Moyle Interconnector Capacity Increase

Options Report

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Executive Summary

The Moyle Interconnector is a 500 MW HVDC link between Northern Ireland and Great Britain. It was energised in 2001. Whilst it has a capacity of 500 MW, it is constrained in Northern Ireland to 295 MW in export to avoid potential voltage excursion risk during a certain contingency. The import was also constrained to 450 MW to avoid overloads of certain 110 kV lines.

A joint economic study was conducted in 2013 by SONI and National Grid. This study sought to optimise generation production costs and identified significant socio-economic welfare benefits. The investments to address the constraints were also listed. The report is available on the SONI website project page.

In Great Britain several of the 275kV conductor uprate projects that were identified have been delivered with firm access for Moyle also supported by local commercial arrangements. In Northern Ireland the uprate of the Ballylumford – Castlereagh 110kV corridor was identified as required investment. The first section of this corridor is being uprated in 2023 as part of wider refurbishment requirement. TNPP approval is being progressed for the uprate of the second section (Eden – Carnmoney). The last section Carnmoney – Castlereagh is to be recovered as part of the Energising Belfast project with a TNPP already in place. Whilst these investments will improve the export capacity on Moyle they have other drivers and their justification is not dependent on the need to increase export on Moyle. Whilst the first project enables an increase in export to 400 MW, a voltage step issue prevents 500 MW export.

The socio-economic welfare benefits have been re-estimated and updated by SONI in 2021 using market simulation software. Table 1 presents the benefits of increasing the import and export interconnection capacity in two steps Case ID 2 (400 MW export) and Case ID 3 (500 MW export) against the base case limits of 450 MW import and 295 MW export.

Case ID	Scenario TYNDP2020 Scenario Report	Interconnector		Production cost-benefit [£m][1]	Renewable integration [GWh]	CO_2 emissions [Mt]	Congestion revenues [£m][1]
		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 - Yearly impacts in NI from increasing the import and export interconnection capacity

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

The Ballylumford – Eden 110kV circuit uprate addresses the overload risk and would resolve the restrictions on import. It is also considered that this project would allow the export to be increased to 400 MW allowing the benefits in Case ID 2 to be realised. However, none of the above projects specifically address the risk of voltage excursion sufficiently to allow a 500 MW export.

The following options in Table 2, including variants, were developed to address the voltage step issues that occur on full export.

Option No	Description	Estimated cost [£m]
1. Do nothing	Restriction relaxed but only to 400MW on export	n/a
2. Derogation	Derogation from TSSPS allowing restrictions to be removed.	n/a
3a. Three cables	Connect Ballycronan More directly to Ballylumford via three cables	17.09
3b. Two cables	Connect Ballycronan More directly to Ballylumford via two cables	9.01
4a. AIS marshalling substation	Establish and connect to a new AIS marshalling station close to Ballycronan More	47.02
4b. GIS marshalling substation	Establish and connect to a new AIS marshalling station close to Ballycronan More	31.81
5a. Statcom	Establish a statcom at Ballycronan More	26.14
5b. Synchronous condenser	Establish a synchronous condenser at Ballycronan More	24.98

Table 2– List and description of options

Option 1: Status quo was shortlisted but ultimately rejected as the Moyle interconnector flows would continue to be restricted and the full socio-economic welfare benefits not realised.

Option 2: Derogation from the TSSPS was rejected due to the increased risk of a voltage excursion that could cause widespread damage to customer equipment. Whilst the risk of a double circuit contingency between Ballycronan More and Ballylumford occurring at a time when the Moyle Interconnector is at full export is estimated to be very low, the impact of a prolonged voltage excursion across all substations in the east of Northern Ireland could be very damaging to customer equipment.

Option 3a: Connect Ballycronan More convertor station directly to the 275 kV switchboard at Ballylumford Power Station through three underground circuits (£17.00m) was shortlisted however not selected as the preferred option as it was significantly more expensive than the least cost option. Option 3b: Connect Ballycronan More convertor station directly to the 275 kV switchboard at Ballylumford Power Station through two underground circuits (£9.01m) was shortlisted and selected as the preferred option as it was the least cost and most deliverable solution. Option 3c: Connect directly Ballycronan More convertor station to the 275 kV switchboard at Ballylumford power station through OHL circuits was not shortlisted as it was considered not deliverable at a location already with a significant number of overhead lines.

Option 4a: Install an AIS switching station at Ballycronan More (£47.02m) was not shortlisted as it was almost five times the cost of the least cost option. Option 4b: Install a GIS switching station at Ballycronan More (£31.81m) was not shortlisted either as it was more than three times the cost of the least cost option.

Neither of Option 5a: Install FACTS based reactive compensation (STATCOM) (£26.14m) nor Option 5b: Install a Synchronous Compensator (£24.98m) were shortlisted based on the capital cost compared to the least cost option.

The lifecycle cost assessment was applied to Options 1, 3a and 3b. It included for the initial capital cost, the benefits, and the operation / maintenance (O&M) costs. For the net present value assessment only the production cost savings between Case ID 2 and Case ID 3 are entered as a benefit, because the restring of the Ballylumford – Eden enables Case ID 2 to be achieved already. The increased revenues to the interconnector would be funded from the market and are not an economic benefit, however based on the business model of Mutual these would be re-invested for the benefit of Northern Ireland consumers.

The conclusion from this assessment is that the option that presents the highest net present benefit is Option 3b. This is based on connecting Ballycronan More convertor station directly to two spare bays at the Ballylumford Power Station 275 kV switchboard through two new underground cable circuits, with the existing overhead connection removed.

1. Introduction

1.1. Background

The Moyle interconnector is a 500 MW High Voltage Direct Current (HVDC), linking the transmission networks from 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 NI and GB has been restricted below the capacity of the link due to transmission network limitations. Mutual Energy, but also the Transmission System Operators (TSOs) on each side of the Irish Sea have sought to remove these limits and increase the power flow through the interconnector to its constructive limits.

The present operational conditions in terms of power flow through the interconnector are the following:

- Export capacity up to 295 MW, which can be increased up to 400 MW if the 110 kV Castlereagh - Carnmoney circuits are operated opened. These limits are in place to manage the risk of an unacceptable voltage excursions that would occur after a specific contingency.
- Import capacity of 450 MW limited due to risk of overloading Ballylumford – Eden 110 kV circuits after a specific contingency.

A joint economic study was carried out, involving National Grid 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. In Northern Ireland this included restring of the Ballylumford – Eden, Eden – Carnmoney and Carnmoney - Castlereagh circuits.

In Scotland the work included:

- Coylton-Mark Hill re-conductor,
- Kilmarnock South-Coylton uprate,
- Kilmarnock South 3rd 275/400kV IBT,
- Uprate 275kV substation and add 3rd auto and
- Coylton-Kilmarnock South 3rd circuit.

Of the above work identified in Great Britain it is understood that the Coylton – Mark Hill circuit was uprated with High Temperature Low Sag (HTLS). Kilmarnock South to Coylton double circuits now have a rating of 1500 MVA each. Kilmarnock South has a 3rd 400/275kV IBTX. There does not yet appear to be a 3rd circuit from Coylton to Kilmarnock South.

In Northern Ireland the Ballylumford - Eden circuit is being uprated in 2023. SONI has just received regulatory approval for the uprate of the Carnmoney – Eden section. The Carnmoney – Castlereagh section is due to be recovered in circa 2027 as part of the Energizing Belfast project. In any case the overloads can be addressed by opening the Castlereagh – Carnmoney circuits allowing the export to increase to 400 MW. However updated studies confirmed the risk of voltage step requiring further work.

1.2. Needs Case

This options report should be read in conjunction with the Needs Case. The needs case identified the economic benefits of addressing the restrictions on the use of the Moyle Interconnector.

1.3. Moyle interconnector Runback service

The Moyle Interconnector Operating Protocol has several instructions, called Cross Border Actions, which can be triggered by SONI or National Grid Electricity System Operator (NG ESO). These instructions include the Interconnector Runback service, and it is useful here to explain the importance of this scheme.

The largest credible demand loss on the NI transmission system is usually the export transfer to Republic of Ireland (RoI). The Runback service was idealised to act automatically against a high frequency event occurring in NI, following the loss of the North-South 275 kV interconnector. Should this 275 kV connection to RoI fail, the Moyle interconnector will automatically reduce the import to NI and/or begin exports to NG ESO transmission network.

The maximum agreed Runback available is a change of 300 MW provided by NG ESO from NI to GB. This service is very useful in days of high wind generation penetration in NI and low wind generation penetration in the RoI, when the North-South 275 kV interconnector is heavily loaded by the export from North to South. If this link between the North and the South fails, NI's transmission network needs to have sufficient capacity to export to GB, up to the 500 MW, including the 300 MW from the Interconnector Runback Service, so that can avoid frequency instability due to the excessive production.

2. Impacts of other projects on addressing the need

There are four projects that will impact on the capacity of the interconnector connection to import and export as follows:

- Ballylumford – Eden 110 kV uprate;
- Eden – Carnmoney 110kV uprate;
- Energising Belfast – Recovery of the CAS-CAR 110 kV double circuit.

Any CAPEX related to the delivery of these projects is not included in this Options Report. These projects are already approved, but their impact on this project is to be considered.

2.1. Balylumford – Eden 110kV circuits uprate

The Ballylumford – Eden 110 kV double circuit uprating project is due be delivered during 2023. This is expected to allow a 500 MW import. It is expected to allow the increase to 400 MW export. However, the Ballylumford - Eden 110 kV circuits uprate project does not address the scenario (known as Case WP3), during winter peak, with the Moyle interconnector exporting 500 MW at high wind generation in NI (80% penetration), where voltage step issues remain.

2.2. Eden – Carnmoney 110kV uprate

This project was also previously identified as an enabler to allow the increase of export to 400 MW. The project requires a significant extent of undergrounding in Carrickfergus and Carnmoney. Regulatory funding has been granted to SONI to commence outline design. However, the project is not essential to enable up to 400 MW export as the Carnmoney – Castlereagh 110kV circuits can still be operated normally open.

2.3. Energising Belfast project

This project involves the installation of a cable connection between Hannahstown and Castlereagh. This work will in turn allow the decommissioning and recovery of the 110 kV double circuit between Carnmoney and Castlereagh substations. The full project is planned to be delivered in 2028, but the decommissioning of the Carnmoney to Finaghy circuits are planned for 2023 and 2024.

On export, which is important to allow excess renewable generation to be exported, this project is not designed to facilitate the 500 MW export. However, the project establishes a more direct cable connection between Hannahstown and Castlereagh grid supply points, meshing these demand centres which, combined with the battery connected to Castlereagh will change the way this system responds to under-voltages.

2.4. Other main stakeholder’s projects

NG ESO has worked to increase the capacity in the GB transmission network towards 500 MW by the end of 2022. Mutual Energy has recently replaced the controls of the interconnector. The main driver for this project was to allow the interconnector to be operated in a more efficient way.

2.5. Drumnakelly – Tamnamore 110 kV circuits uprate

The potential overloads of the Drumnakelly - Tamnamore 110 KV circuts are related to the high wind and are not caused by an increase in the export on Moyle. In any case the uprate of these circuits is included in the TDPNI 2020-2029 and is estimated to be completed by 2027.

2.6. North-South 400 kV interconnector

This project is driven by the need for market integration, security of supply and RES integration. It involves construction of a new 400 kV circuit from existing Woodland 400 kV station to a proposed 400/275 kV station at Turleenan. The estimated completion of this project is for 2026. This project avoids a system separation event, which may allow the run back scheme, discussed earlier to be decommissioned.

3. List of options

The technical solutions proposed to address the issues identified in the Need Case will be presented in the longlist of options. The estimated capital costs of the different solutions are presented in Appendix A. Rationalisation of the longlist has been done to reduce the options to a shortlist.

3.1. Option 1: Status quo

With the "do nothing" option, no actions are taken to address the issues identified in the Need Case. SONI would be required to continue to comply with the Transmission System Security and Planning Standards (TSSPS) and would therefore be required to implement the restrictions. Therefore, the benefits of allowing the interconnector to operate, in particular to 500 MW export would not be realised. However, as the Ballylumford – Eden circuit is to be uprated it is expected that the export capacity could be raised to 400 MW. Therefore this would become the new baseline for the Status Quo option.

3.2. Option 2: Derogation from the TSSPS regarding the step change in voltage

With this option, SONI would consider a derogation from the TSSPS in respect of the voltage issues identified in the Need Case. A derogation is generally only sought where there is a very low probability of an event and/or a low or medium but manageable consequence. With this derogation option SONI would then be able to increase the flow in export from 400 MW to 500 MW. However, there would be an increased risk of voltage excursion which could lead to damage of equipment

3.3. Option 3: Connect Ballycronan More convertor station directly to Ballylumford Power Station

This solution aims to avoid voltage and overload violations by connecting Ballycronan More directly to the Ballylumford Power Station 275kV switchboard. The existing overhead line connection to the substation would be disconnected with the diverted span restored, thus re-establishing a second Ballylumford – Hannahstown circuit. Three variants were considered as follows:

a) Option 3a: Connect through three underground circuits.
b) Option 3b: Connect through two underground circuits.
c) Option 3c: Connect through overhead line circuits.

A single circuit cable connection was ruled out as the risk of a prolonged cable fault and the subsequent complete loss of the interconnector was considered unacceptable.

3.3.1. Treatment within the TSSPS

This section considers the treatment of the Moyle interconnector when exporting in excess of 300 MW.

