Scottish & Southern Electricity Networks

Kinardochy Reactive Compensation

Engineering Justification Paper

1 Executive Summary

The primary driver for this reinforcement is the load related requirement for renewable generator connections on the wider SHE Transmission network and in the local area. Our paper "Planning for Net Zero – Scenarios, Certain View and Likely Outturn[1]" sets out our methodology for determining the certain view. The certain view is every activity and investment that we propose to undertake during the RIIO T2 period where there is compelling evidence of need. This encompasses capital investment to grow the network and accommodate new renewable generators.

This paper provides justification to establish a reactive compensation substation including a double busbar connected onto the 275kV circuit between the existing Tummel and Braco West substations on the Beauly to Denny overhead line (OHL), at Kinardochy.

Following optioneering and detailed analysis, as set out in this paper, the proposed scope of works is:

- Establish a new 400kV substation on the Beauly – Denny 275kV circuit at a site 3km south east of the existing Tummel 275kV substation, Kinardochy substation.
- Equip the substation with 400kV capable switchgear and busbar, operating initially at 275kV with the intention to upgrade to 400kV when the Beauly – Denny line is uprated to 400kV.
- Install reactive compensation at the new Kinardochy substation comprising of a STATCOM with a range of +/-225MVAr, and a 100MVAr MSCDN.
- OHL diversion works and installation of two terminal towers to turn the Beauly – Denny 275kV circuit into Kinardochy substation.

The cost to deliver the preferred solution is £106.04m and the works are planned to be completed in 2024.

This scheme delivers the following outputs and benefits:

- Increases the capability of the SHE Transmission network in line with our goal to transport the renewable electricity that, in total, powers 10 million homes by 2026.
- Facilitates the efficient, economic, and co-ordinated development and operation of the National Electricity Transmission System.
- Facilitates effective competition in the generation and supply of electricity through the timely connection of local renewable generation. This is in line with our licence obligations and our goal to provide network connections to meet our customer's needs, on time and on budget.

[1] RIIO T2 - Planning for Net Zero – Scenarios, Certain View and Likely Outturn

The Kinardochy Reactive Compensation project is above both Ofgem's early and late competition threshold at £106.04m. The project is not flagged as suitable for early competition, or for late competition, as detailed in Section 5 Detailed Analysis of the EJP.

Name of Scheme/Programme	Kinardochy Reactive Compensation	
Primary Investment Driver	Load	
Scheme reference/ mechanism or category	SHT20038	
Output references/type	LRT2SH2012	
Cost	£106.04m	
Delivery Year	RIIO T2 (2024)	
Reporting Table	B0.7_Load_Master_Data	
Outputs included in RIIO T1 Business Plan	No	
Spend Apportionment	**T1**	**T2**
	£13.41m	£92.63m

2 Introduction

This Engineering Justification Paper sets out our plans to undertake network enhancement works during the RIIO-T2 period (April 2021 to March 2026). The planned work is the construction of a new substation at Kinardochy, near Tummel 275/132kV substation, and installation of reactive compensation, as shown on the map in Figure 1.

The Engineering Justification Paper is structured as follows:

Section 3: Need

This section provides an explanation of the need for the planned works. It provides evidence of the primary driver and, where applicable, secondary drivers for undertaking the planned works. Where appropriate it provides background information and/or process outputs that generate or support the "need".

Section 4: Optioneering

This section presents all the options considered to address the "need" that is described in Section 3. Each option considered here is either discounted at this Optioneering stage with supporting reasoning provided or is taken forward for Detailed Analysis in Section 5.

Section 5: Detailed Analysis

This section considers in more detail each of the options taken forward from the Optioneering section. Where appropriate, the results of Cost Benefit Analysis are discussed and together with supporting objective and engineering judgement contribute toward the identification of a selected option. The section continues by setting out the costs for the selected option.

Section 6: Conclusion

This section provides summary detail of the selected option. It sets out the scope and outputs, costs and timing of investment and where applicable other key supporting information.

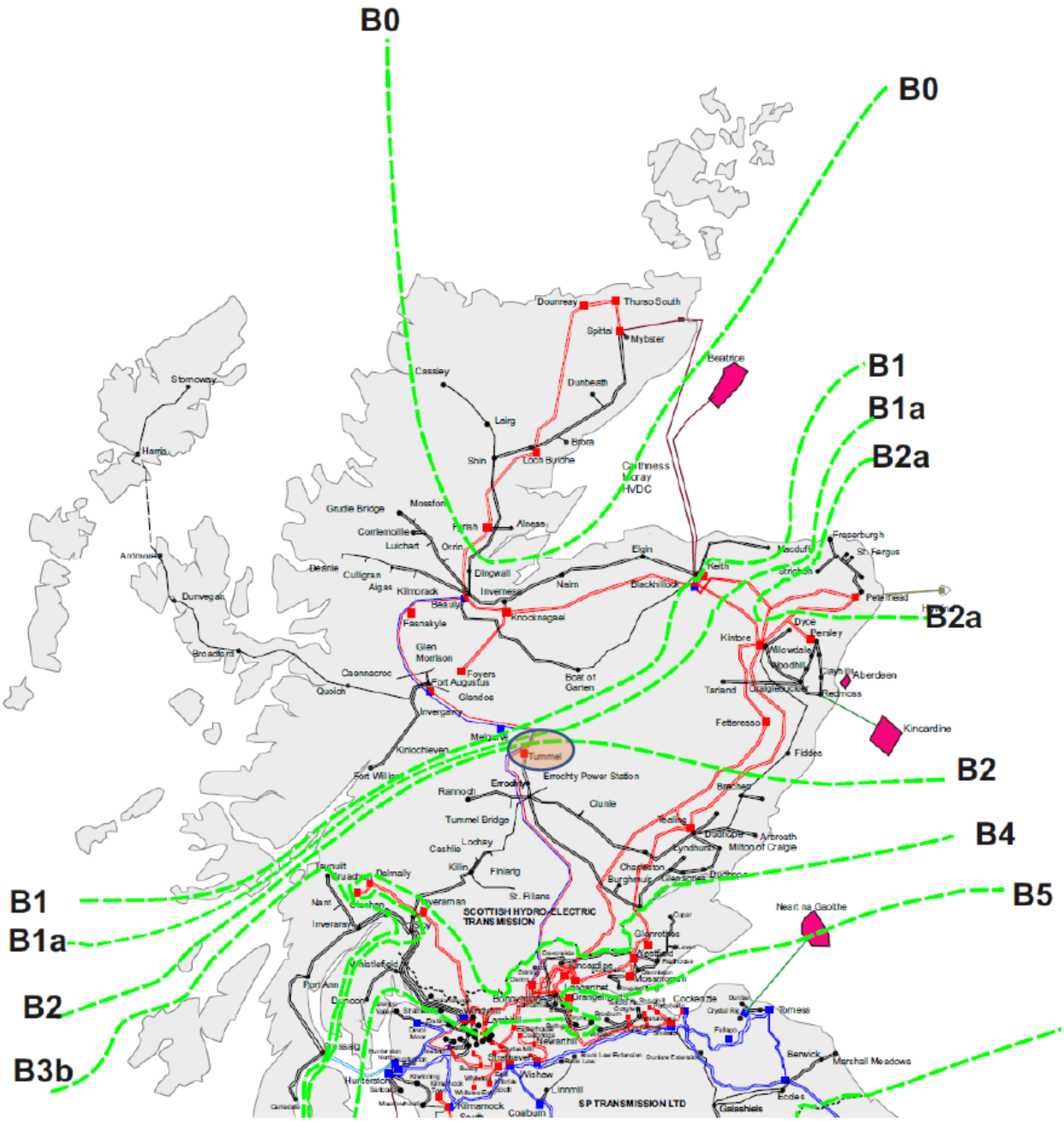
Section 7: Price Control Deliverables and Ring Fencing

This section provides a view of whether the proposed scheme should be ring fenced or subject to other funding mechanisms.

