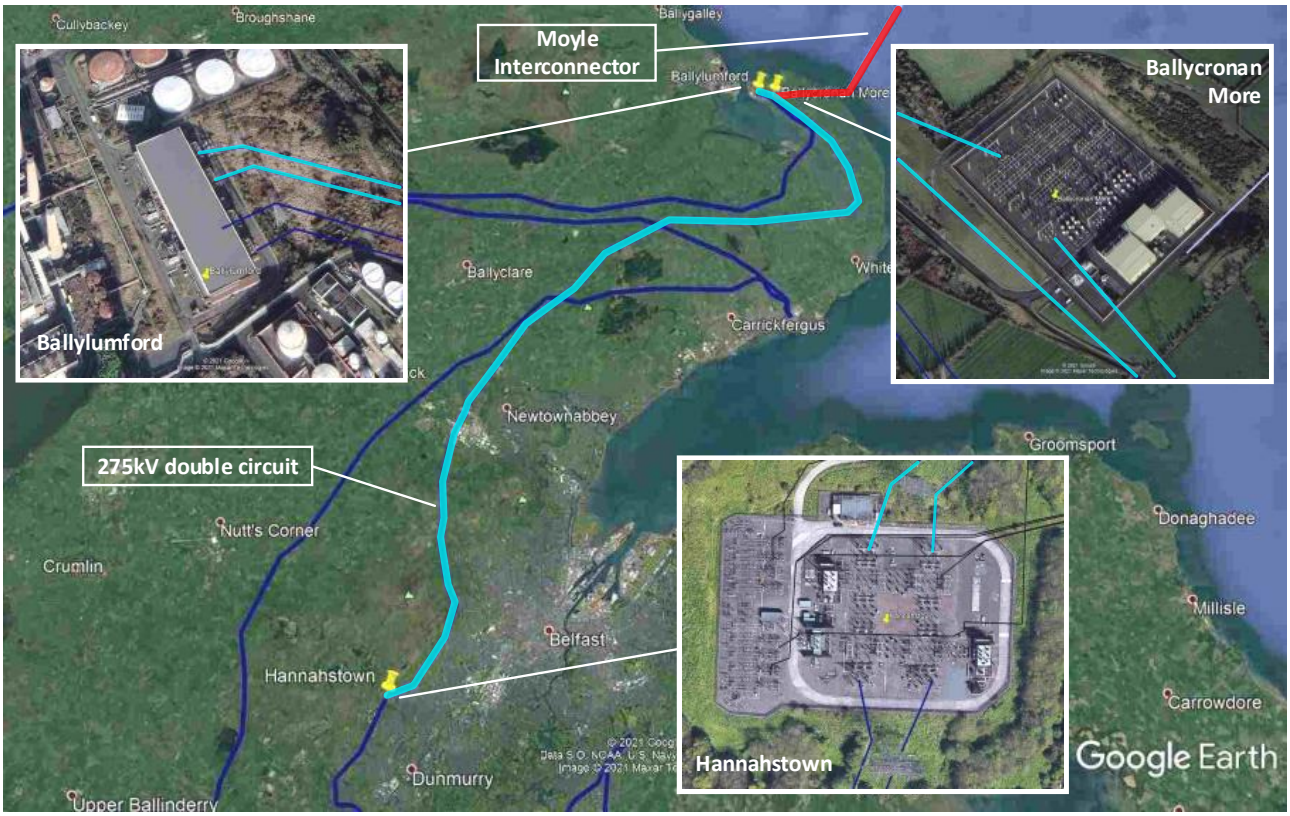

Figure 2 : Location of the main electrical assets connected to the converter station

3. Operational conditions

Power flow through the interconnector is currently limited as follows:

- Export capacity up to approximately 295 MW, which can be increased up to 400 MW if the 110 kV circuits between Castlereagh substation and Carnmoney substation are opened.
- Import capacity of 450 MW, which can be increased to 500 MW if the 110 kV circuits between Castlereagh substation and Carnmoney substation are opened.

4. Legal framework

The operation of the Single Electricity Market is governed according to the Withdrawal Agreement including Regulation (EU) 2019/943 of the European Parliament and of the Council, of 5 June 2019, on the internal market for electricity (superseding Regulation (EC) 714/2009).