The Great Britain SQSS Version 2.2 in the Introduction Role and Scope includes the clause 1.4 states "External interconnections between the onshore transmission system and external systems (e.g., in Ireland & France) are covered by separate agreements, which will normally be consistent with this Standard. This Standard may be specifically referenced in the relevant agreements and shall apply to the extent of that reference."

When in export mode in the event of the loss of the Moyle interconnector there would be the disconnection of the real power being exported. Its impact is not the disconnection of demand in Northern Ireland that would be considered in Table 3.1 of the TSSPS, rather it is the loss of an infeed into the transmission system in Great Britain. The Great Britain SQSS in the definition of a Loss of Power Infeed includes "the output of a single generating unit, CCGT Module, boiler, nuclear reactor or import from an external system via a HVDC Link". The loss of the Moyle Interconnector would be considered well within the *Infrequent Loss of Power Infeed* risk of 1800MW and an increase of the export to 500MW remains well within this limit.

Nevertheless, for completeness and to avoid any doubt it would be prudent to update the TSSPS in Northern Ireland to include a similar clause in the TSSPS.

3.3.2. Option 3a: Three cables between Ballycronan More and Ballylumford Power Station (£17.09m)

This sub-option is based on establishing three underground cable circuits between Ballycronan More and Ballylumford. As there are only two available bays this option would involve a substation extension and diversion of the tower line to avoid it over sailing the extended compound. Figure 1 presents an indicative route for the three 275 kV underground circuits and also shows the switchgear yard expansion. The indicative route for the cable circuits is on land owned by Mutual and NIE Networks. The expansion of the 275 kV switching yard, would be on land owned by Mutual.

As per Figure 1, the route would cross the path of the Scotland – Northern Ireland Pipeline (SNIP). With the information available, it is believed that the crossing would require Horizontal Directional Drilling (HDD)[2] with hand digging to expose and monitor the ground around the SNIP.

[2] At the detail design stage, Mutual Energy – Gas and NIEN should do trail holes and engage to find the final solution. Also, further assessment must be conducted at that stage to identify any impacts in terms of inductive and capacitive currents that might damage the pipeline, and find solutions to mitigate these effects created by the 275kV circuits.

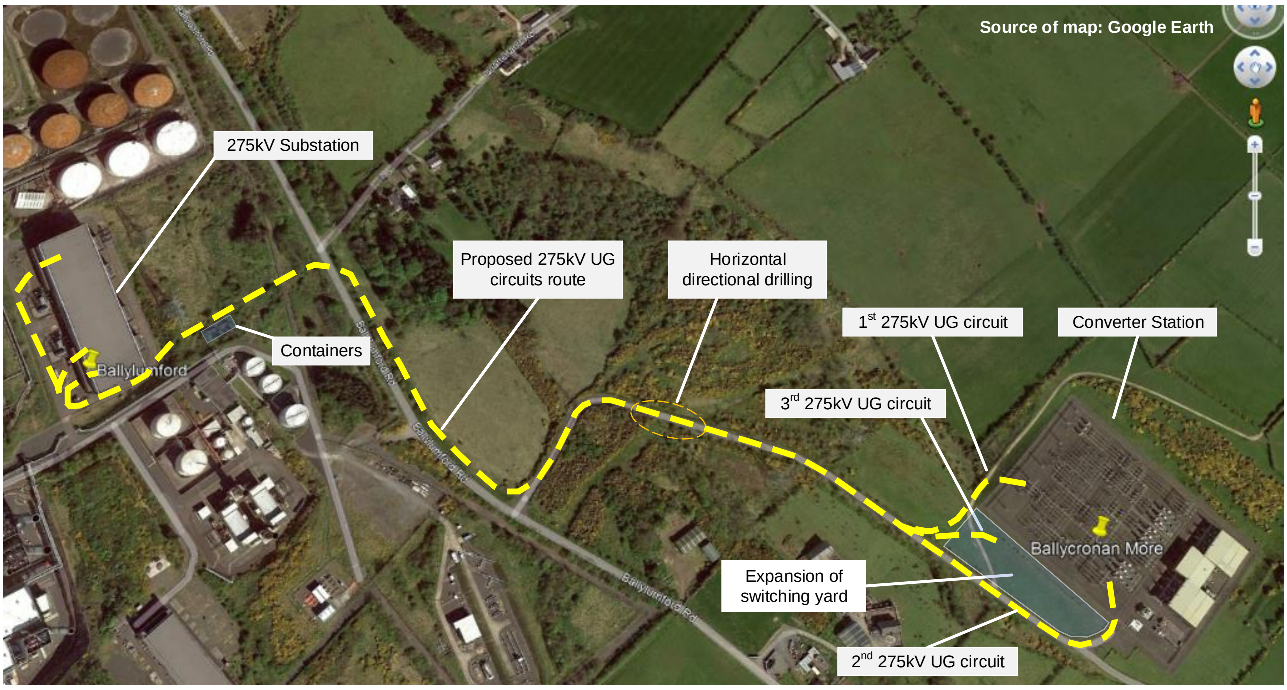

Figure 1 : Option 3.a – Route for the 3x 275 kV underground circuits and BYC switchyard expansion

The existing connection is established with two 275kV substation bays at Ballycronan More. This option would require three bays and as there are no spares or room to extend within the existing compound, it would be necessary to extend the existing switchyard. This in turn would also lead to the oversailing of the extended switching yard by the 275 kV OHL circuits between towers 604 and 605. To solve this issue a number of spans on this tower line would have to be diverted. An indicative solution is presented above in Figure 2.

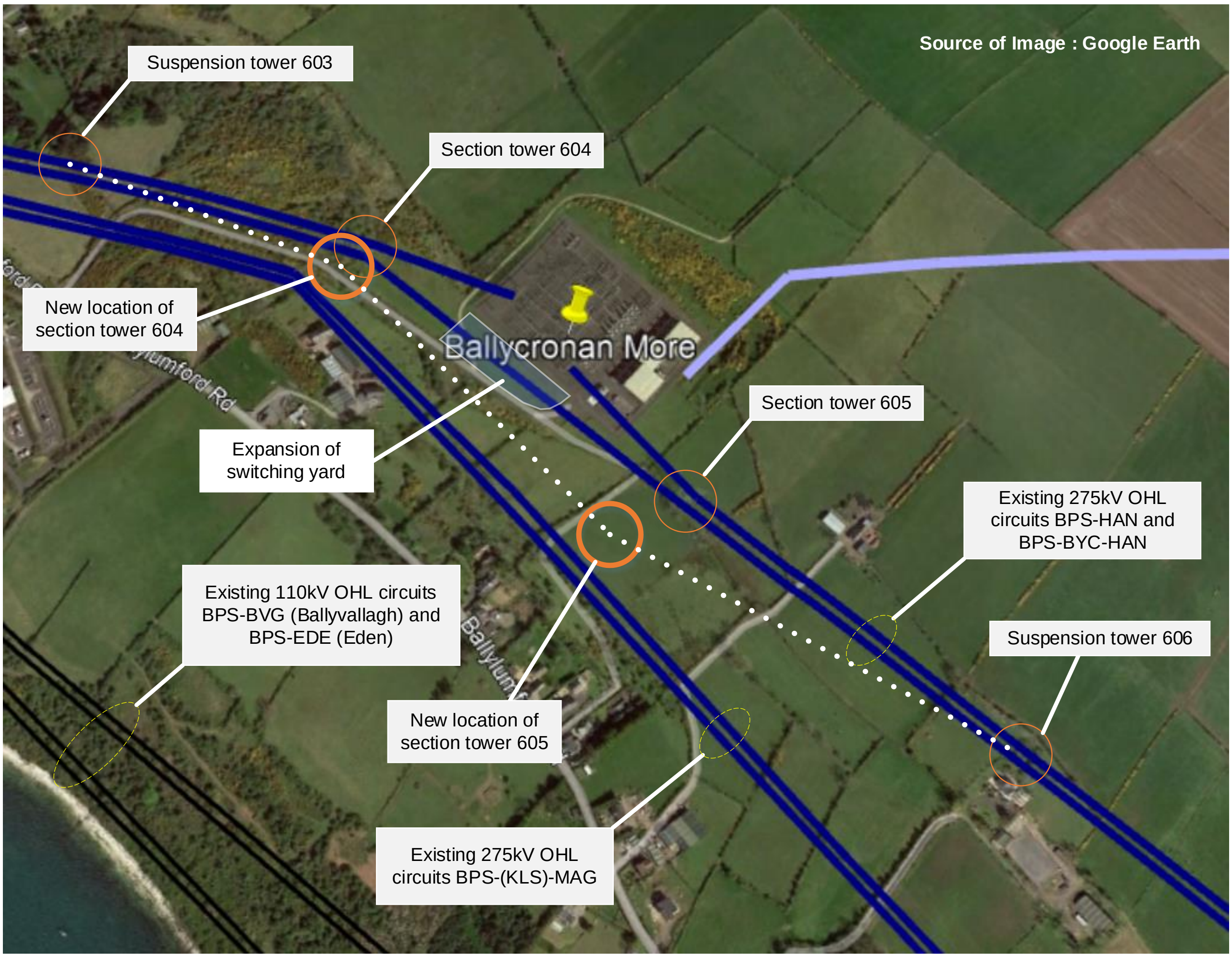

Figure 2 : Option 3.a – Proposed diversion of 275 kV BPS-HAN and BPS-BYC-HAN to avoid oversailing

3.3.3. Option 3b: Two cables between Ballycronan More and Ballylumford Power Station (£9.01m)

This option is based on installing two 275 kV cables using the existing bays at Ballycronan More substation and spare bays at the Ballylumford 275 kV switchboard. This would avoid the need, that exists in Option 3a, for any additional bays, the substation extension, or the line diversion. Figure 3 presents an indicative underground cable route.

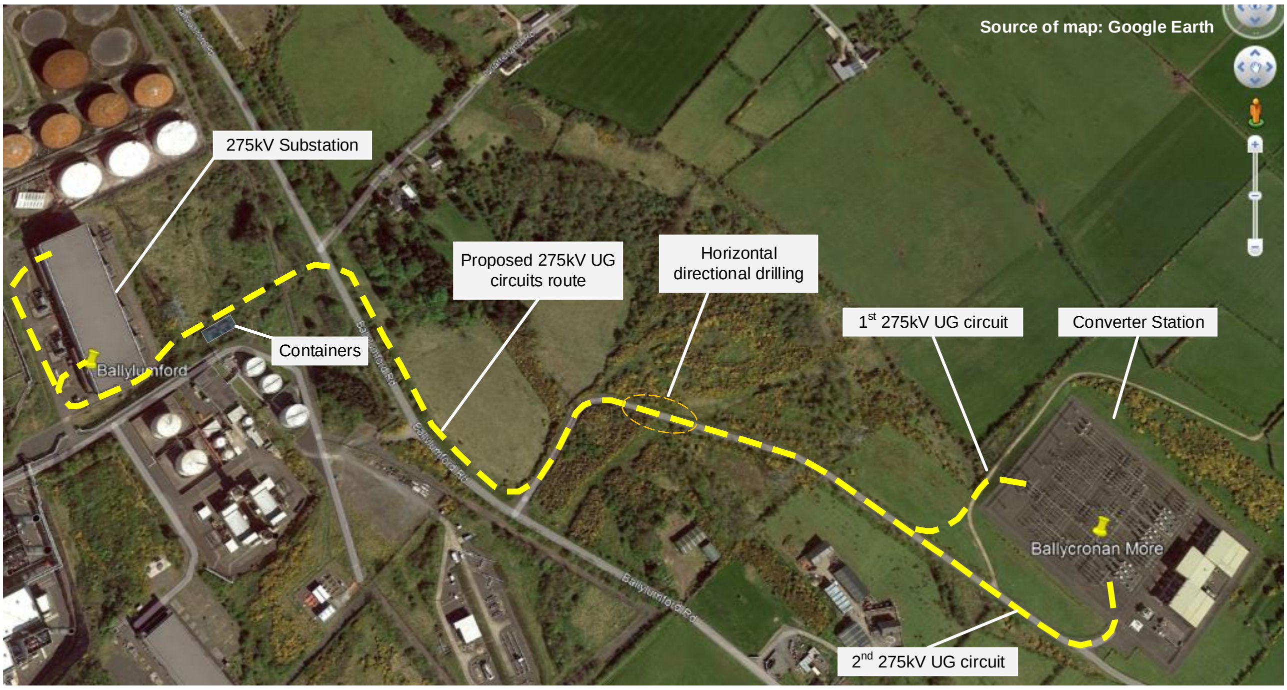

Figure 3 : Option 3.b – Route for the two 275 kV underground circuits

This option is priced on the basis that the line might need diverted to avoid a marginal oversailing of the converter station compound. However, this assumption needs a detailed assessment by NIEN to be confirmed. If there isn't the need to divert the line, then the above cost will be reduced to £8.25m.

Each of the two cables will be designed to cater for the full capacity of the interconnector. The Moyle interconnector comprises of two 250MW converters supplying two HVDC cables that taken together can transport the 500 MW. Therefore, this arrangement matches or betters the security and redundancy inherent to the interconnector itself.

3.3.4. Option 3c: New overhead lines between Ballycronan More and Ballylumford Power Station

This option would be based on establishing two 275 kV overhead line circuits between Ballylumford and the Ballycronan More Converter station. This option would not be feasible as the area already has a significant number of 110 kV and 275 kV OHL circuits.