Section 8: Outputs included in RIIO-T1 Business Plan

This section identifies if some or all the outputs were included in the RIIO-T1 Business Plan and provides explanation and justification as to why such outputs are planned to be undertaken in the RIIO-T2 period.

Figure 1. Map showing the existing 275/132kV Tummel Substation on the SHE Transmission network.



3 Need

3.1 Background

The Beauly to Denny 400/275kV OHL[2] is a key west corridor of the SHE Transmission network for the transfer of power, originating mainly from low carbon generation, from the north and west of Scotland to ScottishPower Transmission's (SPT) area in the central belt of Scotland. The power flow on the Beauly – Denny OHL is expected to increase as more generation connects on the wider system; namely generation towards the west coast, and north of Beauly substation in and around Caithness.

In order to allow a continued increase in generation connection on the wider SHE Transmission network, and in the area local to Tummel and Fort Augustus, system studies undertaken have shown a requirement for reactive compensation to be installed on the 275kV circuit on the Beauly – Denny OHL to maintain voltage within the limits specified in Section 6 of the National Electricity Transmission System Security and Quality of Supply Standard (NETS SQSS). The proposed reinforcement project provides both dynamic and static voltage support for the Beauly – Denny OHL in order to enable the increased power flow, and to maintain compliance with the NETS SQSS.

This reinforcement has been identified as enabling works for the connection of the generators listed in Table 1. By installing the reactive compensation in 2024 for wider system need, we would also enable the connection of Glenshero Energy Park in 2024 – as well as Coire Glas pumped storage hydro scheme and Cloiche wind farm at a later date. The proposed completion date of the project is also driven by a need to maintain NETS SQSS compliance for wider system power flow against our certain view RIIO-T2 scenario background and the FES 2019 background. This reinforcement provides voltage support to enable increased power flow on the Beauly – Denny line, which is critical in enabling us to connect more generation in the SHE Transmission area.

Glenshero Energy Park and Cloiche wind farm are proposed to connect at Melgarve substation on the 400kV side of the Beauly – Denny line. Glenshero Energy Park has applied for consent and Cloiche wind farm is currently carrying out a consultation in advance of applying for consent. The Coire Glas pumped storage hydro scheme is proposed to connect into the Fort Augustus 400kV busbar, and has planning consents. The developers of all three schemes have a history of developing and constructing onshore wind farms in the SHE Transmission area.

[2] The substations on the Beauly – Denny dual voltage (400 and 725kV) overhead line (from north to south) are:
400kV: Beauly – Fort Augustus – Melgarve – Denny North.
275kV: Beauly – Fasnakyle – Tummel – Braco West – Denny North.

Table 1: Generation schemes with Kinardochy Reactive Compensation project as enabling works

Name	Generation Type	Location	TEC (MW)	Contracted Date
Glenshero	Wind/Hybrid	Melgarve	168	31 May 2023*
Coire Glas	Hydro	Fort Augustus	612	31 October 2025**
Cloiche	Wind	Melgarve	200	31 October 2026***

* Glenshero are contracted for May 2023, [redacted]

In addition, we have received an application for the extension of [redacted] wind farm (connected near Fort Augustus) – adding another [redacted] to their existing TEC of 108MW. We have also received an application for [redacted] a [redacted] scheme seeking connection at Melgarve substation. These schemes, as well as any other large schemes which may be looking to connect to the local network near Fort Augustus and Tummel, will now be contingent on this reinforcement to enable connection.

This reinforcement also provides wider system benefit through supporting steady state voltage, which has been shown in the form of an increase in capability of the B1, B1a and B2 boundaries (where the limitation is steady state low voltage on the Beauly – Denny line). These boundaries are shown in Figure 1 in the introduction section. This aspect of wider system benefit has therefore been explored for this reinforcement through the annual Network Options Assessment (NOA) undertaken by the Electricity System Operator (ESO) with support from SHE Transmission.

Results from NOA 2018/19 indicated that the optimal delivery of Tummel reactive compensation[3] (TURC) for the purpose of supporting steady state voltage only is 2029/30 in one scenario out of the 4 Future. As acknowledged in the NOA 2018/19 report[4], the recommendations are based on the ESO's economic assessment of options to deliver boundary capability only, and as such, options listed as enabling works in Users' connection agreements that do not receive a 'Proceed' signal could still be proceeded by the TO if the reinforcement is required for reasons other than delivering boundary capability. In this case, the reinforcement is required to maintain compliance for voltage step change in the NETS SQSS, therefore the reinforcement is being progressed without a recommendation from NOA.

[3] Following stakeholder engagement, the project has been renamed Kinardochy reactive compensation, but Tummel will be used in discussions relating to NOA to provide some continuity.
[4] Network Options Assessment (NOA) Report 2018/19 – published by National Grid ESO, available online at https://www.nationalgrideso.com/publications/network-options-assessment-noa

As we are progressing this reinforcement without a recommendation from NOA, we have requested a statement of support from the ESO on the Kinardochy reactive compensation project. A copy of the statement of support is available in Appendix B. Within the statement the ESO has agreed that we should progress the enabling works if we have identified the works as Enabling Works for the connection of contracted generation. They have stated that "under certain generation scenarios including the existing and contractual ones in that region, when exporting a credible level of generation from the north west of Scotland, especially with 400kV circuit outages between Fort Augustus and Denny North, the system operation would benefit from the reactive power support from this new Reactive Power Compensation".

An additional impact and benefit of this reinforcement is in improving system operability of the SHE Transmission network. At present, the ESO has to switch [redacted] circuit out of service during periods of low power flow on the transmission system in order to alleviate high steady state voltage issues that have been identified on the local network. The installation of reactive compensation can be used by NGESO to alleviate these issues, therefore reducing the need to take [redacted] circuit out of service.

3.2 Local System Studies

Generation applications seeking connection to the Transmission network local to Tummel 275kV substation resulted in system studies being undertaken to examine the need for reactive compensation on both a local (to determine the required enabling works for the generators listed in Table 1) and wider system basis, to keep voltage disturbance for the transmission network users within the limits specified in the NETS SQSS.