Conditions regarding operation of the Moyle Interconnector and the East West Interconnector are governed according to the Trade and Cooperation Agreement (TCA) between the United Kingdom and the European Union, 30th December 20202. The TCA states:

"1. With the aim of ensuring the efficient use of electricity interconnectors and reducing barriers to trade between the Union and the United Kingdom, each Party shall ensure that:

(a) capacity allocation and congestion management on electricity interconnectors is market based, transparent and non-discriminatory; UK/EU/TCA/PART 2/en 366

(b) the maximum level of capacity of electricity interconnectors is made available, respecting the:
(i) need to ensure secure system operation; and
(ii) most efficient use of systems;

(c) electricity interconnector capacity may only be curtailed in emergency situations and any such curtailment takes place in a non-discriminatory manner;

(d) information on capacity calculation is published to support the objectives of this Article"

Based on the above context, Moyle Interconnector should be available to offer its maximum capacity, in order to ensure the market can work in the most efficient way and not be limited by the internal transmission system. Furthermore, any restriction should be addressed if there is an economic case.

4.1. Moyle interconnector runback service

The Moyle Interconnector Operating Protocol has several instructions, called Cross Border Actions, which can be triggered by SONI or NGESO. These instructions include the interconnector runback service. The largest credible demand loss on the NI transmission system is usually the export transfer to the Republic of Ireland. The runback service was developed to act automatically against a high frequency event occurring in NI, following the loss of the North-South 275 kV tie-line. Should this 275 kV connection to Ireland fail, the Moyle interconnector will automatically reduce the import to NI and/or begin exports

[2] https://www.gov.uk/government/publications/ukeu-and-eaec-trade-and-cooperation-agreement-ts-no82021

to NGESO transmission network. The maximum agreed runback available is 300 MW provided by NGESO from NI to GB. This service is very useful in days of high wind generation in NI and low wind generation in the Republic of Ireland, when the North-South 275 kV tie-line is heavily loaded by the export from North to South.

If the tie-line fails, NI's transmission network needs to have sufficient capacity to export to GB, up to the 500 MW on Moyle, including the 300 MW from the interconnector runback service, so that we can avoid frequency instability due to the excess generation. If this excess production of electricity from a Renewable Energy Source (RES) cannot be diverted to the GB network, high frequency trips would occur, and the system is expected to become unstable.

5. Technical assessment in steady state

The steady state studies were carried out to identify any issues with allowing greater transfers of power through the Moyle interconnector than the currently imposed limits. In this analysis, steady-state contingency studies were carried. Winter Peak (WP), Summer Peak (SP) and Summer Valley (SV) cases were assessed against all credible contingencies with different levels of renewables. The assessment was conducted against different scenarios of wind generation3 and Moyle flows, as shown in Table **Error! Reference source not found.**.

Season	Case ID	Moyle interconnector		Wind Generation penetration [%]
		Power flow [MW]	Export / Import	
Winter Peak	WP1	500	Import	0
	WP2	500	Import	80
	WP3	500	Export	80
	WP3.a	400	Export	80
	WP3.b	300	Export	80
Summer Peak	SP4	500	Import	0
	SP5	500	Import	80
	SP5.a	500	Import	70
	SP6	500	Export	80
Summer Valley	SV7	500	Import	0
	SV8	500	Import	48[4]

Table 2 : Scenarios considered on the steady-state assessment

Limits of power flow on import cases were extended to 500 MW to identify any deficiencies against the TSSPS. All the following credible contingencies were applied to ensure the minimum transmission capability:

- All individual circuits.
- All OHL DCTs on the 275 kV tower lines.
- Moyle interconnector itself.

Realistic generator dispatches were used in compliance with the system active constraints. North-South interconnector flows were maintained below 300 MW, in order to comply with the inter-area flow limit of 400 MW as defined in the Operational Constraints document5.

As per TSSPS, section 4.6, for the secured event contingency such as a fault outage or any of the above contingencies, there shall not cause any of the following events:

[3] Wind Generation penetration is presented as a percentage of wind generation installed capacity.
[4] This was the maximum possible wind penetration during the Summer Valley season under the current system operating rules.
[5] See Annex A.

- Unacceptable overloading of any primary transmission equipment.
- Unacceptable voltage conditions or insufficient voltage performance margins.

In the case of the loss of the Moyle interconnector contingency, voltages were assessed under two scenarios, a) the compensating/filtering capacitors at Ballycronan More remaining switched in and b) the capacitors tripping with the interconnector itself, which is the current arrangement.