To avoid the hub-and-spoke effect of overhead lines close to the substations at Ballylumford and Ballycronan More, as well as the likely clearance issues, the new circuits would be undergrounded at the approaches. If approximately 500m are to be considered for the circuits to go from OHL to UG cable, this would mean that only third of the distance would be in OHL.

In any case, as the spare bays were formerly used for the generator circuits, the connections to Ballylumford have to be via underground cables, as per the electrical diagrams in 0.

3.4. Option 4: New switching station at Ballycronan More

This option would be based on establishing a new 275kV switching station adjacent to Ballycronan More either air or gas insulated. The Ballylumford - Hannahstown and the Ballylumford – Kells / Magherafelt 275 kV double circuits would be looped in and out of the new switching station. The converter station would be connected via underground cable from the new switching station to the existing bays. Figure 4 below presents this solution in further detail. On the drawing the existing converter station is labelled as BYC-B and the new switching station as BYC-A.

A new switching station would be required because there is no space in the Ballycronan More 275kV switchyard to accommodate any additional switchgear let alone enough for a new double busbar. This new switching station would be installed, where possible, in land owned by Mutual Energy, or suitable land nearby.

There are two sub-options as follows:

a) Option 4a: An air insulated substation with the existing circuits looped in.
b) Option 4b: A gas insulated switchgear (GIS) substation with circuits diverted in via cable sections.

The AIS or GIS BYC-A substation would have the Single-Line Diagram (SLD) proposed in 0.

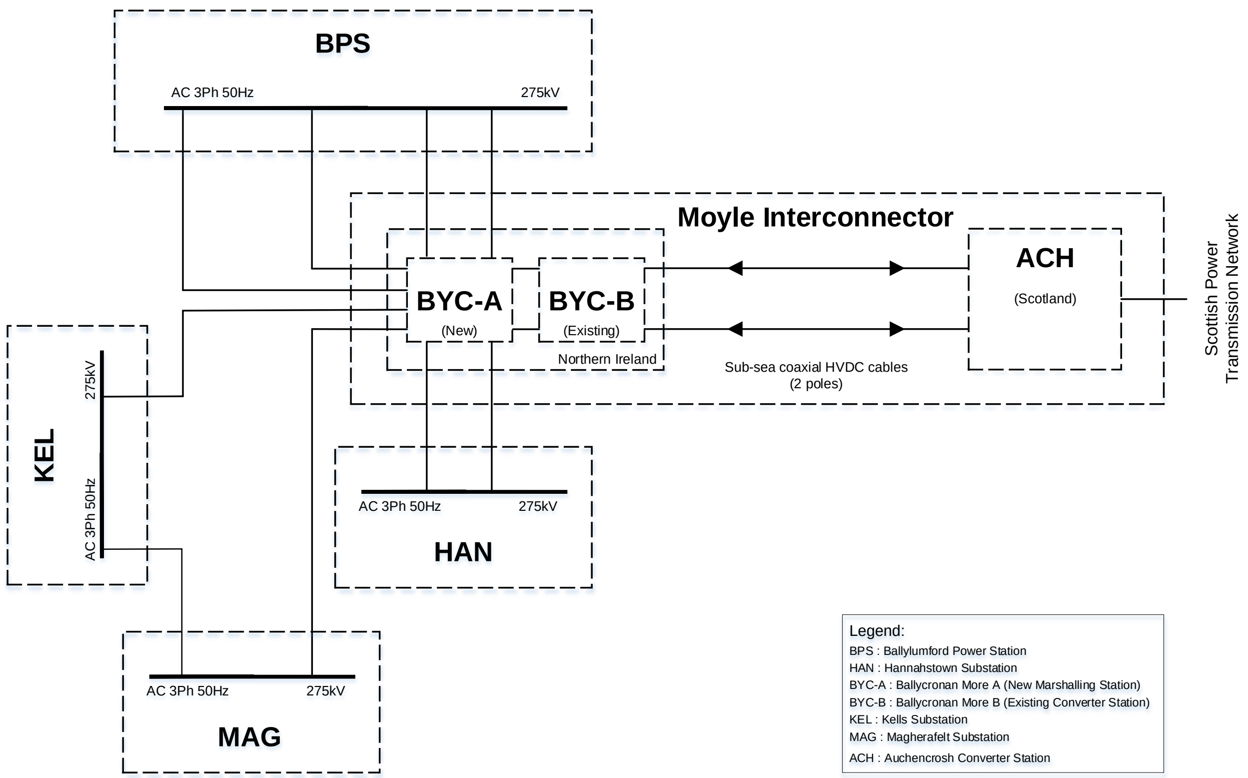

Figure 4 : Looping of Ballycronan More switching station in the 275 kV DCTs

3.4.1. Possible study area for the location of new AIS or GIS switching stations

Figure 5 presents the land owned by Mutual Energy around the converter station. There are three zones of the land available that could be considered. One to the southeast of the converter station with c40,000m^2, another to the northeast with c66,000m^2 (excluding an area were the HVDC cables are laid), and another smaller zone to the northwest with c8,500m^2.

The AIS solution is not suitable for any of the above locations, so a solution outside this study area has to be identified.

Figure 5 : Indicative layout of land owned by Mutual Energy around the converter station

The three zones identified above are large enough to accommodate a GIS switching station. The northeast zone is quite a large hill and not considered suitable. However, the southeast zone will be considered the candidate option for costing purposes as it is the location nearest to the existing circuits and has the space for cable sealing end compounds necessary to turn in the circuits to the GIS station inside the land owned by Mutual Energy. The turn-in of the 275 kV circuits would be more difficult to achieve with the northwest zone.

The fact that the terrain is not level in this zone will require some ground works. Some of this zone is subject to floods[3], so if the GIS became the preferred solution an environmental assessment would be required.

[3] https://arcg.is/ua9Pu

3.4.2. Option 4a: Install an AIS switching station at Ballycronan More (£47.02m)

Option 4.a is based on a new AIS switching station near the existing converter station and the connection of the existing Ballycronan More switchyard via two of underground circuits. The proposed converter station single line diagram is presented in 0. For the AIS switching station an approximate footprint of c280mx125m is required, however there would be additional land around this for screening.

Error! Reference source not found. below shows the study area for a new AIS switching station a nd rearrangement of 275 kV.

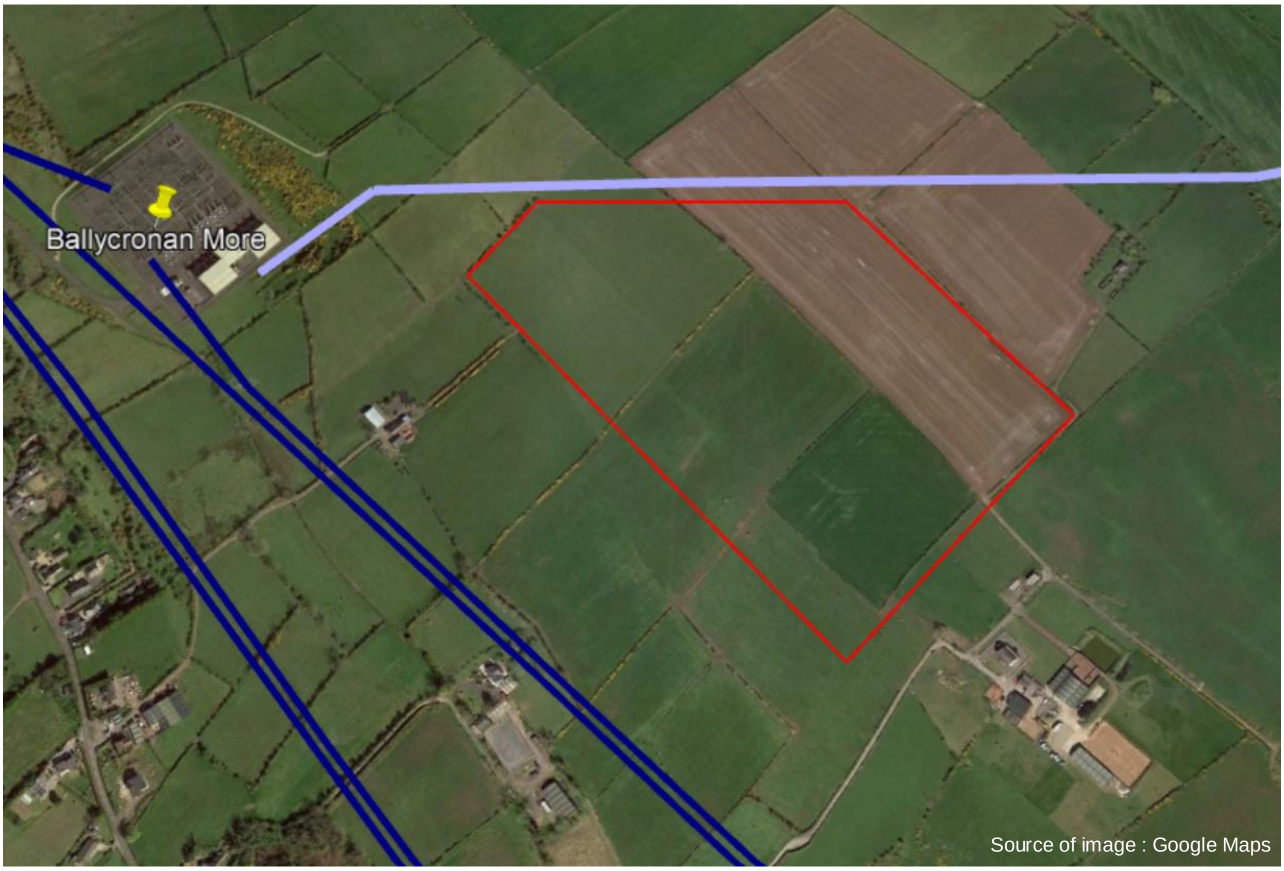

Figure 6 : Study area for the AIS

The existing Ballylumford / Ballycronan More - Hannahstown and Ballylumford – Kells / Magherafelt DCTs would both be diverted to the new switching station. This would be achieved either by diversion of the overhead tower lines or as is more likely by installing new terminal towers, cable sealing compounds and short 275 kV cable sections with some spans of the existing lines recovered.

The new switching station would be connected to the existing Ballycronan More 275 kV switchyard via two new 275 kV underground cable circuits. The cables would go through private property, before entering the Mutual Energy site.

3.4.3. Option 4b: Install a GIS switching station at Ballycronan More (£31.81m)

This option is based on the construction of a new GIS switching station with a single line diagram as in 0. The Ballylumford – Kells / Magherafelt 275 kV double circuit would be turned-in to the new GIS switching station using new terminal towers, cable sealing end compounds and cable sections. The new switching station would be connected to the existing Ballycronan More switchyard via two underground circuits inside Mutual Energy property. The existing turn-in to Ballycronan More would be decommissioned and the span between towers 604 and 605 restored.

Below, figure 7 presents the possible location of 275 kV BYC-A GIS switching station and rearrangement of 275 kV OHL circuits in its vicinity. An area of c35,000m^2 would be required with the GIS solution being c75mx60m or c4,500m^2.

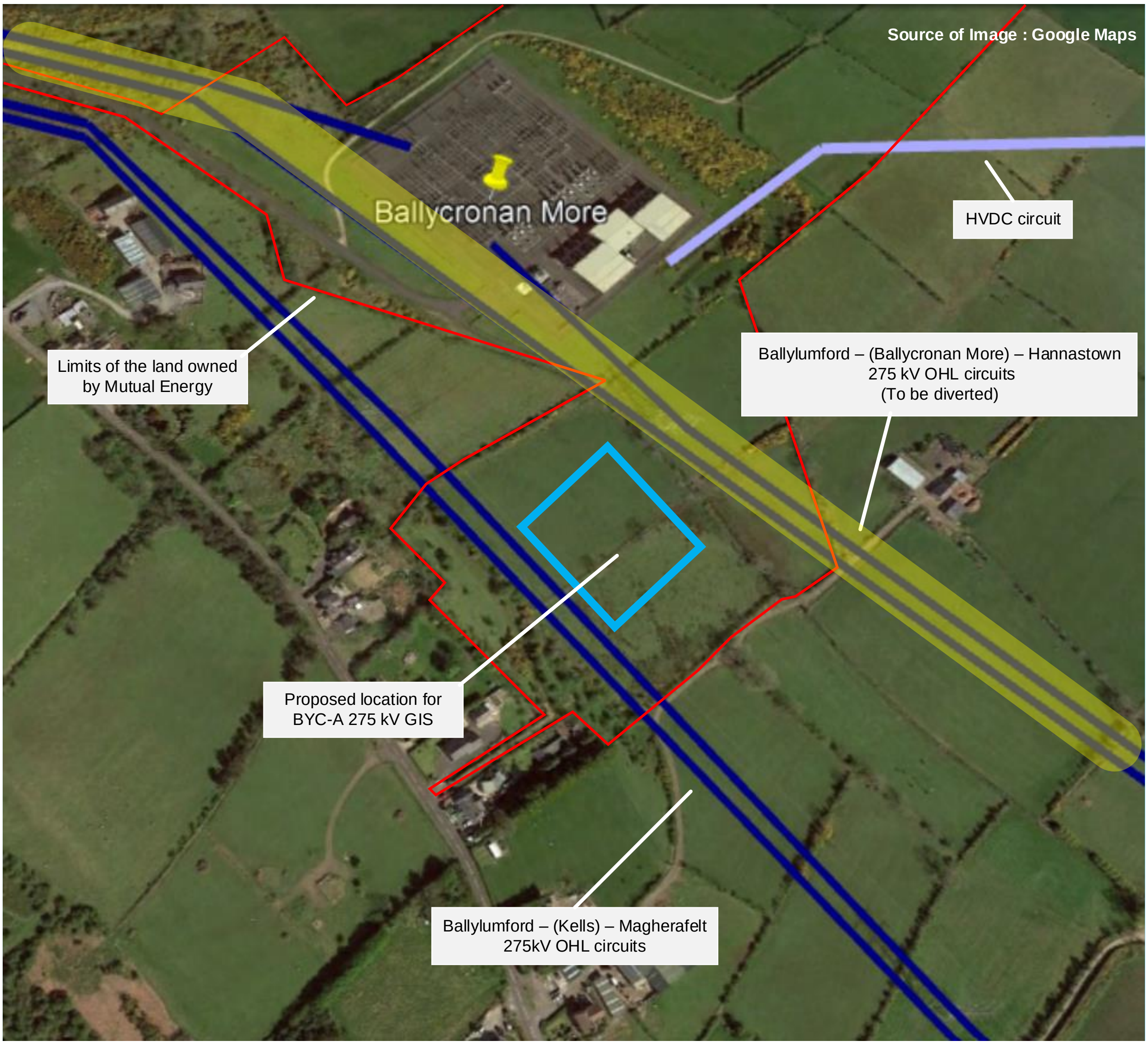

Figure 7: Location of the 275KV BYC-A GIS switching station and rearrangement of 275 kV OHLs

3.5. Option 5: Installation of dynamic reactive compensation

This option is to address the voltage issues by installing a device that provides dynamic reactive power. The technical variants addressed in this section are the following:

a) Option 5a: Flexible AC Transmission Systems (FACTS).
b) Option 5b: Synchronous Compensators (SCs).