The voltage step change at a location on the network is the dynamic change between the pre-switching voltage level on the intact network and the prevailing voltage immediately after a network asset outage. The key voltage limits relevant to this project which SHE Transmission are required to comply with are:

- A pre-fault steady state voltage limit for 275kV of 0.95 per unit in planning timescales (as detailed in part (a) of Table 6.1 within Section 6 of the NETS SQSS)
- A voltage step change limit of +/-3% following operational switching at intervals of more than 10 minutes (as detailed in part (a) 2. of Table 6.5 within Section 6 of the NETS SQSS)
    - This is the maximum operational voltage change permitted from switching out plant or assets on the onshore transmission system – regular ESO practice for voltage control or for safe access to other plant.
- A voltage step change limit of +/-6% following infrequent operational switching (as detailed in part (a) 4. of Table 6.5 within Section 6 of the NETS SQSS)
    - This is the maximum operational voltage change permitted from disconnecting an OHL or cable for routine maintenance.

  - Note 9 for part (a) 4. also states that a voltage step exceeding +/-3% for infrequent operational switching is only accepted on a busbar (or circuit) fed directly by the transmission circuit involved in the infrequent operational switching.

The need for the reactive compensation was examined under a wide range of network conditions set up for different types of studies, including:

- Generation connection studies to achieve compliance with Section 2 of the NETS SQSS – Generation Connection Criteria.
- Boundary capability studies for Section 4 of the NETS SQSS – Design of the transmission system.
- Summer minimum system operability studies for Section 5 of the NETS SQSS – Operation of the transmission system.

Negative voltage step change violations against the -3% limit were identified at the Tummel 275kV substation on the Beauly – Denny line, when switching out the Melgarve – Denny North 400kV circuit under low power flow conditions. This violation is against the criteria for both the operational switching and infrequent operational switching of this circuit. Violations were also observed at Fort Augustus 275kV substation and Braco West 275kV substation although the step change is less severe than at Tummel. As a result of these studies there is a requirement for dynamic capacitive reactive compensation of +225MVAr to be installed locally on the network.

Positive voltage step change violations against the +3% limit were also identified at Tummel 275kV substation, under the same system conditions as the previous study, when switching out the Braco West – Denny North 275kV circuit. Again, this would be a violation against the criteria for both the operational switching and infrequent operational switching of this circuit. As a result of these studies there is a requirement for dynamic inductive reactive compensation of -75MVAr to be installed locally on the network.

In order to optimise the availability of the dynamic reactive compensation, system studies have identified the need for 100MVAr of static compensation in addition to the +225/-75 MVAr dynamic compensation. The standard solution is to provide this via an MSCDN. The system studies confirmed that the dynamic reactive compensation would be contributing 63MVAr on the intact network to maintain the steady state voltage at Tummel without the 100MVAr MSCDN. The 100MVAr MSCDN also helps to alleviate a more significant negative voltage step change at Tummel, for the operational switching and infrequent operational switching out of the Melgarve – Denny 400kV circuit, which occurs during periods of high power flow on the system when the 1400MW North Connect interconnector to Norway is significantly exporting.

It was concluded that dynamic compensation with a +225/-75MVAr range and 100MVAr of static compensation is required to mitigate voltage step change and alleviate steady state low voltage on the 275kV circuit of the Beauly – Denny line. In total the reactive compensation required is

+325MVAr/-75MVAr. This level of reactive compensation ensures satisfactory voltage support of the Beauly – Denny line.

Operability studies were undertaken to investigate any potential high voltage issues on the SHE Transmission network during summer minimum demand and low generation output conditions. These studies showed that there were high voltage step change violations identified at Braco West. 275kV substation under the outage of the Braco West – Denny North 275kV circuit, requiring inductive reactive compensation on the local network. As a result, there is a requirement for dynamic inductive reactive compensation to be installed locally on the network. This issue is resolved by the proposed -75MVAr inductive reactive compensation.

The injection of more power into Fort Augustus and the local area, when there is an outage south of Fort Augustus on the Fort Augustus to Denny North 400kV circuit, results in a higher power flow on the adjacent 275kV circuit and therefore a lower steady state voltage at Tummel 275kV substation and further south at Braco West and Denny North. Q-V analysis (involving studies on how variations in reactive power injection at a busbar affects the voltage at the same busbar) was carried out to determine the most effective location on the Beauly – Denny 275kV circuit to connect the reactive compensation in order to support voltage in the local Tummel and Fort Augustus area. The resulting QV curves demonstrated that connecting the reactive compensation at or near to the existing Tummel 275kV substation provides the most effective improvement in the voltage stability of the network in the area, compared to other potential locations such as the Fort Augustus 400/275kV substation or Braco West 275kV substation.

3.3 Wider System Studies

System studies have been carried out to consider system performance (for voltage step and steady state) influenced by wider network power flows rather than local network power flows based on contracted position.

Firstly, a wider system study was carried out to determine the level of generation on the SHE Transmission network which causes a voltage step violation at Tummel, and when this quantity of generation will appear - to answer the question of when voltage support is needed to alleviate significant voltage step change at Tummel on a wider system basis.

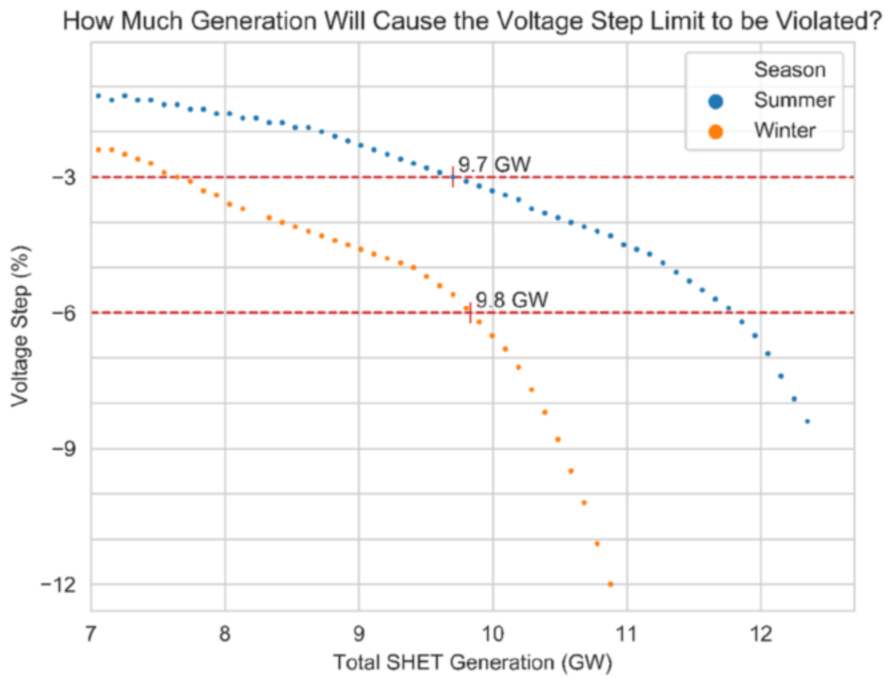
Secondly, a wider system sensitivity study was carried out to identify if voltage support was needed to maintain steady state voltage on the Beauly – Denny line (under normal operating conditions) to within the limits specified in the NETS SQSS, following the connection of any local contracted generation in any combination (i.e. not linked to contracted date).