A sensitivity analysis was also carried out using the same studies, but with the Castlereagh – Carnmoney 110 kV circuits open, in order to prevent overloads on the Ballylumford – Eden 110 kV circuits as observed in the initial set of studies.

5.1. Current configuration of the network for contingencies analysis

Looking at figure 1, two credible contingencies, known to cause issues, were assessed:

1. Double circuit trip of 275 kV HAN-BPS and BPS-BYC.

   In this scenario only the 275 kV BYC- HAN will be available to allow the flow of electrical energy through the Moyle interconnector.
2. Double circuit trip of 275 kV DCTs HAN-BPS and BYC-HAN.

   In this scenario only the 275 kV DCT BPS-BYC will be available to allow the flow of electrical energy through the Moyle interconnector.

The above scenarios are represented below in figure 3.

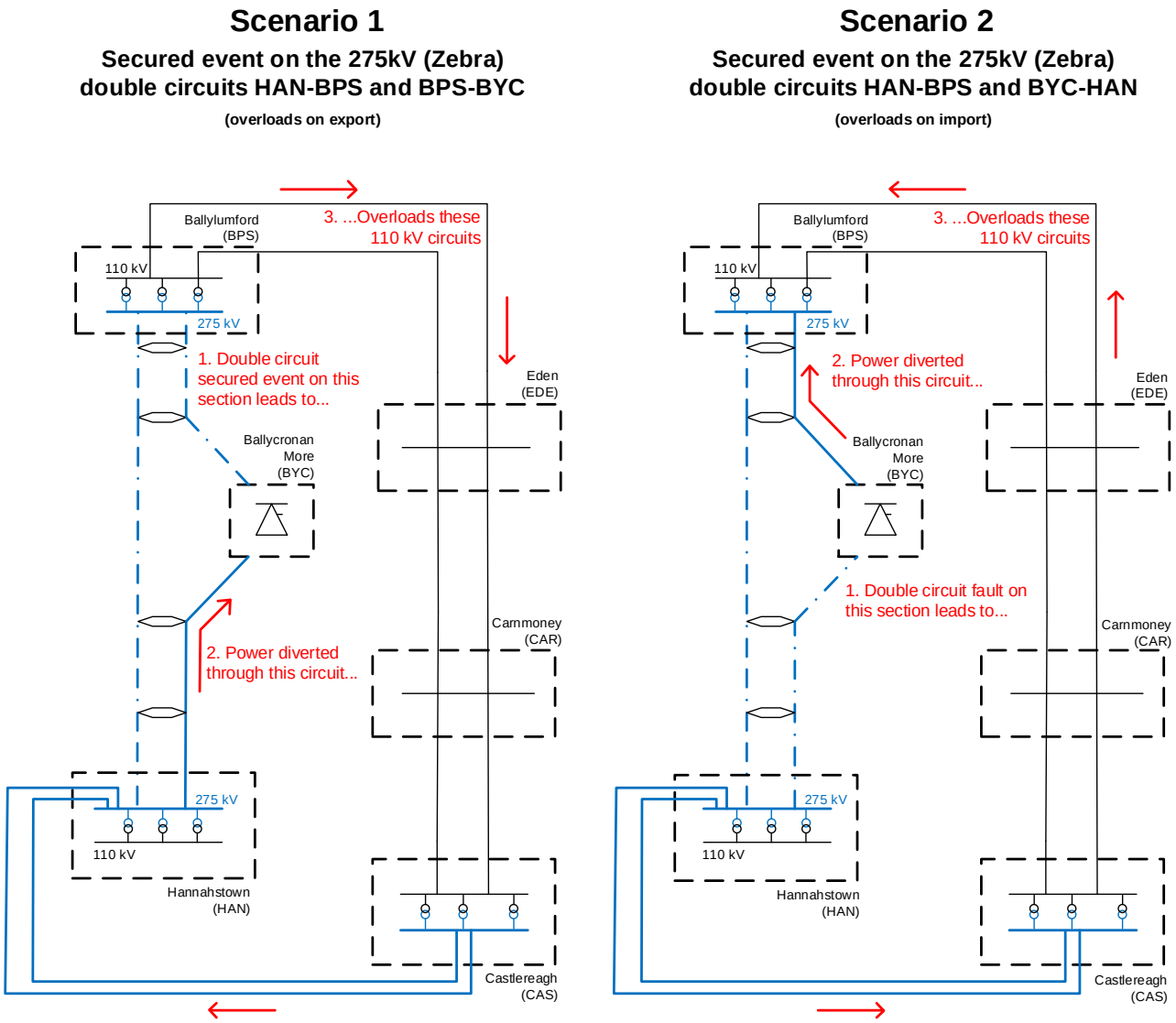

Figure 3 : Current configurations of the network connected to BYC for contingency analysis purpose

These studies showed that overloads were likely on the Ballylumford – Eden 110 kV circuits unless the Carnmoney – Castlereagh circuits were left open. These circuits are planned to be retired under the Energising Belfast project.