3.5.1. Option 5a: Install FACTS based reactive compensation

Shunt compensation using static compensators for reactive power management is possible by:

- Static Var Compensators (SVCs);
- STATic synchronous COMpensators (STATCOMs)

An SVC is capable of absorbing or generating reactive power to control the system voltage. Most use thyristor-controlled reactors (TCR), thyristor-switched capacitors (TSC), harmonic filters, and/or breaker-switched or fixed capacitors as basic branches. They also have a shunt coupling transformer for connection the converter to the AC network. A STATCOM is a similar device with improved voltage performance, lower harmonics issues but higher losses.

At this option appraisal stage high-level load flow studies were conducted to confirm that a FACTs device would be a potential solution. It is expected that a shunt based STATCOM would be rated to approximately one third of the capacity of the Moyle interconnector, i.e., approximately ±167 MVAr. This is equivalent to an HVDC link with a power factor range of 0.95 leading and lagging as now required through the Network Codes.

The minimum CAPEX figures[4, 5] expected for SVCs are £28.99k/MVAr and for STATCOMs are £48.32k/MVAr. Therefore, considering the amount of reactive capacity required the cost for the device itself would range between £10.65m for an SVC and circa £17.74m for a STATCOM. There would also be other costs which will be discussed below.

It is estimated that a compound of c80x80m would be required for an SVC. A STATCOM would require a smaller compound of c40x40 m.

It is expected that a STATCOM would be the most suitable solution from a technical performance perspective for consideration at this stage. But if any further studies were able to demonstrate that SVCs or hybrid STATCOMs have the technical performance required to deliver

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[4] Based on A. L'Abbate et al. paper [30], table 2. The minimum values were considered as these costs refer to 400KV compensators, and not 275kV as in this study. Assuming the minimum values will reduce the costs increase due to the higher network voltage, making this estimate more conservative. The major impact will be on the coupling transformer that connects the converters to the AC network, as the majority of the remaining components of the compensator wok at much lower voltages (e.g., 20kV) than the AC network voltage.

FX rate on the 25th January 2022 : 1.19EUR/GBP.

[5] For the purpose of this analysis and as the origin of data is in Euros from 2010, inflation considered in the CAPEX estimate is of ≈15%. for 2020 prices. Source : The World Bank (https://data.worldbank.org/indicator/FP.CPI.TOTL.ZG)

the project scope, these solutions could be the answer as they are cheaper. For costing purposes, it is assumed that the connection of a STATCOM to the 275 kV network would be through a single 275kV cable[6].

3.5.2. Study area for possible location of the STATCOM

The different zones available in Mutual Energy owned land are presented in section 3.4.1. The Northwest Zone with c8,500 m^2 would be considered sufficient to accommodate the 1,670 m^2 as the expected footprint for the STATCOM. However, this location poses issues regarding oversailing of the STATCOM by the 275 kV OHL circuit from Ballylumford to Ballycronan More. So, this location is not suitable for a STATCOM, and instead the Southeast Zone will be preferred, as per the same reasoning in section 3.4.3 to justify the location for the 275 kV GIS.

A STACOM would be connected with a 275 kV underground cable to new bay. This would require the switchyard to be extended and the diversion of 275 kV Ballylumford – Ballycronan More / Hannahstown double circuit tower line to avoid oversailing as proposed in figure 2, section 3.3.2 for option 3a.

3.5.3. Option 5b: Install a Synchronous Compensator (£24.98m by third party)

This option is based on the installation of a new synchronous compensators at the Moyle site or Hannahstown. Figure presents the main components of a synchronous compensator.

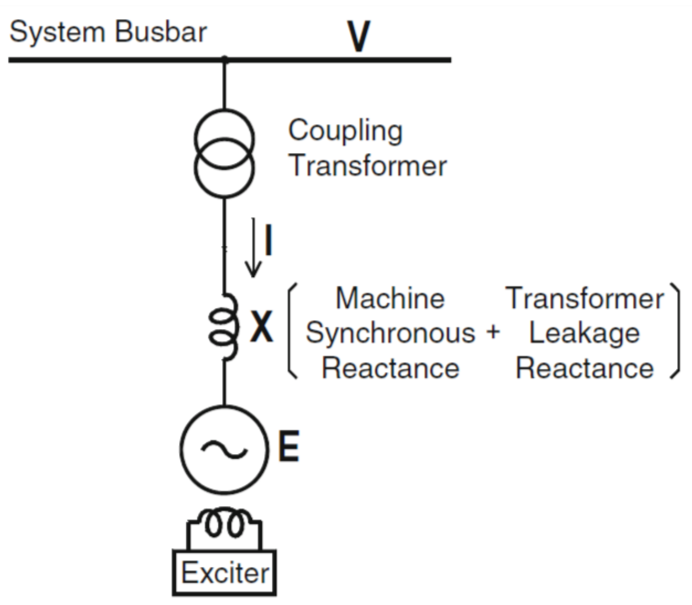

Figure 8 : Representation of the main components of a synchronous compensator

Some of the features of a synchronous condenser are as follows:

[6] 275 kV Cu 1000 mm^2 XLPE, in trefoil arrangement, enabling 900A at 65°C

- The SC provides instantaneous mechanical inertia, which contribute to frequency stability and control as RoCoF[7] reduces.
- It contributes to increase fault levels, which can reach up to 3-4 times MVA rating, as per Annex 0.
- Short-term overload capability, as unlike FACTs, the SCs have a large current overload capability, which can provide transient and steady-state voltage support.
- Responds slower than a STATCOM.
- It requires more maintenance than a STATCOM.
- It requires a pony motor to accelerate shaft to operating speed.
- Does not require harmonic filtering, which sometimes might be necessary in STATCOMs.

The cost to deliver a new synchronous compensator is estimated to be between £77.78k/MVAr to £100k/MVAr (see CIGRE TB 186 [2, p. 25], see also assumptions[8, 9]). Using the needs of reactive power estimated in section **Error! Reference source not found.** of not less than 167 M VAr exporting, the cost is estimated to be c£16.7m plus connection costs. This device is expected to require an area of c37x37m, which is less than any FACTs footprint. Such a device would be connected via a 275 kV cable and a new 275kV bay. On the basis that it was a third party other than Mutual Energy, this would require an extension of the compound and diversion of the tower line to avoid over sail.

Maintenance figures for much smaller SCs are presented in F. Igbinovia et al. paper [3], "Cost Implication and Reactive Power Generating Potential of the Synchronous Condenser". The values presented range from 2% to 4%.

SCs are one of the preferred solutions identified by SONI in the "Shaping our electricity future" reports to provide ancillary services to the electricity system for the lack of dynamic reactive power for voltage control[10]. SONI is tendering for a number of synchronous condensers to strengthen the network in the north and west of Northern Ireland, however as the reactive power is required in either Moyle or Hannahstown the current tender process will not address the need. In addition, any project to install such a device though this market must come from the participant in the System Services market and not from the Transmission System Operator (TSO) or the Transmission Owner (TO).

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[7] The Rate of Change of Frequency (RoCoF) varies approximately to the inverse of inertia. This means that if a flywheel is added to the system it will improve frequency stability.

[8] FX rate on the 25th January 2022 : 1.35USD/GBP.

[9] For the purpose of this analysis and as the origin of data is in US Dollars from 2001, inflation considered in the CAPEX estimate is of ≈50% for 2020 prices. Source : The World Bank (https://data.worldbank.org/indicator/FP.CPI.TOTL.ZG).

[10] This relates to the DS3 DRR (Dynamic Reactive Response) System Service.

4. Appraisal of options

4.1. Rationalising the longlist of options

The options in the long list are initially appraised according to the following criteria:

- Technical performance
- Deliverability
- Capital Cost

At this stage the assessment will be mainly qualitative, except for the CAPEX. In the end an overall summary will rank the different options. Based on this hierarchy, it will be possible to reject some options and identify the shortlist of options.

4.2. Capital cost

The capital costs of each infrastructure-based option is shown in

Table 3.

Options Cost (£m)					
3.a	3.b	4.a	4.b	5.a	5.b
17.09	9.01	47.02	31.81	26.14	24.98

Table 3 : CAPEX per option

It is noted that Option 3b (cabling back to Ballylumford) is the least cost with Option 4a (new AIS switching station) being the most expensive.

4.3. Technical performance

4.3.1. Option 1 Do nothing

Option 1 would not allow the interconnector to operate at its full capacity and this would prevent the consumers in Northern Ireland from realising the socio-economic welfare benefits. It would also not be consistent with the aim to achieve 80% renewables by 2030. However, it is technically possible to continue to constrain the output of the interconnector to its current limits.

4.3.2. Option 2 Derogation

A derogation from the TSSPS would in theory address the TSSPS non-compliance. After derogation, Option 2 would in theory allow the interconnector to be operated at the higher export capacity immediately following approval. However, from the limited analysis in section 3.2, whilst there would be a very low probability firstly of a double circuit fault between Ballycronan More and Ballylumford and secondly of that occurring at a time during high export, such an event would have very high consequence to customers supplies in Northern Ireland. As there would be an excursion of 110 kV and 275 kV voltage levels there is a likelihood that system services would also trip to protect their equipment.

This option would not be robust to other changes in the power system as the basic connection arrangement, which gave rise the contingency and its consequences would remain. Therefore, the connection of additional generation at Ballylumford or new demand in Belfast would exacerbate the problem.

4.3.3. Options 3a, 3b and 3c

All Option 3 variants would establish direct connections between Ballycronan More and Ballylumford and therefore the double circuit contingency that created the risk to supplies associated with a voltage excursion is removed.

Option 3a would have three cable circuits. In the event of a fault on two cables the third cable would be available. However, the risk of a failure that resulted in two cables being affected is extremely low. In addition, the additional security provided on this connection would be excessive as a) there are only two converters and HVDC cables and b) there is only a single 400 kV line in Scotland. Finally, this option requires a compound extension and line diversion at Ballycronan More and the use of three of the five currently spare bays at Ballylumford (one of which could be used for another purpose).

Option 3b provides two cables. This ensures that if there is a failure of one cable then the full import and export capacity of the interconnector can continue on the remaining cable. This would be a significant improvement on a single cable as it would avoid a lengthy outage of the interconnector for repairs to be arranged on the single 275kV cable. Being based on two cables the level of redundancy is consistent with that of the HVDC link and is superior to the single line in Scotland. Finally, it can also be accommodated with the existing number of bays at Ballycronan More and therefore avoids the need to extend the substation and divert the 275kV tower line.

It is noted that this option makes use of capacity of the Ballyumford switchboard. Whilst it is of the double busbar design it is of a limited busbar rating of 2000 amps. Whilst this is expected adequate for the direct connection of the Moyle interconnector this will use up capacity.

Option 3c is technically viable but not considered deliverable.

4.3.4. Option 4a and 4b (AIS and GIS switching stations)

These solutions address the need, but they require a new marshalling substation to loop both 275 kV DCTs coming from Hannahstown and Kells/Magherafelt. These options are also superior to Option 5a and 5b because rather than trying to correct the voltage excursion, they design out the risk in the first place.

These options also have some advantages over the variations of Option 3. They would establish a new 275 kV double busbar switchboard rather than connecting into an older existing one. This would allow the bays that are free at Ballylumford to be used for generation or system services at that location. Potentially this option avoids the accumulated reactive power from the cables that is present with the variants of Option 3. Shunt reactors are used across the system to compensate for reactive power from cables and lightly loaded lines during light demand, however there is a limited number of bays available to connect.

It is useful to note that these options, in particular the AIS option, which also would be extendable, and could also be used to connect other parties to the transmission system. Finally, as this would be a new switchboard, all of the components could be rated higher than that of the existing switchboard, i.e. to 4000 amps. This would also facilitate future connections and prevent these from causing an overload of the Ballylumford switchboard in the future.