3.4 Voltage Step

This study investigated how much generation (large, embedded and small) in the SHE Transmission area can be accommodated by the transmission network before a voltage step violation is encountered. Given that we had already identified negative voltage step change violations, against NETS SQSS voltage limits, at the Tummel 275kV substation (more severe than at Fort Augustus and Braco West), when switching out the Melgarve – Denny North 400kV circuit, the study was based on monitoring voltage step at Tummel for the same single circuit outage.

A forecast of the network and of the generation and demand background at the beginning of the RIIO-T2 period was used as a base case for the study. Generation (large, embedded and small) was then scaled up uniformly across the SHE Transmission area, and the voltage step change at Tummel is calculated for the single circuit outage of Melgarve – Denny 400kV. The generation schemes which have Kinardochy Reactive Compensation as enabling works (as detailed in Table 1) were not included in the background. The aim of the study was to therefore highlight the impact of wider system flows only on voltage step change at Tummel, rather than local contracted generation. The study was carried out for the winter and summer season, with conditions on the system set to those which ought reasonably to be foreseen to arise during a year of operation. The results of this analysis are shown in Figure 2.

Figure 2 – Voltage step at Tummel as a result of total generation in the SHE Transmission area

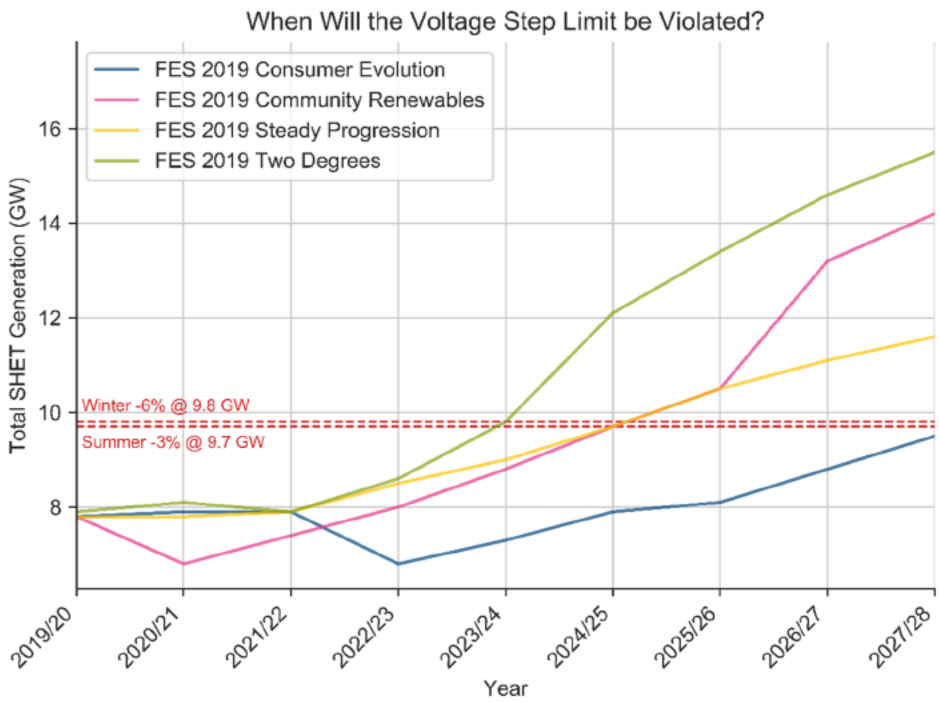


Under summer ratings and a summer lightly loaded system we have highlighted the limit of total generation in the SHE Transmission network for the -3% voltage step limit and highlighted under winter ratings the total generation limit for a more onerous -6% voltage step limit when there is more generation on the system which can provide background voltage support. As can be seen in Figure 2, around 9.7-9.8GW is the limit of total generation in the SHE Transmission network before a negative voltage step change violation occurs at Tummel.

This generation total is above the total current connected generation in the SHE Transmission area (7.3GW), and our forecast for the end of the RIIO-T1 period (8GW) but is significantly below (around 1.4GW less than) our certain view RIIO-T2 scenario of 11.2GW total generation. To meet the certain view RIIO T2 scenario we would need to install dynamic compensation at or near to Tummel during the RIIO-T2 period to maintain NETS SQSS compliance. Figure 2 also highlights a faster rate of increase in voltage step violation under winter conditions (i.e. on a higher loaded system) for an additional 1GW of total generation (leading to around a -12% voltage step at 10.8GW) – further highlighting the need for dynamic reactive compensation. Total generation (large, embedded and small) in the SHE Transmission area according to FES 2019 is detailed in Figure 3. This shows that to maintain NETS SQSS compliance for three out of the four FES 2019 scenarios (namely Two Degrees, Community Renewables and Steady Progression) we would need to install this dynamic compensation by 2024. This also aligns with the proposed date for Glenshero Energy Park.

Dynamic compensation with a range of +225MVAr/-75MVAr and an additional 100MVAr of static compensation (+325MVAr/-75MVAr in total), which is needed by 2024, ensures satisfactory voltage support of the Beauly – Denny 275kV line throughout the RIIO-T2 period.

Figure 3 – Total generation in the SHE Transmission area for FES 2019



3.5 Steady State Voltage – Sensitivity Study

The sensitivity study investigated the reactive (MVAr) capability required at Tummel at the end of the RIIO-T2 period to maintain a steady state pre-fault voltage in the range 0.95 - 1.0 per unit at Tummel. The reactive (MVAr) capability required was assessed against different scenarios of large generator connections in the central region of the SHE Transmission network – comprising of generators connecting at Invergarry, Melgarve and on Skye (as detailed in Table 2). The voltage range considered extends above the 0.95 per unit pre-fault steady state planning limit specified in the NETS SQSS for 275kV to provide a prudent margin. This is justified in reference to Figure 2 that indicates that the voltage performance at Tummel becomes increasingly sensitive to generation volume connected (and consequently power flow) on the network. This is shown by the more rapid increase in the depth of voltage step as generation volumes increase. Therefore, the quantity of reactive compensation has been targeted to be sufficient to maintain a mid-range voltage (i.e. around 0.98 per unit) throughout a variety of local background conditions. This level of reactive compensation ensures network compliance is maintained in the event of actual future network conditions different from those used as the study background assumptions and provides operational flexibility to maintain 275kV system voltage closer to nominal thus providing voltage margin.