In one case (WP3, export 500 MW), there were also voltage step violations at all 110 kV buses in Belfast and the southeast of NI. This is because all Belfast demand centres supplied from Hannahstown and Castlereagh, as well as the export on Moyle, becomes electrically distant from the dynamic reactive power support located at Ballylumford. As a result, cases WP3a and WP3b (export of 400 MW and 300 MW respectively) were assessed to ascertain if these voltage step violations would occur at lower levels of export, which they did not.

5.2. Battery Storage Schemes

In recent years, battery energy storage schemes have connected to the transmission network at Kells, Castlereagh, Tamnamore and Tandragee 110 kV substations, with a number of further battery connections planned. These batteries have dispatchable reactive power equivalent to +/- 0.95 power factor at their maximum export capacity. The currently connected batteries are all rated at +/- 50 MW and +/- 16.4 MVar.

At present the reactive power of these batteries is dispatched at a fixed Mvar setpoint. However, theses batteries are capable of operating in voltage control mode, with reactive output varying to maintain a voltage setpoint. Study WP3 (worst case scenario) was rerun with the batteries in voltage control mode, dispatched at 1.03 p.u. (113.3 kV). Two versions of this study were run – one with the batteries at 0 MW, and one with the batteries on full import (50 MW each). Table 3 shows the voltage step seen at both Ballycronan More and at 110 kV buses in Belfast in each case. Operation of the batteries in voltage control mode resolves the issues previously seen.

Study	Peak voltage step (Ballycronan More)	Peak voltage step (Belfast)
Original	12.8%	11.2%
Batteries 0 MW, voltage control mode	6.4%	5%
Batteries full import, voltage control mode	8%	6.2%

Table 3 - Impact of batteries

5.3. Future Developments

Significant additional generation is planned to connect at Ballylumford: 1000 MW of offshore wind and an additional 500 MW CCGT unit. This has potential to significantly increase flows on the 275 kV network near Moyle. To understand the impact this would have on the ability to export on Moyle, a full-year analysis was carried out for the year 2030 assessing the peak voltage step at several substations under the worst-case contingency (Scenario 1 in Figure 3, a double circuit 275 kV fault between Ballylumford and Ballycronan More). This included the above-mentioned batteries in voltage control mode, as well as additional voltage support in the form of synchronous condensers (which are being procured through the Low Carbon Inertia Services process). Full year dispatches were taken from a PLEXOS market study based on the expected network configuration and connections in 2030. Figure 4 shows a duration curve for the voltage step across the year at Hannahstown 275 kV, Ballycronan More 275 kV, and Ballynahinch 110 kV (a proxy for all 110 kV BSPs connected to Castlereagh).

For this particular study the voltage step exceeds the 10% limit approximately 2% of the year (190 hours). Note that this dispatch was market-based, and did not have Moyle exporting at 500 MW in all hours.

Therefore, while it may be possible to release the full Moyle export capacity of 500 MW on the current network, subject to changing the operating protocol for the batteries, even with this change it will still not be possible to provide full export across a full year with the connection of planned generation at Ballylumford.