4.3.5. Option 5a (Facts) and 5b (SC)

These solutions would address the need by controlling the voltage at Ballycronan More. Ultimately the single circuit loop in of Moyle gives rise to a contingency that puts electrical distance between Moyle (plus the Belfast demand block) and the reactive support that would otherwise be available at Ballylumford. The installation of reactive support at Moyle or Hannahstown, unlike Options 3 and 4, would be a remedy to treat the symptoms rather than a prevention in the first instance. However, the voltage excursion risk could be prevented by Ballycronan More being directly and securely connected to a source of reactive power.

There are some technical differences between Option 5a and 5b. Option 5a (FACTS), which is based on a STATCOM, would not provide inertia or fault level. Option 5b (SC) however would provide inertia (allowing for better frequency stability and control, as RoCoF[11] reduces) and increased fault level making improvements to power quality. This is also important for the Moyle interconnector which requires a minimum fault level.

4.4. Deliverability

4.4.1. Do nothing

Not applicable

4.4.2. Derogation

Not applicable

4.4.3. Option 3a (three cables), 3b (two cables) and 3c (new overhead line)

For option 3a it is estimated that the timescale for delivery would be six years in total. This includes three years for outline design, planning permission to extend the switching yard and diversion of the lines to avoid oversailing and other consents such as easements. The remaining three years would be required for construction.

Option 3b (two cables) is easier to deliver than 3a. It does not require a substation extension or line diversion. It is estimated therefore that the timescale for delivery would be four years in total, i.e. two years earlier. This includes two years for outline planning, detail design, easements, wayleaves and a further two for construction.

Option 3c (new overhead line) is not considered to be deliverable.

[11] Rate of Change of Frequency.

4.4.4. Option 4a (AIS switching station) and 4b (GIS)

It is assumed that Option 4a could be delivered in six years from project approval. This would be made up of four years for outline design, planning application, detailed design, easements and wayleaves and a further two years for construction. However, the purchase of the land from a 3rd party may take longer than expected and could be a risk to the delivery. This option may also be perceived as having greater environmental impact and may take longer to progress through planning than first understood. There is an active anti cavern group “No Gas Caverns” that may also engage on a new proposed large substation.

For Option 4b (GIS switching station) it is thought that this could be delivered in 5 years after approval. This would be made up of three years for planning permissions, detailed design, easements, and wayleaves and a further two years for construction. There could become issues with the use of SF6 gas, which is a very potent greenhouse gas. The manufacturers are warning that it may not be possible purchase an SF6 based GIS switchboard into the future. In any case an environmental study will be required which considers the use of SF6. Whilst there are alternatives being researched, Option 4b may have deliverability issues.

4.4.5. Option 5a and 5b

For Option 5a, it is assumed that this could be delivered in 5 years. This would be made up of three years for planning permissions, detailed design, easements, and wayleaves with a further two years for construction.

Option 5b is not deliverable by SONI as a capex investment. Whilst a market was created for system services that include SCs, at this stage the tender requests are aimed at seeking SCs in the north and west of Northern Ireland where there is also a need for reactive power. For this reason, at this stage this option is not deliverable. However, at a future date even whilst this project is in pre-construction, if a party commits to installing an SC at either Moyle or Hannahstown then this will be considered.

4.5. Cost

Option 3b (two cables back to Ballylumford) is the least cost option. The most expensive options are those that involve the new switching station close to Ballycronan More. The STATCOM and synchronous condenser options are also significantly more expensive than Option 3b.

4.6. Comparison of the longlist of options

Table 4 presents the comparison of the longlist of options. A five-colour scheme is used to identify the ranking of the options against each of the criterion. Options 1 and 2 do not resolve the issues identified in the Need Report, so it does not make sense to discuss the deliverability of these options, or give them a final classification. However, for the rationalisation of the longlist, option 1 will progress, as it is the reference and it will be shortlisted. Option 5b will not be ranked on the final assessment as it has to be delivered by third parties within the system services market.

Less favourable | | | | | | More favourable

Option	Description	Technical	Deliverability	Cost	Final rank (Longlist)
1	Status quo / Do nothing		n/a		n/a
2	Derogation		n/a		n/a
3.a	Connect directly Ballycronan More convertor station to Ballylumford power station through three underground circuits				
3.b	Connect directly Ballycronan More convertor station to Ballylumford power station through two underground circuits				
4.a	Establish an AIS at Ballycronnan More				
4.b	Establish a GIS at Ballycronnan More				
5.a	Install STATCOM at Ballycronnan More				
5.b	Install Synchronous Compensators at Ballycronnan More				n/a

Table 4 : Comparison of the longlist of options

5. Shortlist of options

5.1. Options framework for the identification of the Optimum Solution

The options Framework for the identification of the Optimum Solution will be based on the following criteria:

1. Technical performance.
2. Preliminary environmental
3. Economic performance.

5.2. Technical performance

A comparison of Options 3a and 3b was conducted in Section 3.7.1. Option 3a with three cables is considered excessive as a) there are only two converters and HVDC cables and b) there is only a single 400 kV line in Scotland. In addition, whilst the substation at Ballycronan More is a double busbar arrangement it only has one coupler. A fault on this coupler would also disconnect all three cables.

Option 3b provides two cables. This ensures that if there is a failure of one cable then the full import and export capacity of the interconnector can continue on the remaining cable. This would be a significant improvement on a single cable as it would avoid a lengthy outage of the interconnector for repairs to be arranged on the single 275kV cable. Being based on two cables the level of redundancy is consistent with that of the HVDC link and is superior to the single line in Scotland.

5.3. Preliminary environmental impact

The shortlisted options are not expected to raise significant long term environmental impacts. The routes for the underground circuits will be mainly in land owned by either Mutual Energy or NIE Networks, which are both stakeholders in this project. The remaining part of the route is in the public road, where it will cross the Ballylumford Road.

Whilst the road will need to be opened for some time to install the cables, there are alternative routes to Ballylumford Power Station, residential dwellings and other facilities which will mitigate the impact. Because the 275 kV circuits will have to cross the SNIP, regardless of the option, a solution of HDD or hand digging will be considered.

5.4. Lifecycle costs

Assumptions taken in the lifecycle cost appraisal are as follows:

- The benefits were appraised using market simulation software, Plexos, and using the National Trends (NT) scenario.
- For each option that have capital costs these are assigned at the expected construction year. Operation & Maintenance costs were assumed at 1.3%.
- The Net Present Value (NPV) assessment period is based on 25 years. The NPV uses the same discount rate of 3.5%.

- Only production cost savings between Case ID 2 and Case ID 3 are considered to be Socio Economic Welfare (SEW) of the project. Case ID 2 is assumed as the new baseline following restring of the Ballylumford – Eden circuits which is expected to allow an export of 400 MW and is due to be completed in 2023. These have been assigned as benefits consistent with ENTSOE practice.
- These benefits are production savings across the single electricity market and also in Great Britain. A Cost Benefit Cost Allocation (CBCA) study would be required to determine the split.
- The analysis shows increased congestion rent on the Moyle Interconnector. With the Moyle Interconnector being operated on a not-for-profit basis this increased revenue is reinvested into the interconnector.
- Whilst some savings in CO_2 emissions where recorded, it was noted that the analysis had predicted a small increase in CO_2 between the baseline and Case ID 2.
- Option 3b can be delivered more quickly that Option 3a as it does not require an extension to the Ballycronan More compound. This is considered in the NPV analysis.

Table 5 below presents the summary of the NPV assessment per shortlisted option. Note that for the purposes of the NPV, all of the costs and benefits are allocated to Northern Ireland. To confirm this assumption, it would be necessary to conduct a Cost Benefit Cost Allocation study.

NPV of the shortlisted options [£m]		
Option 1	Option 3a	Option 3b
0	-71.44	-92.90

Table 5 : Summary of the NPV assessment per shortlisted option

Negative NPV values, as in options 3a and 3b, means that the net present values are benefits. It is noted that Option 3b provides the highest net present value.

5.5. Comparison of the shortlist of options

Table 6 below presents the shortlisted options colour-code for each of the criteria applied in the shortlist assessment.

Option	Description	Technical	Environmental	Economic
1	Status quo / Do nothing		n/a	
3.a	Connect directly Ballycronan More convertor station to Ballylumford power station through three underground circuits			
3.b	Connect directly Ballycronan More convertor station to Ballylumford power station through two underground circuits			

Table 6 : Comparison of the shortlist of options

In conclusion Option 3b has the least environmental impact between Option 3a and 3b. It is also the least cost option that addresses the constraint and also over the lifecycle delivers the greatest net present value.

5.6. Preliminary preferred option

Based on the assessment, the preliminary preferred option is 3b. Option 3b is the least cost option to deliver the benefits. For the avoidance of doubt regarding the treatment of the Moyle interconnector in the TSSPS it is also proposed that this will be updated similar to the SQSS in Great Britain. For the purposes of the TNPP preparation Option 3b is the preferred option.

6. Conclusions

This assessment identified that laying two 275 kV underground circuits between Ballylumford Power Station and Ballycronan More converter station (option 3b) is at this stage the preliminary preferred solution. At a cost of £9.01m, this preferred option is about half the cost of the second cheapest option (option 3.a). This solution is the one that presents the best NPV and will maximise the benefits over this solution life cycle. In the review of planning standards, the TSSPS should clarify that an export is not considered as demand in Northern Ireland.

The above conclusion should be kept under review as any new connection applications are assessed. For example the variations of Option 4 may be more suitable if combining for a significant offshore wind farm connection and a revised connection of Moyle Interconnector.

Appendix A. Captial costs of the options

Options 1 and 2 will not have any capital costs.

Capital costs of option 5.b will be estimated, but this solution has to be driven by participants in the System services market.

Ap A.1. Option 3.a

Connect directly Ballycronan More convertor station to Ballylumford power station through three 275 kV underground circuits.

<table>
<tr><th>Item description</th><th>Unit cost [£m / Un]</th><th>Units</th><th>Qty</th><th>Subtotal [£m]</th><th>Source / Notes</th></tr>
<tr><td>Planning, site procurements and agreements</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Buy land from Mutual Energy</td><td>0.25</td><td></td><td>1</td><td>0.25</td><td>SONI estimate</td></tr>
<tr><td>Easements to lay underground cables and install 275 kV towers 604 and 605 in new locations</td><td>0.05</td><td></td><td>1</td><td>0.05</td><td>SONI estimate</td></tr>
<tr><td>OHL & Cable works</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Disconnect BYC from the existing double OHL 275 kV 2x400 mm^2 ACSR (Zebra) circuits between HAN and BPS</td><td rowspan="3">11.59</td><td rowspan="3">10 km</td><td rowspan="3">0.137</td><td rowspan="3">1.59</td><td rowspan="3">NIEN Standard Cost Database 31st Mach 2020</td></tr>
<tr><td>Diversion of the 275 kV BPS-HAN circuit, between, and including, towers 603 and 606, as it will oversail the 275 kV compound extension</td></tr>
<tr><td>Restring about 1.37 km of the OHL 275 kV 2x400 mm^2 ACSR (Zebra) coming from HAN to BPS</td></tr>
<tr><td>Lay in trench three 275 kV circuits of UG 2000 mm^2 Cu XLPE cable (Outside the substation).</td><td>1.91</td><td>km</td><td>3.39</td><td>6.46</td><td>NIEN Standard Cost Database 31st Mach 2020</td></tr>
<tr><td>Lay in trench 500 m inside the BYC compound three 275 kV circuits of UG 2000 mm^2 Cu XLPE cable.</td><td>0.65</td><td>100 m</td><td>5</td><td>3.26</td><td></td></tr>
<tr><td>Substation works (BYC)</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Pre-enabling works for expansion of the 275 kV converter station switching yard (fence alteration, stoning, exterior arrangements)</td><td>1.48</td><td>m^2</td><td>0.18</td><td>0.27</td><td>NIEN Standard Cost Database 31st Mach 2020. Unit cost applies for a 160mx160m green field site.
Approximately 4,600m2 are required.</td></tr>
<tr><td>Install a third 275 kV cable bay and extend the AIS DBB (excluding cabling)</td><td>1.42</td><td></td><td>1</td><td>1.42</td><td>NIEN Standard Cost Database 31st Mach 2020</td></tr>
<tr><td>Lay 275 kV circuits of UG 2000mm2 Cu XLPE cable inside the substation compound.</td><td>0.65</td><td>100 m</td><td>1.5</td><td>0.98</td><td>NIEN Standard Cost Database 31st Mach 2021</td></tr>
<tr><td>Upgrade control building</td><td>0.03</td><td></td><td>1</td><td>0.03</td><td>SONI estimate</td></tr>
<tr><td>Substation works (BPS)</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Revamp existing bay to BALLYCRONAN MORE (socket 3) in the 275 kV substation in BPS and rebrand it to connect the HANNASTOWN 'A' circuit	0.1		1	0.10	SONI estimate. The majority of works are mainly resetting of protections.
Reactivate the 275 kV bays at BPS substation where previously G.1B, G.4B and G.6B where connecting. This will allow the connection to BPS of the three 275 kV UG circuits coming from BYC.	0.3		3	0.90	SONI estimate adapted from the cost of an additional GIS DBB bay in the NIEN Standard Cost Database 31st Mach 2020.
Miscellaneous					
Horizontal Directional Drilling for three 275 kV circuits under the SNIP	0.58	100 m	0.4	0.23	See notes in the report for the cost estimate.
Subtotal				**15.53**	
10% contingency				1.55	
Total				**17.09**	

Table 7 : Option 3.a – CAPEX

Notes:

- The length of the three 275 kV circuits, including a 25% of excess to account for diversions and changes of profile, is 1.11 km for circuit 1, 1.22 km for circuit 2 and 1.06 km for circuit 3.
  The total length of circuit is 3.39 km.
  It was considered UG 2000 mm^2 Cu XLPE cable.
  The three circuits are considered to be apart from each other by 5m.
- Based on information from Mutual Energy – Gas, the pipeline has 609.6 mm OD in the zone where it is being considered the crossing of these infra-structures.
  NIEN requires a safety clearance distance of 1.5 times the outer diameter, with a minimum of 250 mm, which means that the minimum distance between infrastructures will be 914.4mm.
  If a safety clearance depth of 1000 mm for the 275 kV underground circuits is assumed, then the top of the pipeline will have to be at least at a depth of 1,914.4 mm.
  By the information provided by Mutual Energy – Gas, the pipeline was delivered at a depth of 1490mm, which point to deliver an HDD for the 275 kV circuits to go below the pipeline.
  However, a recent survey conducted by the Mutual Energy – Gas team identified zones where the pipeline might be deeper than 1,914.4mm. So, further investigation will be required to accurately identify if the crossing of the SNIP requires an HDD.
  For the purpose of estimating the capital costs an HDD will be considered with 40m/circuit drilling.
- It is assumed that the internal gas pipes inside Ballylumford Power Station, as per figure 1, is now decommissioned according to Mutual Energy.