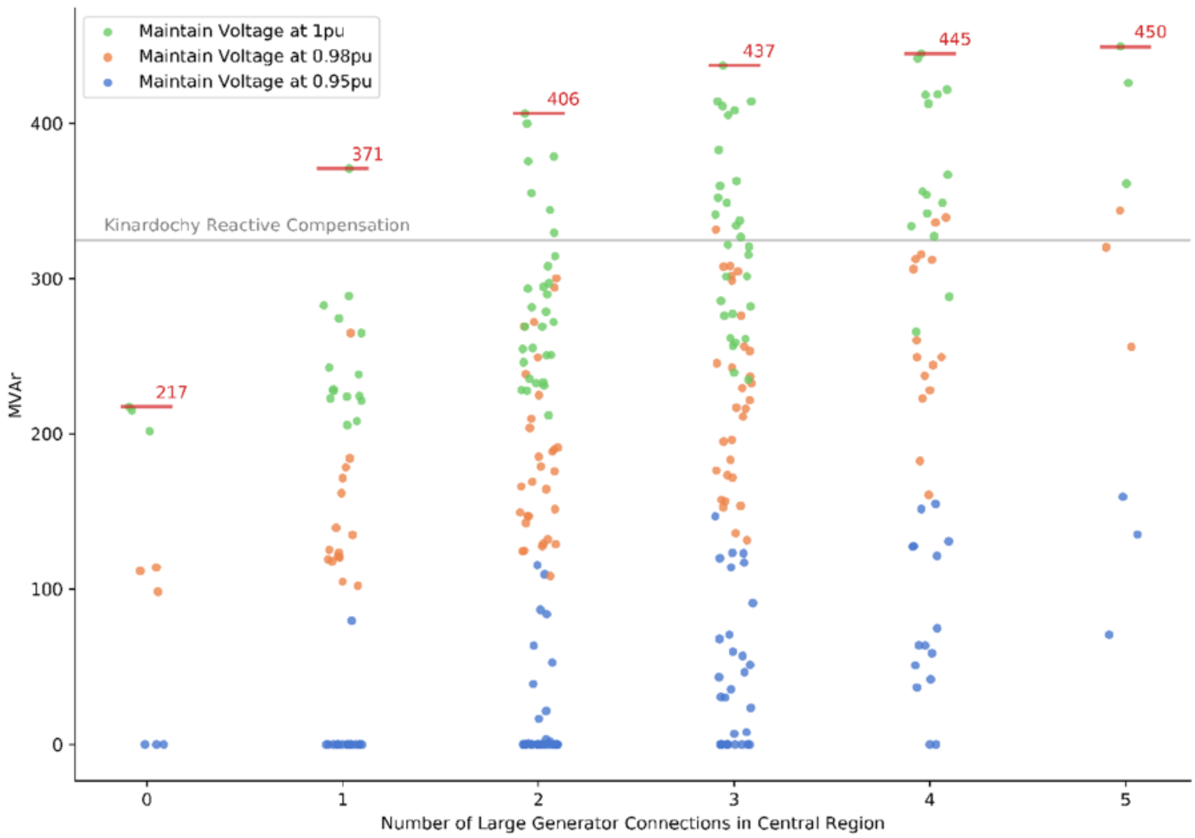
The results of the sensitivity analysis are shown in Figure 4 where each determined reactive (MVAr) capability at Tummel is the peak MVAr requirement for the specific local generation scenario and local area studied considering all associated network outages. The results show that the reactive support proposed at Tummel (+325MVAr in total) is sufficient in the majority of cases to meet steady state voltage compliance. Note that even without any generator connections in the local areas studied, reactive power is required for an outage on the Beauly – Denny OHL to maintain a mid-range voltage of 0.98 per unit at Tummel.

Furthermore, it is clear from Figure 4 that if only dynamic compensation at the recommended range (+225/-75MVAr) is installed, then 225MVAr of capacitive support would not be enough to maintain a voltage of 0.98 per unit at Tummel for around half of the scenarios (for local generation and local area) that could materialise in the RIIO-T2 period. The static compensation recommended (100MVAr) is therefore not only needed to ensure that the full range of dynamic compensation is available to support dynamic voltage performance, but also to ensure that steady state voltage compliance is met throughout the RIIO-T2 period.

Table 2 Generators considered in the sensitivity analysis

Generator	TEC (MW)	Connection	Contracted Date
Cloiche	200	Melgarve	October 2026
Coire Glas	612	Invergarry	October 2025
Glenshero	168	Melgarve	August 2024
Glen Ullinish	42	Skye	October 2024
Glean Eoghainn	25	Dunvegan	May 2027

Figure 4 – Required reactive (MVAr) capability across each combination of generators



4 Optioneering

This section presents all the options considered to address the need that is described in Section 3. Each option considered here is either discounted at this Optioneering stage with supporting reasoning provided or is taken forward for Detailed Analysis in Section 5.

The optioneering for this reinforcement, informed by system studies, considered the size, location and type of reactive compensation required to ensure satisfactory voltage support for the 275kV side of the Beauly – Denny line. In addition, a site selection process has been undertaken to confirm the most technically, environmentally and economically suitable site in which to develop the solution.

Do Nothing Option

The deferral and 'do nothing' scenarios are not technically acceptable, as:

- NETS SQSS compliance would not be maintained for our certain view RIIO-T2 scenario on account of wider system power flows on the Beauly – Denny line (resulting in a voltage step change violation at Tummel, and under heavier power flows steady state violations); and
- the generation outlined in Table 1 would not be able to connect.

Reactive Compensation Solution

The system studies (as previously described) identified the required size for the reactive compensation. The system studies concluded that dynamic compensation with a +225/-75MVAr range and 100MVAr of static compensation is required to mitigate voltage step change and alleviate steady state low voltage on the 275kV circuit of the Beauly – Denny line. In addition, the QV analysis curves demonstrated that connecting the reactive compensation at or near to the existing Tummel 275kV substation, is the most effective location to improve the voltage stability of the local 275kV network.

A technical assessment of potential reactive compensation solutions for Tummel recommends a Static Synchronous Compensator (STATCOM) with a range of +/-225MVAr rather than a Static Var Compensator (SVC) or Synchronous Condenser (SYNCON) as the most appropriate solution to provide the required dynamic reactive support, and a Mechanically-Switched Capacitor with Damping Network (MSCDN) to provide the required 100MVAr static capacitive reactive support. The vendor responses to our request for information indicated a preference for STATCOM technology over alternative hybrid solutions. Also highlighted was that a STATCOM has a smaller footprint and less noise output as compared to other available technologies and offers more flexibility for the control and operation of the network. More information on this can be found in the Technical Assessment paper[5].

[5] Technical Assessment of Reactive Compensation Solutions for Projects Alyth and Tummel

Site Selection

As the optimal location on the network for reactive compensation has been determined to be at or near to the existing Tummel 275/132kV substation, a site selection process has been undertaken to confirm the most technically, environmentally and economically suitable site at which to develop the solution. The selection process has been undertaken in accordance with the SHE Transmission document - Substation Site Selection Guidelines.