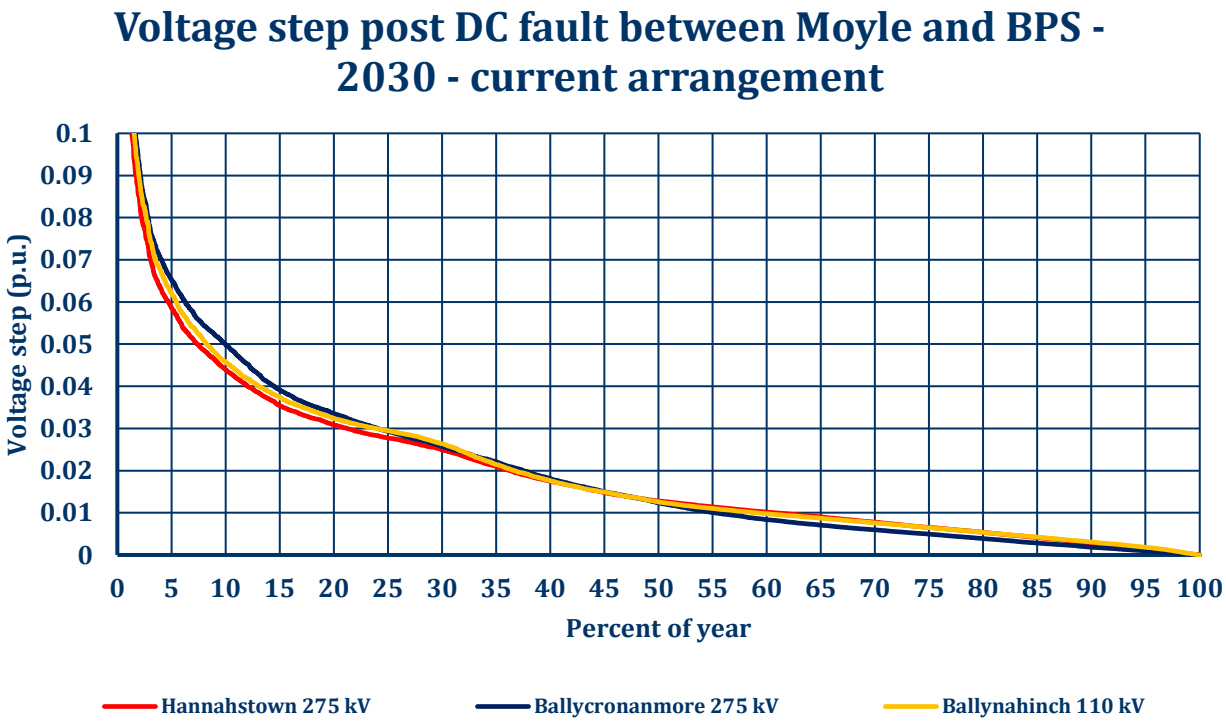

Figure 4 - full year results for 2030

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5.4. Present Operational restrictions

When the Integrated Single Electricity Market (I-SEM) conditions are favourable to export or import between Ireland and GB, the Moyle interconnector sometimes has economic advantages over the East West Interconnector (EWIC). This advantage is due to the lower losses on the converter stations, as Moyle interconnector uses LCC technology and EWIC uses voltage source converter (VSC) technology6, and the HVDC cables are shorter in length on Moyle interconnector7.

To take advantage of these conditions on export, the Castlereagh - Carnmoney 110 kV DCT is being operated in an open condition, allowing the Moyle export to reach 400 MW rather than 300 MW. This would typically be on days of high wind conditions, subject to National Grid ESO restrictions. The only time the Castlereagh - Carnmoney circuits are

[6] European Network of Transmission System Operators for Electricity (ENTSO-E) technical paper, "HVDC Links in System Operations", 2nd December 2019, Section 2.4, Table 1 : Comparison between LCC and VSC technology, page 19 [11].

[7] The Moyle Interconnector's cables length are smaller with just 53km subsea and 9km in land, comprising a total of 62km, and operating at 250kV. While EWIC are 186km subsea and 75km in land, in a total of 261km, and operating at 200kV.

typically required to be closed is for a 275/110kV interbus transformer maintenance in Castlereagh 110 kV substation.

On import, the interconnector is now able to operate to a maximum of 500 MW as long the Castlereagh – Carnmoney double 110 kV circuits are normally open.

5.5. Technical assessment summary

On export, the most onerous contingency associated with full utilisation of the Moyle interconnector's capacity is a fault on the Ballylumford – Ballycronan More 275 kV double circuit.

Full utilisation of this capacity is possible with the current network configuration pending further studies to confirm) if the 110 kV connection between Ballylumford and Castlereagh is severed, and transmission connected batteries are run in voltage control mode. However, this will not be the case following connection of planned future generation at Ballylumford and therefore the need remains valid.