Ap A.2. Option 3.b

Connect directly Ballycronan More convertor station to Ballylumford power station through two underground circuits.

Item description	Unit cost [£m / Un]	Un	Qty	Subtotal [£m]	Source / Notes
Planning, site procurements and agreements					
Easements to lay underground cables and install 275kV tower 605 in a new location	0.05		1	0.05	SONI estimate
OHL & Cable works					
Disconnect BYC from the existing OHL 275kV 2x400mm2 ACSR (Zebra) circuit between HAN and BPS	11.59	10km	0.076	0.88	NIEN Standard Cost Database 31st Mach 2020. The relocation of the tower 605 might not be required, depending on a detailed assessment by NIEN.
Relocation of the tower 605 of the 275kV BPS-HAN circuit, as it may over-sail the 275kV compound					
Lay in trench two 275kV circuits of UG 2000mm2 Cu XLPE cable.	1.91	km	2.33	4.44	NIEN Standard Cost Database 31st Mach 2020
Substation works (BYC)					
Lay 275kV circuits of UG 2000mm2 Cu XLPE cable inside the Substation compound.	0.65	100m	3	1.96	NIEN Standard Cost Database 31st Mach 2021
Substation works (BPS)					
Revamp existing bay to BALLYCRONAN MORE in the 275kV substation in BPS and rebrand it to connect the HANNASTOWN 'A' circuit.	0.1		1	0.1	SONI estimate
Reactivate the 275kV bays at BPS substation where previously G.4B and G.6B where connecting. This will allow the connection to BPS of the two 275kV UG circuits coming from BYC.	0.3		2	0.6	SONI estimate adapted from the cost of an additional GIS DBB bay in the NIEN Standard Cost Database 31st Mach 2020.
Miscellaneous					
Horizontal Directional Drilling for three 275kV circuits under the SNIP	0.40	100m	0.4	0.16	See notes in the report for the cost estimate.
Subtotal				**8.19**	
10% contingency				0.82	
Total				**9.01**	

Table 8 : Option 3.b – CAPEX

Notes:

- The length of the two 275 kV circuits, including a 25% of excess to account for diversions and changes of profile, is 1.11 km for circuit 1 and 1.22 km for circuit 2.
  The total length of circuit is 2.33 km.
  It was considered UG 2000 mm^2 Cu XLPE cable.
  The two circuits are considered to be apart from each other by 5m.
- Based on information from Mutual Energy – Gas, the pipeline has 609.6 mm OD in the zone where it is being considered the crossing of these infra-structures.
  NIEN requires a safety clearance distance of 1.5 times the outer diameter, with a minimum of 250 mm, which means that the minimum distance between infrastructures will be 914.4 mm.
  If a safety clearance depth of 1000 mm for the 275 kV underground circuits is assumed, then the top of the pipeline will have to be at least at a depth of 1,914.4 mm.
  By the information provided by Mutual Energy – Gas, the pipeline was delivered at a depth of 1490mm, which point to deliver a HDD for the 275 kV circuits to go below the pipeline.
  However, a recent survey conducted by the Mutual Energy – Gas team identified zones where the pipeline might be deeper than 1,914.4 mm. So, further investigation will be required to accurately identify if the crossing of the SNIP requires an HDD.
  For the purpose of estimating the capital costs an HDD will be considered with 40 m/circuit drilling.
- It is assumed that the internal gas pipes inside Ballylumford Power Station, as per figure 1, is now decommissioned according to Mutual Energy.
- If the diversion of tower 605 is not required, as per NIEN detailed assessment, the OHL & cable works above with a cost of £0.88m, will be reduced to £0.19m as only the 275 kV resting of one side of the DCT will be required. If this is the case, then the total cost of option 3.b will be reduced to £8.25m.

Ap A.3. Option 4.a

Install an AIS switching station at Ballycronnan More.

Item description	Unit cost [£m / Un]	Un	Qty	Subtotal [£m]	Source / Notes
Planning, site procurements and agreements					
Buy land to install switching station	0.5	acre	8.65	4.32	SONI estimate
Wayleaves and easements for the new routes of the 275 kV OHL and underground circuits	0.2		1	0.2	SONI estimate
Substation works (BYC-A)					
275 kV pre-enabling works for the construction of the new BYC-A substation, including 500 m of access toad	1.48	m^2	1.37	2.03	NIEN Standard Cost Database 31st Mach 2020. Unit cost applies for a 160 m x160 m green field site. Approximately 35,000 m^2 are required.
275 kV control building and storage building	0.2		1	0.2	SONI estimated based on NIEN Standard Cost Database 31st Mach 2020
275 kV AIS DBB (excluding cabling)	1.42		18	25.51	NIEN Standard Cost Database 31st Mach 2020
Lay 275 kV circuits of UG 2000 mm^2 Cu XLPE cable inside the substation compound	0.65	100 m	2.5	1.63	NIEN Standard Cost Database 31st Mach 2021.
275 kV underground cable in rural terrain	1.15	km	2.7	3.11	SONI estimated based on NIEN Standard Cost Database 31st Mach 2020. 2x circuits with 2000 mm^2 XLPE cable.
Substation works (BYC-B)					
Lay 275kV circuits of UG 2000 mm^2 Cu XLPE cable inside the substation compound.	0.65	100 m	1.5	0.98	NIEN Standard Cost Database 31st Mach 2021
OHL & Cable works					
Decommission of 275 kV circuit	0.1	span	6	0.6	SONI estimate
275 kV steel tower twin 400 mm2 ACSR - double circuit	11.59	10 km	0.36	4.17	NIEN Standard Cost Database 31st Mach 2020
Subtotal				**42.74**	
10% contingency				4.27	
Total				**47.02**	

Table 9 : Option 4.a – CAPEX

Notes:

- For the AIS bays it were considered 18 slots with the following space reserved:
  - 1 slot per HV feeder.
  - 2 slots per sectionaliser between sections[12].
  - 2 slots per wing couplers[13].
- For the restrung of OHL a 20% increase was considered to accommodate changes in height between towers, the conductors sag, and any diversion not considered.
- Circuits connecting BYC-A to BYC-B the circuits will be lay in a rural area outside roads. SONI considered a 40% discount over the cost of laying on the road. So, a value of £1.15m/km was assumed.

[12] Consisting of a circuit-breaker with two sectionaliser disconnectors connecting two busbar sections on the same busbar.

[13] Consisting of a circuit-breaker with two sectionaliser disconnectors connecting two busbars sections on different busbars.

Ap A.4. Option 4.b

Install a GIS switching station at Ballycronan More.

Item description	Unit cost [£m / Un]	Un	Qty	Subtotal [£m]	Source / Notes
Planning, site procurements and agreements					
Buy land from Mutual Energy	0.25		1	0.25	SONI estimate
Substation works (BYC-A)					
275 kV pre-enabling works for the construction of the new BYC-A substation, including 250m of access toad	1.3	m^2	0.18	0.23	SONI estimate based on NIEN Standard Cost Database 31st Mach 2020. Unit cost applies for a 160 m x 160 m green field site. Approximately 4,500 m^2 are required.
275 kV control building and storage building	0.2		1	0.2	SONI estimated based on NIEN Standard Cost Database 31st Mach 2020
275 kV GIS DBB (excluding cabling) for 6 bays	11.45		1	11.45	NIEN Standard Cost Database 31st Mach 2020
275 kV GIS DBB (excluding cabling) for additional 12 bays	0.98		12	11.77	NIEN Standard Cost Database 31st Mach 2021
Lay 275 kV circuits of UG inside the substation compound.	0.65	100 m	3	1.96	NIEN Standard Cost Database 31st Mach 2021. 30 m/circuit x 10 circuits will be considered.
Substation works (BYC-B)					
Lay 275 kV circuits of UG 2000 mm^2 Cu XLPE cable inside the substation compound.	0.65	100 m	1.5	0.98	NIEN Standard Cost Database 31st Mach 2021
OHL & Cable works					
Decommissioning of 275kV circuits	0.10	span	1	0.1	SONI estimate
275 kV restring, two sides of DCT	2.51	10 km	0.15	0.38	Based on NIEN Standard Cost Database 31st Mach 2020. It was considered the double value of restring one side.
275 kV underground cable rural terrain	1.15	km	1.4	1.61	NIEN Standard Cost Database 31st Mach 2020. This will connect the two sections of the DBB in BYC-A to the existing two HV cable bays in BYC-B. Circuits with 2000 mm^2 XLPE cable.
Subtotal				**28.92**	
10% contingency				2.89	
Total				**31.81**	

Table 10 : Option 4.b – CAPEX

Notes:

- For the GIS bays it were considered 18 slots with the following space reserved:
  - 1 slot per HV feeder.
  - 2 slots per sectionaliser between sections.
  - 2 slots per wing couplers.
- For the restrung of OHL a 20% increase was considered to accommodate changes in height between towers, the conductors sag, and any diversion not considered.
- In the 275 kV restring were considered the two sides of the DCT with 2 x Zebra with HTLS equivalent, no tower strengthening or raising required.
- It were considered additional 4x 150 m of "275 kV underground cable in the road" per OHL turn-in to the new GIS, as there is no information about this cost. Further detailed assessment will be required by NIEN.
- Circuits connecting BYC-A to BYC-B the circuits will be lay in a rural area outside roads. SONI considered a 40% discount over the cost of laying on the road. So, a value of £1.15m/km was assumed.

AP A.5. Option 5.a

Control of voltage in the network by managing the reactive power through a STATCOM.

Item description	Unit cost [£m/ Un]	Un	Qty	Subtotal [£m]	Source / Notes
Planning, site procurements and agreements					
Buy land from Mutual Energy	0.1		1	0.1	SONI estimate
Substation works (BYC)					
Pre-enabling works for expansion of the 275 kV converter station switching yard (fence alteration, stonning, exterior arrangements)	1.48	m^2	0.18	0.27	NIEN Standard Cost Database 31st Mach 2020. Unit cost applies for a 160 m x 160 m (25,600 m^2) green field site.
Install a third 275 kV cable bay and extend the AIS DBB (excluding cabling)	1.42		1	1.42	NIEN Standard Cost Database 31st Mach 2020
Upgrade control building	0.03		1	0.03	SONI estimate
STATCOM works					
Pre-enabling works (on a green field site). Build and pave access road to BYC-A on a length of c250 m	1.48	m^2	0.065	0.1	NIEN Standard Cost Database 31st Mach 2020. Unit cost applies for a 160 m x 160 m (25,600 m2) green field site.
Install a ±167 MVAr 275 kV STATCOM, including HV GIS bay to connect through cable to BYC	17.74		1	17.74	SONI estimate.
OHL & Cable works					
Disconnect BYC from the existing double OHL 275 kV 2x400mm2 ACSR (Zebra) circuits between HAN and BPS	11.59	10 km	0.137	1.59	NIEN Standard Cost Database 31st Mach 2020
Diversion of the 275 kV BPS-HAN circuit, between, and including, towers 603 and 606, for oversail					
Restring about 1.37 km of the OHL 275 kV 2x400 mm^2 ACSR (Zebra) coming from HAN to BPS					
Lay in trench 100m inside the STATCOM compound plus 200 m inside the BYC compound	0.65	100 m	3	1.96	NIEN Standard Cost Database 31st Mach 2020
Lay in trench outside of the substation and STACOM compounds c300m of 275 kV cable	1.91	km	0.3	0.57	NIEN Standard Cost Database 31st Mach 2020
Subtotal				**23.77**	
10% contingency				2.38	
Total				**26.14**	

Table 11 : Option 5.a – CAPEX

Ap A.6. Option 5.b

Control of voltage in the network by managing the reactive power through a Synchronous Compensator.