The 2018/2019 Substation Site Selection Report reviews and furthers the exercise undertaken in 2013/14 to determine a preferred location for this project. The 2013/14 Site Selection Report reviewed 9 potential site locations. Sites were considered on their suitability to accommodate a reactive compensation substation with a recalibrated site footprint based on reasonable assumptions derived from similar reactive compensation solutions on the network. As several technological options are available for the reactive compensation, a base case footprint was employed for modelling which could accommodate any one of the solutions – all site options were considered utilising a design envelope with capacity for expansion (due to technology availability or change) or future development.

The 9 sites were reviewed in this context and several were discounted due to a lack of suitability. These sites are considered as follows (distance provided from existing Tummel 275kV substation):

- **Site 1 (at existing site):** Expansion of the existing operational substation would be required adjacent to the existing site. However due to land limitations, Gas Insulated Switchgear (GIS) is the only option for this site.

  Progressed to site selection exercise

- **Site 2 (1km east):** The area surrounding the existing Errochty Substation is constrained by the river Tummel, B846 and holiday cottage, this results in the limited space available to accommodate the new reactive power compensation equipment.

  Not Progressed to site selection exercise

- **Site 3 (2km south east):** The area surrounding site 3 has significant ecological value and peat land. The site is also located a distance away from the Beauly – Denny OHL therefore diversion of the Beauly – Denny line would be required.

  Not Progressed to site selection exercise

- **Site 4 (3km south):** The site area has suitable space for future expansion and for site compound and laydown area. The site however would require large excavation and visual impact if Air Insulated Switchgear (AIS) was to be considered at this site therefore GIS is only being considered.

  Progressed to site selection exercise

- **Site 5 (2.5km south):** The area surrounding Tombreck would be visible from Tombreck cottage and would have a significant footprint towards Tombreck holiday cottage. There would also be a requirement to significantly upgrade the access track to access the site.

Not Progressed to site selection exercise

- **Site 6 (7km south):** The area is next to a campsite and recreational activities, it also has significant visual and noise impact.

Not Progressed to site selection exercise

- **Site 7 (11km south):** This site is located in a flood plain and could have significant reputational impact due to it being located in a tourist area and just off the main road (B846).

Not Progressed to site selection exercise

- **Site 8 (13km south)**: This site is located on the potential substation location for Crossburns wind farm. However, Crossburns wind farm is not going ahead, and the location of the proposed reactive compensation equipment would be potentially inaccessible for 1/3rd of the year due the altitude of the substation.

Not Progressed to site selection exercise

- **Site 9 (17km south)**: This site is located within Crossburns wind farm. However, Crossburns wind farm is not proceeding, and the location of the proposed reactive compensation equipment would potentially be inaccessible for 1/3rd of the year due the altitude of the substation.

Not Progressed to site selection exercise

Following the initial review of the available sites, two viable options were taken forward for further optioneering (Sites 1 and 4). Both sites were reviewed with respect to their performance against operational/technical, economic and environmental criteria. The selection of the preferred site for the substation at Tummel has been undertaken as a combination of the operational/technical, economic and environmental assessment scores for each site using the SHE Transmission guidelines. Table 3 below provides the overall summary scores for each site.

Table 3 Substation site selection summary

Topic	Site	
	Site 1	Site 4
Operational/ Technical	2.11	1.44
Economic	3	2
Environmental	3	0
Total	8.11	3.44
Site Ranking	**2**	**1**

Further detail is provided in the 2018/19 Substation Site Selection Report (which is available on request), however the preferred site for development is considered to be Site 4 and the key conclusions are summarised below:

- Site 4 is 1st in terms of operational/technical factors due to ease of connectivity to the Tummel-Braco West 275kV circuit, the ability to allow for future network expansion without expanding the footprint, and the reduction in complications associated with nearby stakeholder and landowners.
- Site 1 is 2nd in terms of operational/technical factors due to the limited future expansion capability and significant health and safety construction challenges associated with site.
- Site 4 is preferable to Site 1 Environmentally due to the distance from sensitive residential receptors, distance from any Special Areas of Conservation, absence of any Ancient Woodland Inventory habitats and the distance from people using the area recreationally.

Site 4 is preferable to Site 1 economically, due to reduced OHL and cumulative plant cost estimates, although it is noted that the total civil works estimate is higher at Site 4.

Switchgear Technology

Following the technical assessment undertaken on the potential reactive compensation solutions, along with the detailed site selection report that has been undertaken, the proposal is to install a new double busbar, a +/-225MVAr STATCOM, and a 100MVAr MSCDN at a new substation site (Kinardochy) 3km south of the existing Tummel 275kV substation. The switchgear is proposed to be GIS. SHE Transmission have made a commitment to reduce the use of new GIS containing SF_6. Tendering contractors will be asked to provide options to minimise the use of SF_6 and use alternative gases where possible.

400kV vs 275kV

As detailed in our paper "A Network for Net Zero – Scenarios", our plans within RIIO T2 should be able to be flexed to support the achievement of the net zero target by 2050. Given the increase in generator connections in the local area, and the wider area on the west side of our network, there is likely to be a requirement to upgrade the 275kV side of the Beauly – Denny circuit to 400kV in the future. The OHL was constructed to be capable of operating at 400kV on both sides of the tower line. Because of this, it is prudent to consider two options for proceeding to detailed analysis with:

- Construct a 275kV GIS double busbar at Kinardochy substation (including reactive compensation devices specified above).
- Construct a 400kV GIS double busbar at Kinardochy substation (including reactive compensation devices specified above) but initial operating at a voltage of 275kV.

5 Detailed Analysis

This section considers in more detail each of the options taken forward from the Optioneering section. Where appropriate the results of Cost Benefit Analysis (CBA) are discussed and together with supporting objective and engineering judgement contribute toward the identification of a selected option. The section continues by setting out the costs for the selected option.

Two options have been taken forward from the optioneering for detailed analysis and inclusion in the CBA.

Baseline Option

Construction of a 275kV GIS double busbar at a new substation at Kinardochy, located 3km to the south of the existing Tummel 275kV substation. Install a new +/- 225MVAr STATCOM and a new 100MVAr MSCDN. Include space provision for a second 100MVAr MSCDN and for two SGTs. Within the CBA the works required to transition Kinardochy substation to 400kV operation at a later date have been included, as per the timing scenarios below.

Option 2

Construction of a 400kV GIS double busbar to be initially operated at 275kV at a new substation at Kinardochy, located 3km to the south of the existing Tummel 275kV substation. Install a new +/- 225MVAr STATCOM and a new 100MVAr MSCDN. Include space provision for a second 100MVAr MSCDN and for two SGTs. Within the CBA the works required to facilitate the upgrade and transition of Kinardochy 275kV reactive compensation substation to 400kV operation at a later date have been included, as per the timing scenarios below.