6. Production cost-benefit analysis

A joint economic study was carried out, involving NGESO and SONI in late 2013. The aim of the study was to assess the benefits of increasing the capacity at the time from 450 MW import (and 410MW under certain scenarios) and 80MW export to 500 MW import and export. Works were identified in both Northern Ireland and Scotland to facilitate this. NGESO has completed several of the projects identified at that time and entered into commercial arrangements to ensure firm access for Moyle. SONI has also progressed the upgrade of the Ballylumford – Eden circuits with plans for the remaining sections. However, with the voltage step issue under high export levels emerging as an issue also to be addressed.

The economic study has been updated by SONI in December 2021. The detailed assessment is presented in the report "Moyle Interconnector Capacity Increase – Production cost-benefit analysis". The cost-benefit analysis was conducted on the bases of optimizing the production cost-benefit.

Transfer capacity cases

The simulation performed in this study used a Pan-European 2030 market model. Table 44 presents the scenarios used in the cost-benefit analysis from NI's perspective. This study will use as base scenario the actual context. It performs an assessment for an intermediate scenario and a maximum Transmission Entry Capacity[8] (TEC).

Case ID	Description of scenario	Import [MW]	Export [MW]
1	Base scenario with existing conditions	450	300
2	Intermediate scenario	500	400
3	Maximum TEC scenario	500	500

Table 4 : Scenarios used in the economic assessment

Each of the above scenarios are simulated for 1982, 1984 and 2007, which are three weather years based on ENTSO-E's Pan-European Climate Database.

Study Results

Below are presented the most relevant conclusions of the study in terms of:

- Yearly reduction production costs in terms of fuel costs savings.
- Annual increase integration of RES.
- Yearly reduction of carbon dioxide (CO_2).

[8] TEC is defined as the maximum contractual right in MW it can flow power onto the transmission.

- Moyle interconnector annual congestion revenues[9].

The yearly impacts in NI of increasing the import and export interconnection capacity provided by PLEXOS are presented in table 5.

Case ID	Scenario TYNDP2020 Scenario Report	Interconnector		Production cost-benefit [£m][10]	Renewable integration [GWh]	CO_2 emissions [MT]	Congestion revenues [£m][10]
		Import [MW]	Export [MW]				
2	NT	500	400	14.1	307.1	-0.068	9.7
3		500	500	19.7	563.3	0.032	16.4

Table 5 : Yearly impacts in NI of increasing the import and export interconnection capacity

These results present variations, or relative values, and not absolute values, so the results reflect the increases and decreases in comparation to case 1.

The most evident conclusions from the above information are that:

- Production cost-benefit increases in either case reflecting a fuel cost avoided (or saved) for electricity production.
- Renewable integration (or renewable generation) increases in either case
- CO_2 emissions positive change means emissions avoided (or saved).[11]
- Congestion revenues, which are the main source of income for the interconnector will increase by £16.4m if the interconnector operates at its maximum capacity.

[9] Congestion revenues (or rents) are sales of interconnection capacity to users who wish to move electricity between markets with different prices. These rents represent the biggest source of revenue for the Interconnector.

[10] Exchange rate on 21st December 2021 : 1GBP = 1.17EUR. Rounded to the 1st decimal case.

[11] Case 2 results are not in line to the expectations. The reason for getting a negative value is that the PLEXOS optimises by changing the dispatch based on economic grounds rather than CO_2 emissions.

7. Conclusions

This assessment brought up the four main contexts, in terms of legal, operational, technical and socio-economical levels, to justify the need to increase the capacity of the transmission network in NI to provide the conditions for the Moyle interconnector to be able to operate to its maximum capacity of 500 MW on import or export.

The TCA between the United Kingdom and the European Union requires that all interconnectors, including the Moyle Interconnector, should where possible and efficient operate at maximum capacity thus maximising trade between the neighbouring markets.

The export is currently limited to 295 MW, increasing to 400 MW if the 110 kV circuits between Castlereagh and Carnmoney are operated open. The analysis showed that full utilisation of the 500 MW export capacity is currently possible if transmission-connected batteries are operated in voltage control mode, and this approach is currently being investigated. However, planned additional generation at Ballylumford prevents this being the case on the future network and shows a need for a change to the configuration of the Moyle connection if 500 MW capacity is to be maintained. Maximising the export on Moyle is particularly important given the targets set out in the Climate Change Act (Northern Ireland) 2022 and Northern Ireland's net zero ambitions by 2050.

The benefits in terms of Socio-Economic Welfare of enabling an increase to 500 MW therefore are the difference in production costs between Case ID 2 (£14.1m) and Case ID 3 (£19.7m). Therefore, the maximum benefit in terms of production cost per annum is expected to be approximately £5.6m.