Item description	Unit cost [£m/ Un]	Un	Qty	Subtotal [£m]	Source / Notes
Planning, site procurements and agreements					
Buy land from Mutual Energy	0.1		1	0.1	SONI estimate
Substation works (BYC)					
Pre-enabling works for expansion of the 275 kV converter station switching yard (fence alteration, pave road, exterior arrangements)	1.48	m^2	0.18	0.27	NIEN Standard Cost Database 31st Mach 2020. Unit cost applies for a 160 m x 160 m (25,600 m^2) green field site. Approximately 4,600 m^2 are required or c18% of unit cost.
Install a third 275 kV cable bay and extend the AIS DBB (excluding cabling)	1.42		1	1.42	NIEN Standard Cost Database 31st Mach 2020
Upgrade control building	0.03		1	0.03	SONI estimate
Synchronous Compensator works					
Pre-enabling works (on a green field site) to install a SC in the Southeast Zone. Build and pave access road to BYC-A on a length of c250 m, including the construction of a small parking place in the exterior of the fence for lightweight vehicles	1.48	m^2	0.052	0.08	NIEN Standard Cost Database 31st Mach 2020. Unit cost applies for a 160 m x 160 m (25,600 m^2) green field site. Approximately 1,335m2 are required or c5.2% of unit cost. Approximately 1,335 m^2 are required
Install a 167 MVAr 275 kV SC, including HV GIS bay to connect through cable to BYC	16.7		1	16.7	SONI estimate. In the price of the SC is included the control building
OHL & Cable works					
Disconnect BYC from the existing double OHL 275 kV 2x400 mm^2 ACSR (Zebra) circuits between HAN and BPS	11.59	10 km	0.137	1.59	NIEN Standard Cost Database 31st Mach 2020
Diversion of the 275 kV BPS-HAN circuit, between, and including, towers 603 and 606, as it will oversails the 275 kV compound extension					
Restring about 1.37 km of the OHL 275 kV 2x400 mm^2 ACSR (Zebra) coming from HAN to BPS					
Lay in trench 100m inside the STATCOM compound plus 200m inside the BYC compound of 275 kV circuits of UG cable	0.65	100 m	3	1.96	NIEN Standard Cost Database 31st Mach 2020
Lay in trench outside of the substation and STACOM compounds c300m of 275 kV cable	1.91	km	0.3	0.57	NIEN Standard Cost Database 31st Mach 2020

Subtotal				**22.71**	
10% contingency				2.27	
Total				**24.98**	

Table 12 : Option 5.b – CAPEX

Appendix B. Mean time to fail of electrical assets

The objective of this assessment is to provide an estimate of the average time for a failure to occur, also known as the Mean Time To Failure (MTTF), of a double circuit fault on the Ballylumford – Ballycronan More / Hannahstown tower line section.

MTTF mathematical definition of a component or set of components is given by equation [1]:

$$MTTF = \int_0^\infty R(t)\,dt \qquad [h] \tag{1}$$

, where

$R(t)$: reliability of a component or set of components during time.

Reliability is the probability of a certain component or set of components to not fail (or survive) during time t.

From the reliability study conducted in 1985 on the 275 kV and 400 kV transmission network in the South West of England and in South Wales for the Central Electricity Generating Board, table 1, on page 209, it is presented below on Table 13 the information about the frequency and mean duration in hours of adverse weather in the summer and winter seasons.

	Season	
	summer	winter
Frequency of adverse weather periods per month	0.39	0.45
Mean duration of an adverse weather period [h]	3	3.3

Table 13 : Frequency and mean duration of adverse weather in the summer and winter seasons

Based on the information on Table 13, and considering that a typical 365 days' year has 8760 h, with an average of approximately 730 h/month, and knowing that for this study the summer season represents 7 months of the year and the winter season the remaining 5 months, it is possible to present Table 14 with the yearly hours of normal and adverse weather considered in the reliability study.

	Number of hours per year [h]	
Season	**Normal weather**	**Adverse weather**
summer	5101.81	8.19
winter	3642.57	7.43

Table 14 : Yearly hours of normal and adverse weather for each season

The weather conditions under this model have been classified as normal or adverse, following a chronological variation from [6, p. 267] as presented in figure 7.

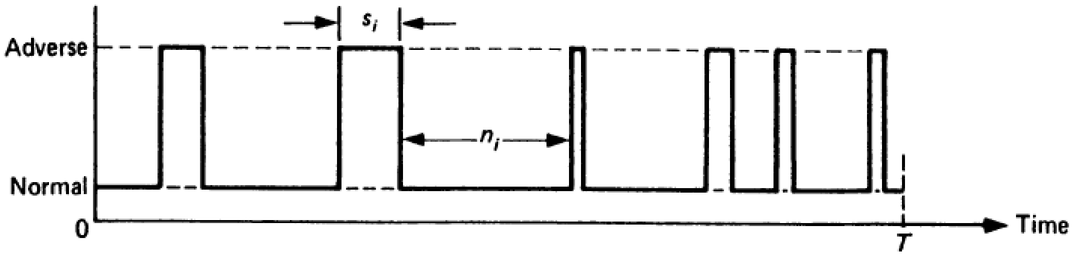

Figure 7 : Chronological variation of weather

This is called a two-state weather model, which represents a simplification of the weather model with just two states, normal, n_i, and adverse, s_i, weather.

The expected duration of normal, N, and adverse, S, weather during a certain period, T, is presented in figure 8 as per [6, p. 268]. λ, λ' and $\hat{\lambda}$ represent the failure rates during normal and adverse weather, as well the average value.

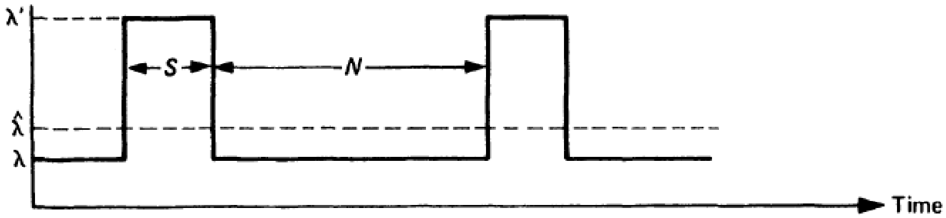

Figure 8 : Average weather duration profile

Because the data available has more details, it is also subdivided in summer, S, and winter, W, seasons, with different failure rates per season and weather state.

The expected duration in normal and abnormal weather, considering only the summer and winter seasons, are calculated using equations [2] and [3]:

$$N = \sum_i \frac{n_i}{T} = \frac{n_S}{T} + \frac{n_W}{T} = N_S + N_W \quad [h] \tag{2}$$

$$S = \sum_i \frac{s_i}{T} = \frac{s_S}{T} + \frac{s_W}{T} = S_S + S_W \quad [h] \tag{3}$$

, where

n_i : duration of a i normal weather period, in h. The S and W in the lower index refers to summer and winter seasons.

s_i : duration of a i adverse weather period, in h. The S and W in the lower index refers to summer and winter seasons.

T : period of analysis, in h, which correspond to adding N and S. In this assessment is 1 year or 8760 h.

By adapting equation (8.26a) in [6, p. 268], considering that normal and adverse are split in summer and winter seasons, an average of the failure rate per year can be calculated by equation [4]:

$$\hat{\lambda} = \frac{N_S}{N+S}.\lambda_S + \frac{N_W}{N+S}.\lambda_W + \frac{S_S}{N+S}.\lambda_S' + \frac{S_W}{N+S}.\lambda_W' \quad [failure/(y.km)] \tag{4}$$

Ap B.1. Single circuit OHL failures

The study from Central Electricity Generating Board [7] concludes that the most important effect to trigger a failure in a single circuit are the weather conditions. Table 15 presents part of the contents of table 3 in [7, p. 210], which is the failure rate on single circuit OHL with the inclusion of weather effects, for a typical transmission line with 50 km of length. Also are presented the same values but in $failure/(y.km)$.

Season	Failure rate [failure/(1000 h)] (in 50 km of single circuit transmission line)		Failure rate [x10^{-3} failure/(y.km)]	
	Normal weather	Adverse weather	Normal weather	Adverse weather
summer	0.022	21.7	3.854	3801.84
winter	0.016	57.7	2.803	10109.04

Table 15 : Single circuit failure rate due to weather events

By replacing in equation [4] the figures in tables 14 and 15, it is possible to obtain the average single circuit failure rate per year and per kilometre, which is $\hat{\lambda} = 15.54 \times 10^{-3}$ $failure/(y.km)$.

AP B.2. Double circuit OHL failures

DCT OHL failures are more rare than single circuit failures and they are mainly triggered by:

- Weather conditions, which trigger common mode failures in both circuits.
- Maloperation of the protection equipment in one circuit for a fault on an adjoining circuit, which trigger cascade failures in both circuits.

Ap B.2.1. Common mode double circuit OHL failures

Table 16 presents the contents of table 5 in [7, p. 214], which is the simultaneous DCT failure rate on OHL due to weather effects, for a typical transmission line with 50 km of length. Also are presented the same values but in $failure/(y.km)$.

Season	Failure rate [failure/(1000 h)] (in 50 km of single circuit transmission line)		Failure rate [x10^{-3} failure/(y.km)]	
	Normal weather	Adverse weather	Normal weather	Adverse weather
summer	0.002	1.2	0.35	210.24
winter	0.005	3.2	0.876	560.64

Table 16 : Simultaneous DCT failure rate due to weather events

Comparing tables 15 and 16 it can be seen that the likelihood for a DCT failure to occur due to weather effects is much lower when compared to single circuit failure.

By replacing in equation [4] the figures in tables 14 and 16, it is possible to obtain the average DCT failure rate per year and per kilometre, which is $\hat{\lambda} = 1.24 \times 10^{-3}$ $failure/(y.km)$.

Ap B.2.2. Cascade failures originating double circuit OHL failures

The Central Electricity Generating Board [7] study estimated that a fault on one circuit had an average probability of 0.59% of causing protection maloperation on a particular adjoining circuit. Assuming that this percentage applies during a full year regardless of the weather conditions, Table 17 presents the failure rate in DCT, when this failure occurs in cascade. These values are obtained by applying this percentage to be values in table 15.

Season	Failure rate [x10^{-3} failure/(y.km)]	
	Normal weather	Adverse weather
summer	0.023	22.43
winter	0.017	59.64

Table 17 : Simultaneous DCT failure rate due to maloperation of protections on an adjoining circuit

Comparing tables 15 and 16 it can be seen that the likelihood for a DCT failure to occur due to weather effects is much lower when compared to single circuit failure.

By replacing in equation [4] the figures in tables 14 and 17, it is possible to obtain the average DCT failure rate per year and per kilometre, which is $\hat{\lambda} = 0.092 \times 10^{-3}\ failure/(y.km)$.

Ap B.3. Failure of the circuits that more affects the Moyle interconnector

Moyle interconnector can be affected by different contingencies, but the one that raises more concerns is identified as scenario WP3 in the Need Case. This scenario occurs during periods of high wind production (with wind generation penetration of 80%), when the interconnector is exporting 500 MW, and loses both the BPS-HAN and BPS-BYC 275 kV circuits either as a double circuit fault on this section of tower line or as a cascade event due to a protection maloperation. This creates a voltage step of -8.5% on the 275 kV network and in the 110kV network of -10.8% in some busbars in Belfast and the Southeast of Northern Ireland. These step voltages are in breach of TSSPS lower limit of -10% following the loss of a DCT OHL.

The probability of a loss of both circuits is the sum of that of a double circuit fault on the short 0.8km section (0.8 * 1.24 x 10^{-3} = 1.239 x 10^{-3}) plus that of a cascade fault (0.092 x 10^{-3} x 45.5 = 4.86x10^{-3}). The total fault rate for the section is therefore 0.0061. This equates to a return period of 163.96 years.

However, a voltage excursion would only occur if it where at a time when the Moyle interconnector would be exporting in excess of limits. This will depend on the future market and is uncertain. It is possible to conduct a market simulation study.

One study that includes an offshore renewables connection at Ballylumford indicates that the risk of an excursion in excess of 5% would occur for approx. 10% of the year. If this figure is used would allow for a factor for uncertainty. The probability of an unacceptable voltage excursion is therefore 0.0061 x 0.1 = 0.00061. This would equate to a return period of 1600 years. However as renewable penetration increases this figure is expected to reduce.