5.1 Cost Benefit Analysis

If 275kV assets were to be installed initially, then a requirement to upgrade to 400kV in the future would lead to the scrapping of busbar and switchgear assets ahead of the lifetime of the assets. In addition, the reactive compensation at Kinardochy substation would be out of service for a significant period of time during the transition of the substation from 275kV to 400kV capability. The period of unavailability would be significantly reduced under Option 2 where 400kV capable switchgear would be installed initially, although there would need to be some outages on the STATCOM and MSCDN to change to the primary operating voltage, allow for the protection system to be modified, and undertake work at remote end substations.

A Cost Benefit Analysis (CBA) has been undertaken to help determine the optimal solution to proceed with in RIIO T2, and whether the substation should be constructed at 275kV, or 400kV and avoid the potential need to scrap assets ahead of their lifetime. As the required date for this upgrade is as yet unknown, due to the uncertainty of timing for future generation on the network, a number of different delivery date scenarios have been devised for assessing in the CBA:

- 2030 – 400kV requirement within the RIIO T3 period should the higher generation scenarios outturn
- 2040 – middle scenario
- 2050 – five years post the date for achieving Net Zero in Scotland

In order to assess any benefit of installing 400kV capable switchgear within the RIIO T2 period, the costs of the initial work at 275kV and the costs of the transition to 400kV in the future had to be accounted for in the CBA. The total forecast expenditure costs included in the CBA results tables 4-6 include initial costs, 400kV transition costs, and operational expenditure costs.

Net Present Values (NPV) for both options were calculated and compared against each other. The output from each CBA scenario is shown in Table 4 (2030 scenario), Table 5 (2040 scenario), and Table 6 (2050 scenario).

Table 4. CBA results for the 2030 Beauly – Denny 400kV uprate scenario.

CBA Reference	Total Forecast Expenditure *(£m)*	Total NPV *(£m)*	Delta *(Option to baseline £m)*
Baseline	-£135.60	-£116.57	
Option 2	-£117.34	-£107.17	£9.40

Table 5. CBA results for the 2040 Beauly – Denny 400kV uprate scenario.

CBA Reference	Total Forecast Expenditure *(£m)*	Total NPV *(£m)*	Delta *(Option to baseline £m)*
Baseline	-£135.60	-£108.29	
Option 2	-£117.34	-£105.57	£2.72

Table 6. CBA results for the 2050 Beauly – Denny 400kV uprate scenario.

CBA Reference	Total Forecast Expenditure *(£m)*	Total NPV *(£m)*	Delta *(Option to baseline £m)*
Baseline	-£135.60	-£102.13	
Option 2	-£117.34	-£104.39	-£2.25

The results from the CBA show that if the upgrade of the Beauly – Denny 275kV circuit to 400kV was needed before 2040, it would be economical to install 400kV assets at the new substation at Kinardochy now and initially operate at 275kV. However, for the 2050 scenario the results showed it would be better to install 275kV assets and make the necessary upgrades at the time 400kV is required.

Additional analysis was undertaken to determine the trigger point at which the baseline option (275kV switchgear initially installed) becomes the preferred option from the CBA. The analysis showed that the trigger date would be 2046. This analysis shows that if 400kV operation is required prior to 2046, 20 years post RIIO T2, then from a CBA perspective 400kV switchgear should be installed initially. It is only optimal to install 275kV switchgear initially if 400kV operation is not required until beyond 2046.

We believe the need for 400kV capable switchgear will materialise prior to 2046, based upon future generation growth predicted on the local and wider network that is required in order to meet Net Zero, which includes future large offshore wind farms off the coast of Scotland and the pumped hyrdo scheme at Coire Glas.

5.2 Project Sensitivity

As outlined in our core RIIO-T2 business plan document, “A Network for Net Zero”, we believe we have a critical role to play in delivering Net Zero ambitions in both the UK and Scotland. Therefore our plan has been carefully designed with the flexibility to deliver pathways to Net Zero. Our policy paper “Planning for Net Zero – Scenarios, Certain View and Likely Outturn” demonstrates that the investments which we are making are consistent with the UK Governments’ net zero emissions by 2050 target. In preparing our RIIO-T2 Business Plan, we ensured that our Certain View provides flexibility for the north of Scotland transmission network to accommodate greater volumes of renewable generation connections during the RIIO-T2 period. The strategic investments included in the Certain View –on the East Coast and near Tummel–are critical to ensuring that flexibility. While the need for these investments can be evidenced now, timely delivery also maintains long term net zero emissions pathways. Our approach to using a ‘Certain View’ means that there is strong evidence-based need and justification that the load related works are necessary for connections of renewable generation. These works are necessary to meet our legal and regulatory obligations to provide a connection to any customer who requests it.

Table 7. Sensitivity Analysis table

Sensitivity	Test and impact observed – switching inputs
Asset Performance / deterioration rates	N/A
Ongoing efficiency assumptions	Switching efficiency assumption: increased or decreased. Test would have no impact on (feasible) option selection, as the options move in parallel and have no impact on ordering within CBA.
Demand variations	No significant demand forecast.
Energy scenarios	Sensitivity considered in Section 3 (Need) already. As we have adopted a "Certain View" approach, as outlined in our "Planning for Net Zero – Scenarios, Certain View and Likely Outturn" policy paper, means that there is strong evidence-based need and justification that the load related works are necessary for connections of renewable generation. These works are necessary to meet our legal and regulatory obligations to provide a connection to any customer who requests it. Please see Section 3 of the EJP and our "Planning for Net Zero – Scenarios, Certain View and Likely Outturn" policy paper for further details.
Asset utilisation	As outlined in the energy scenarios section, we are anticipating increasingly more generation connecting to our Transmission network. As outlined in our "Planning for Net Zero – Scenarios, Certain View and Likely Outturn" policy paper our business plan has been carefully designed with the flexibility to deliver pathways to Net Zero. There is strong evidence-based need and justification that the load related works are necessary for connections of renewable generation. These works are necessary to meet our legal and regulatory obligations to provide a connection to any customer who requests it. We are unable to consider the known unknowns.
Timing / delivery	We have considered timing of investments as part of our CBAs.
Consenting / stakeholders	Where applicable we have considered consenting and stakeholder engagement as part of section 5 (Detailed Analysis) and the impact which this has had on the selection of the preferred solution.
Public policy / Government legislation	We have considered the impact of public policy, government legislation and regulations as part of the need (section 3), optioneering (section 4) and detailed analysis (section 5) and the impacts this has on the selection of the preferred solution. For example, the projects have considered the impact of the UK Governments' Net Zero emission by 2050 target, SQSS and ESQCR.

5.3 Proposed Solution

Based on the output from the CBA, the proposed solution we will proceed with in RIIO T2 is Option 2 (400kV capable switchgear operated at 275kV initially). The CBA analysis has shown that if we need to upgrade the 275kV side of Beauly – Denny OHL to 400kV before 2046, then it would be beneficial to initially install a 400kV double busbar (to be operated at 275kV) and 400kV capable switchgear. This solution includes for provision of future tie-ins of the existing Melgarve -Denny 400kV circuit into Kinardochy reactive compensation substation.