Annex A. Constraints

An A.1. SONI' system constraints

The system constraints are detailed in the Operational Constraints Update document, Version 1.98_September 2020[12], Section 3 [13].

There are three groups of permanent system constraints that apply for NI, for the RoI and for the all-island transmission network. Those limits represent the normal intact transmission network limits, but they may vary from time to time due to changing system conditions.

Annex A presents extracts from the tables with the active constraints for the system wide and NI, which are the ones relevant for this assessment.

An A.2. Transmission Entry Capacity constraints

The TEC details related with the interconnector are presented by Mutual Energy Limited through the document "Interconnector Capacity Calculation", June 2017 [14], and the information available in their website[13].

The TEC of the interconnector are 500 MW, but power flows in both directions are constrained by both National Grid and SONI.

An A.2.2. SONI operational constraints

The current operation conditions imposed on the NI side, which are in place since the 2nd July 2019, are defined on Mutual Energy Limited website, and they can be resumed in table 6.

Direction	Dates	Capacity available [MW]
West to East	All year	400
East to West	All year	500

Table 6 : Current operation conditions imposed in NI

Contrary to the Scottish' side, in NI there isn't at the present a calendar to remove constraints that will allow to take advantage of the of the interconnector's full TEC.

On the East to West direction, NI already is able to allow a power flow at full TEC through the interconnector, however due to the restrictions presented in table 7, the maximum power flow in this direction will be 450 MW.

[12] https://www.eirgridgroup.com/site-files/library/EirGrid/OperationalConstraintsUpdateVersion1_98_September_2020.pdf
[13] https://www.mutual-energy.com/wp-content/uploads/2021/08/170720-Moyle_Capacity_Calculation_July2017-approved.pdf.

An A.2.2. National Grid ESO operational constraints

The current and future operation conditions imposed on the Scottish side are defined on the "Interconnector Capacity Calculation", section A3, and they can be resumed in table 77.

Direction	Dates	Capacity available [MW]
West to East	Up to 31 October 2021	250
	1 November 2021 to 31 March 2022	160
	End of 2022 onwards[14]	500
East to West[15]	--------	450

Table 7 : Current and future operation conditions imposed on Scotland

An A.2.3. Constraints considered for the reinforcement assessment

Because this document aims to identify the reinforcement needs to take advantage of the full TEC of the interconnector, table 8 presents the operational conditions considered for the reinforcement assessment.

Direction	Capacity available [MW]	Capacity limit set by
West to East	500	Interconnector full TEC
East to West	450	National Grid ESO operational constraints

Table 8 : Operation Conditions considered for the reinforcement assessment

In NI the reinforcement must consider the full use of the TEC of the interconnector.

These operation conditions however might not be achievable due to:

- the risk of overload;
- and adverse voltage step change in the event of the loss of the interconnector or the double circuit 275 kV connection between BPS, HAN, and BYC, as presented in figure 1.

[14] Information provided by NG ESO and Mutual Energy.

[15] The 450MW present limitation will endure in time as it relates to the requirement to meet the voltage step change criteria contained in the security standards. See further details on the "Interconnector Capacity Calculation", Section A3, Scotland to Northern Ireland Capacity.

AN A.3. Northern Ireland constraints

Moyle Interconnector **(S_MWMIN_MOYLE)** **(S_MWMAX_MOYLE)**	MW	B	-400* < MW < 442	Moyle Interconnector[4]	It ensures that all flows do not exceed an import of 442 MW to Northern Ireland and an export of 400 MW* to Scotland (values taken from NI). This is required to ensure that the limits are respected. *Notes: 1. Firm export limit on Moyle increased to 250MW from 80MW on 1st December 2020. There is an agreed process between Moyle and NGET on releasing additional "non-firm" export capacity when GB system conditions allow. 2. BREXIT - Impact on Scheduling Day-Ahead Markets, effective from 31 December 2020, will not include any SEM-GB interconnection capacity. This first day ahead LTS run should be considered more indicative than it would normally be, given that firm interconnector schedules for the first part of the next day (from 23:00 D-1 to 11:00 D) will not be available until post IDA1 (after 18:10). The LTS that is published each evening post IDA1 will reflect the firm interconnector schedules.

Figure 5 : Table extracted from the operational constraints with NI constraints