Appendix C. Indicative Single-line diagram for BYC-A AIS or GIS 275 kV substation

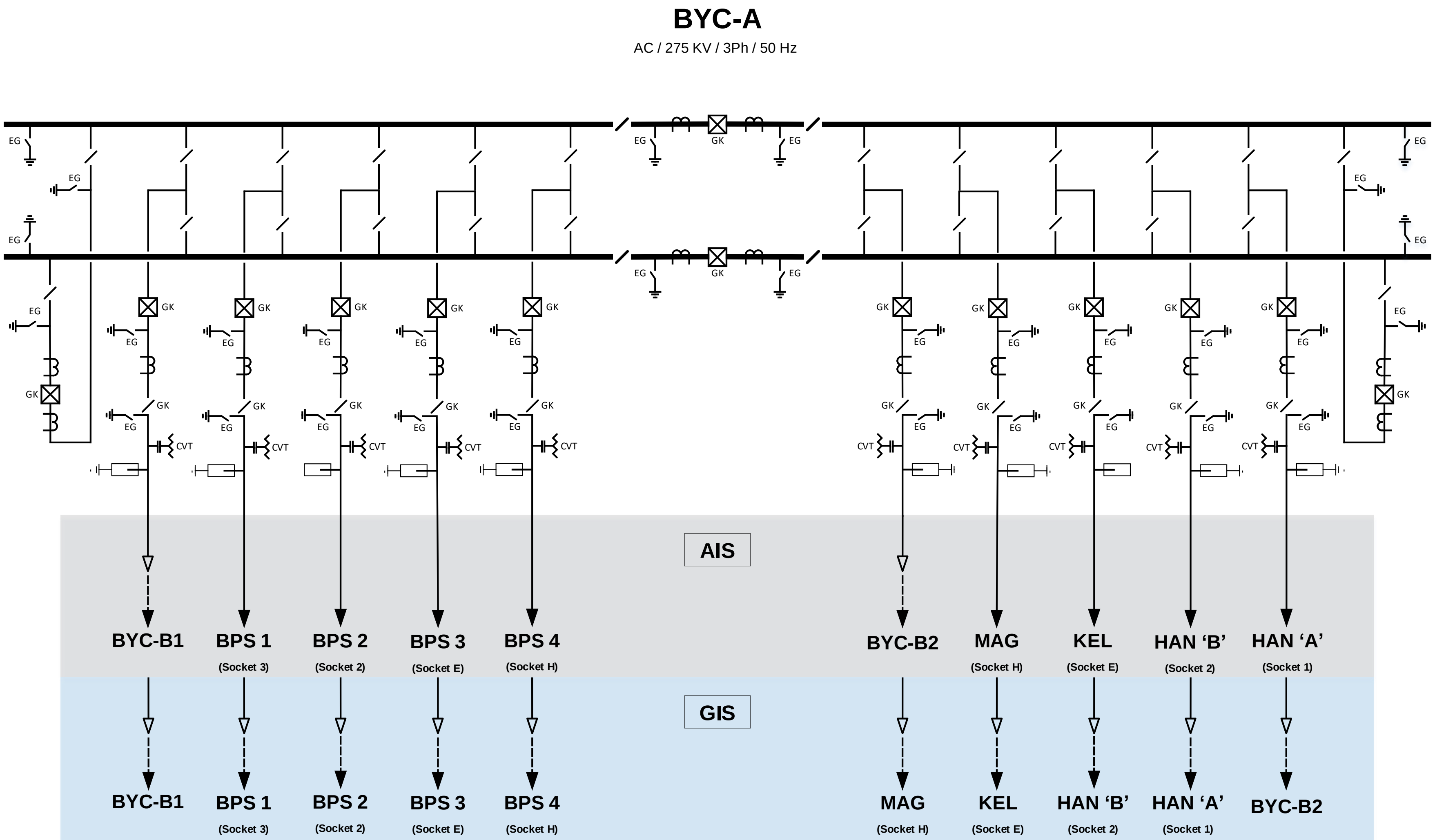

Figure 9 : Single line diagram for BYC-A AIS or GIS 275 kV switching station

Appendix D. Electrical diagrams

(Source : NIEN | System Diagram no. 81-3090-017)

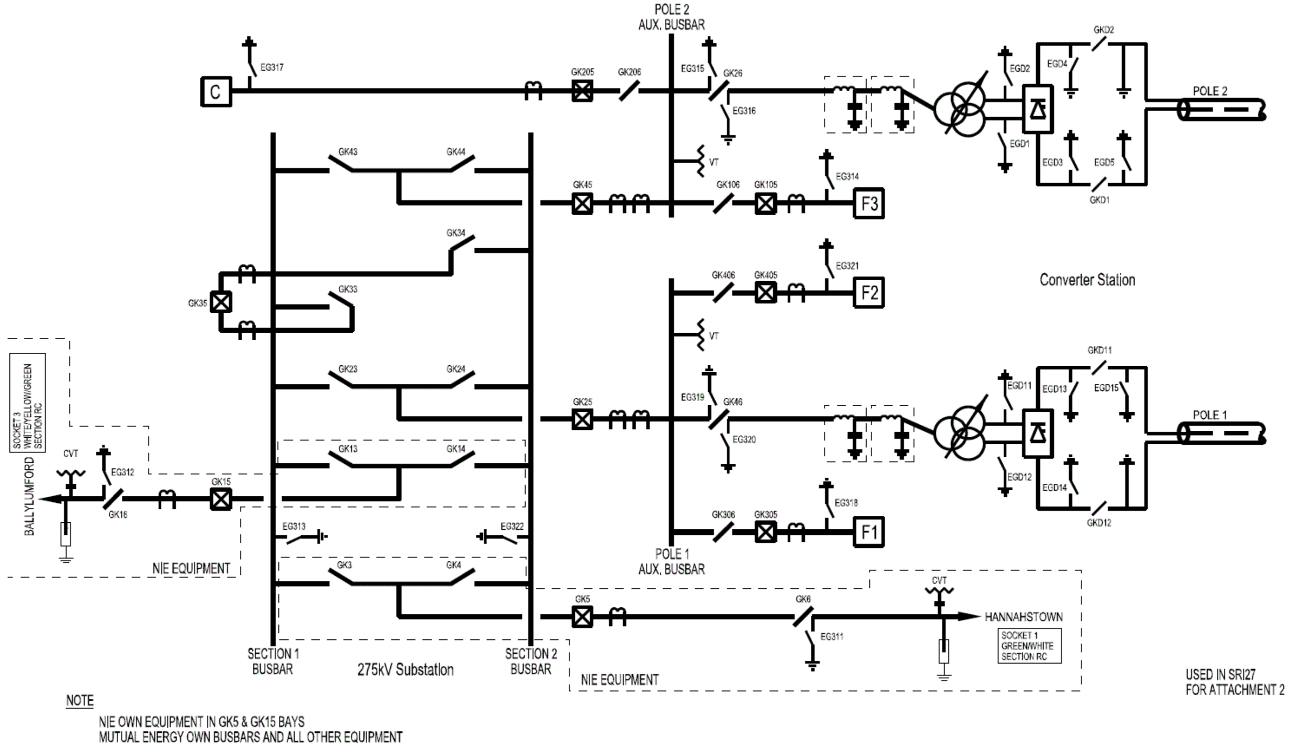

Figure 10 : Ballycronan More converters station single line electrical diagram

(Source : NIEN | System Diagram no. 81-3090-021)

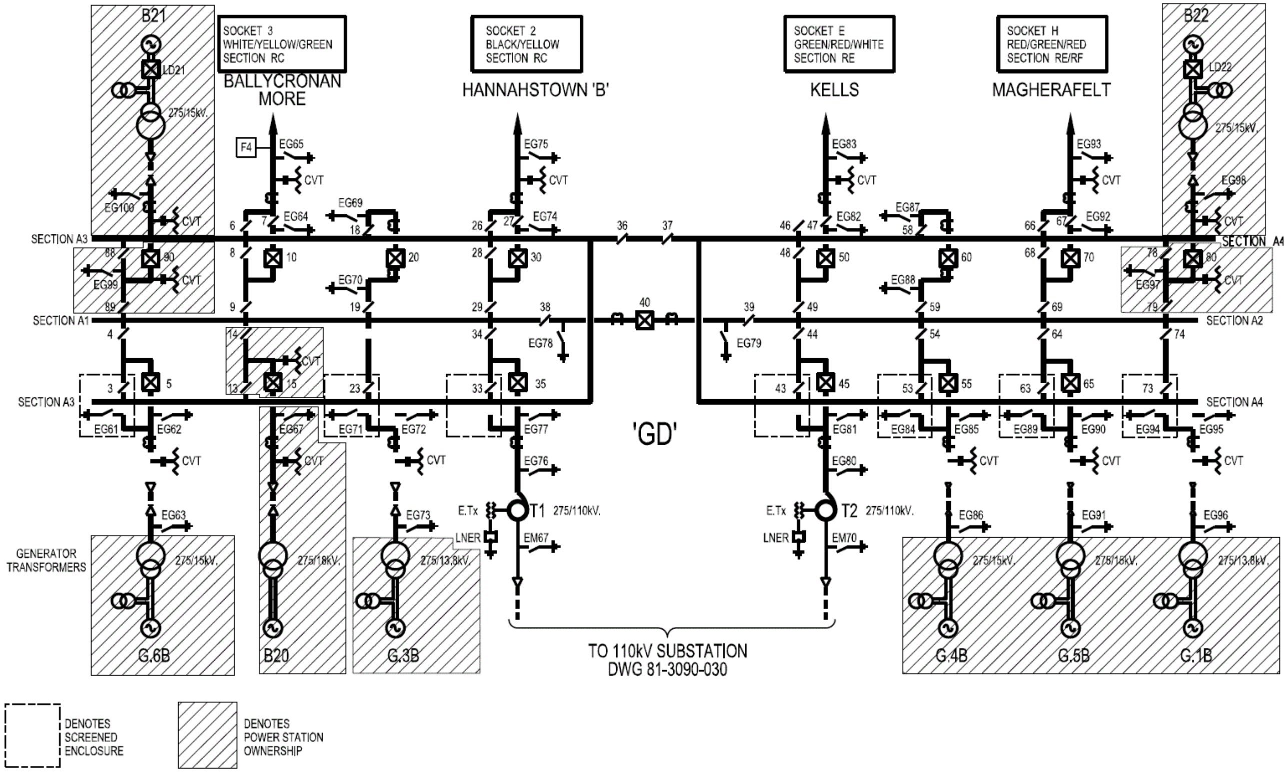

Figure 11 : Ballylumford 275 kV substation (Showing Control Boundaries)

Annex A. Comparation of reactive power compensators

An A.1. Comparation of SVCs and STATCOMs by the CIGRE Green Book : FACTS

Source : CIGRE Green Book : FACTS [8, p. 105]

Attributes	SVC	STATCOM
Semiconductor device	Thyristor	IGBTs or any other high-power device with turn-off capability
V/I characteristic	Superior overvoltage performance	Superior undervoltage performance
Application	Bulk transmission system and in the past in industrial applications	High/medium/low voltage (T&D)
Reactive power range	Branches optimally designed for any range	Naturally symmetrical; asymmetrical ranges achieved with hybrid STATCOM/TSC/TSR (See Fig. 11)
Short circuit level requirement	$h_{rated}/SCC > 3–4^{a}$ (lower values require advanced control strategies)	Virtually any Q_{rated}/SCC
Valve reaction time –inherent switching frequency of the valves	≈half-cycle	1–2 ms
Low-frequency harmonics	Higher content due to TCR harmonic generation	Negligible content if properly controlled
High-frequency harmonics (>30th)	Low content	Very low content but still needs to be analyzed
Power quality (flicker, voltage sags, load balancing, active filters)	Good capability for voltage sags	Superior performance at fast load variations; active filter capability (when properly dimensioned)
Availability[b]	High (>99%)	High (>99%)
Footprint	Larger depending on the rating and number of branches	Small; larger for hybrid STATCOMs
Losses	Lower total losses than STATCOM at full capacitive/ reactive operation	Lower no load losses than SVC at 0 Mvar
Renewables and distributed generation	More difficult to comply with some Grid Codes	Easier integration for achieving Grid Code compliance
Technology status	Mature with limited scope for valve improvements; well-known among utilities	Technology is mature but still improving; number of applications increasing particularly at lower voltages

[a]Q_{rated} = SVC or STATCOM rated reactive power; SCC = short circuit capacity
[b]Availability should be driven by the power system and customer requirements, not from the technology

Table 18 : Comparation of SVCs and STATCOMs by the CIGRE Green Book : FACTS

An A.2. Comparation of SVCs, STATCOMs and Rotating Synchronous Compensators by CIGRE TB144 : STATCOM

Source : CIGRE TB144 : STATCOM [9, pp. 3-21]

	SVC	STATCOM	Rotating Synchronous Compensator
Basic operating principle	Controlled or switched shunt impedance	Controlled voltage or current source behind reactance	Controlled voltage source or current source behind reactance.
Steady-state operating characteristic	See figures 3.1 and 3.2	See figures 3.1 and 3.2	As STATCOM
Behaviour at high/low voltage	Constant impedance / susceptance. Minimum voltage for thyristor turn-on/off	Constant current.	Constant current
Reactive power regulation	Within control range	Within control range	Within control range
Space requirements	Large (reactor, capacitor)	Smaller than SVC	Smaller then SVC
Losses	1.0-1.5%	1.0-1.5%	1.0-1.5%
System frequency variation	Behaves as constant C or L	Behaves as constant current source	Behaves as constant current source
Contribution to Fault Level	None	Maximum rated current	3-4 times MVA rating
Voltage control and response	Response depends on system strength and may require variable gain control	Response depends on system strength, but faster and more robust than SVC	Slower and more robust than SVC
Power transfer, stability, damping improvement	Dependent upon rating and location	Dependent on rating and location but significantly better than SVC	Limited by excitation system response
Initial energisation	By direct energisation from HV system	Rapid charging of energy storage to operating voltage	Requires accelerating shaft to operating speed
Fault ride-through capability	Small delay on thyristor re-enable unless free firing is maintained	No delay with d.c. capacitor voltage maintained	As provided by excitation system response
Behaviour under or after short-circuit conditions, voltage dips, short-time interruptions	Passive depending on control. No additional short-term capability.	Current source until storage discharged. Short-term capability dependent on thyristor thermal condition.	Voltage source behind transient/synchronous reactance.
Instantaneous real power supply	No	Dependent upon provision of energy storage	No
Load/phase balancing	Yes	Yes	No
Flicker compensation	Yes	Better than SVC	Passive mitigation through contribution to increased system fault level
Harmonic generation	TCR acts as a low order harmonic current source	High order harmonic voltage source based on switching pattern	High order harmonic voltage source dependent upon design
System and harmonic resonance	Effects existing resonance	No significant effect	No significant effect
Harmonic filtering	Passive filter usually required	Not usually required for higher pulse order equipment. May reduce existing distortion. Passive filters may be required for lower pulse order equipment.	Not required.
Voltage / Power quality improvement capability	Some response limitations	Significantly better than SVC	Better than SVC

Table 19 : Comparation of SVCs, STATCOMs and Synchronous Compensators by CIGRE TB144