[redacted]

The proposed scope of works is:

- Establish a new 400kV GIS substation on the Beauly – Denny 275kV circuit at a site 3km south east of the existing Tummel 275kV substation, Kinardochy substation.
- Equip the substation with 400kV capable GIS switchgear and busbar and operate initially at 275kV.
- Install reactive compensation at the new Kinardochy substation comprising of a STATCOM with a range of +/-225MVAr, and a 100MVAr MSCDN and operate initially at 275kV.
- Allow space provision for an additional MSCDN, and for two SGTs.
- OHL diversion works and installation of two terminal towers to turn the Beauly – Denny circuit into Kinardochy substation.

The proposed programme for this solution would see completion in 2024. The total cost for delivering the scope of works for the proposed solution is £106.04m.

5.4 Stakeholder Engagement

The Stakeholder Engagement for this project has been carried out and has included meetings and discussions with landowners and the customer. The option to develop Site 1 was adjacent to an aqueduct owned by the customer and meetings were held with the Aqueduct Project Manager in October 2018 to investigate the engineering issues with constructing the extended asset at this location. The output from this fed into the Site Selection exercise which ultimately lead to Site 1 being deselected as an option following the balance of all contributing site selection parameters. Site 4 has been selected as the preferred site and further consultation with the incumbent landowners is underway.

A site selection consultation event for this project was held at Kynachan Hall on 29th August 2019 where the site selection results and early draft design proposals were presented.

5.5 Carbon Modelling

We are committed to managing resources over the whole asset lifecycle – i.e. including the manufacturing of assets, construction, operations and decommissioning activities – to reduce our greenhouse gas emissions in line with climate science and become a climate resilient business. It is our aspiration that the carbon lifecycle cost of investment options plays a key role within our project development and is considered in the selection of a preferred solution. We have therefore developed an internal carbon pricing model that estimates a carbon cost for each option considered in our CBA through deriving values for:

1. Embodied carbon, which relates to the carbon emissions associated with the manufacturing and production of the materials use in production of the lead assets (transformer, reactors, underground cables and Overhead lines. Overhead line is made up of tower/wood pole/composite pole, conductor and fittings) procured and installed as part of the project.

2. The carbon emissions associated with the main stages of the project lifecycle (construction, operations and decommissioning).

It is our vision to embed carbon considerations within our strategic optioneering and project development processes, which will require us to determine a way of flagging high carbon options within our CBA outputs. We will continue to develop our thinking in this space, which will involve our model being validated by a third party, so the results included in this EJP are indicative and subject to change.

Table 8. Carbon Footprint Modelling for the Kinardochy Reactive Compensation project.

	Project Information	Baseline	Option 2
Project Info	Project Name/number	Baseline	Option 2
	Construction Start Year	2022	2022
	Construction End Year	2024	2024
Cost estimate £GBP	Embodied carbon	£ 596,012	£ 947,315
	Construction	£ 2,094,746	£ 2,096,861
	Operations	£ 856,035	£ 1,612,557
	Decommissioning	£ 1,000,736	£ 1,001,746
	Total Project Carbon Cost Estimate	**£ 4,547,529**	**£ 5,658,479**
Carbon footprint tCO2e	Embodied carbon	8,472	13,465
	Construction	29,302	29,332
	Operations	4,180	7,874
	Decommissioning	2,930	2,933
	Total Project Carbon (tCO2e)	**44,884**	**53,605**
Project Carbon Footprint by Emission Category	Total Scope 1 (tCO2e)	4,023	7,718
	Total Scope 2 (tCO2e)	157	157
	Total Scope 3 (tCO2e)	40,704	45,730
SF6 Emissions	Total SF6 Emissions 3 (tCO2e)	3,996	7,690

In line with our sustainability strategy commitments, the carbon impact of the preferred option along with the regional gross value add (GVA) have been assessed for this scheme.

Table 9. Carbon impact and Regional Gross Value Add table showing CBA value impact.

Benefit category	Details	CBA value impact
Whole life costs	The CBA has been carried out based on TOTEX (i.e. includes both capex and opex). Whole life costs have been incorporated into the CBA calculations.	Annual opex is estimated to be £0.08m per year, totalling £4m across the 45-year asset life (undiscounted).
Reduced losses	*Losses have not been included in this draft as the methodology for quantifying losses has not been finalised.*	
Carbon impact – embedded carbon	Embedded carbon relates to carbon emissions associated with the manufacturing and production of the materials procured and installed as part of the project.	The discounted value of embedded carbon is estimated at around £3.5m over the lifetime of the assets.
Carbon impact – carbon displacement	Carbon displacement is determined through allocating a value to the displacement of fossil fuels from connecting new renewable generation.	The estimated annual discounted carbon abatement associated with Glenshero (168MW), Cloiche (200MW) and Coire Glas (612MW) is the region of £70m, according to the Scottish Governments Renewable Electricity Output Calculator[1].
Regional Gross Value Add (GVA)	GVA is a measure of the value generated in an economy by any unit engaged in the production of goods and services. SHE Transmission has developed a tool to quantify the estimated regional GVA on the Scottish economy resulting from expenditure associated with the new generation connections enabled, and the work associated with SHE Transmission investments. Total GVA is calculated by measurements at three levels: 1. Direct GVA: value generated from direct project expenditure 2. Indirect GVA: value generated from employment of sub-contractors and demand for goods and services from suppliers down the supply-chain 3. Induced GVA: value generated from greater demand and spending on goods and services such as accommodation, food, fuel and retail by employees who are employed as a result of the direct and indirect impact.	The total direct regional GVA to the Scottish economy associated with the onshore wind generation projects enabled (Glenshero and Cloiche) is estimated at £8m (discounted over estimated asset life). Indirect and induced GVA totals £9m (discounted). The direct GVA associated with the SHE Transmission expenditure is estimated at £16m (discounted), indirect and direct GVA totals £19m. *(Note Coire Glas GVA not included)*

[1] https://www2.gov.scot/Topics/Statistics/Browse/Business/Energy/onlinetools/ElecCalc

5.6 Competition

The Kinardochy Reactive Compensation project is above both Ofgem's early and late competition threshold at £106.04m. However, as outlined within Section 4 "Optioneering", SHE Transmission has completed an extensive optioneering exercise and the chosen option has been determined as the most economic solution to meet compliance ('the contestability test'). The project is required to maintain compliance with voltage limits section 6 of the NETS SQSS for the increase in generation connections on the wider SHE Transmission network and for the connection of local generation.

In addition, the timescales required to run an effective competitive tendering exercise (including pre-qualification etc) could lead to the over process taking 18-24 months. Whilst this project potentially meets Ofgem's competition criteria, the proposed connection date of local enabling generators, drives the date of this project and as such there is insufficient time in which to appoint an alternative delivery provider.

The project has also been assessed against Ofgem's 'new' and 'separable' criteria for applying late competition. The Kinardochy Reactive Compensation project is flagged as potentially suitable for late competition. This is based on an initial technical and engineering assessment. However, as highlighted above this project is required as enabling works for local generation to maintain NETS SQSS compliance, and as such we believe the project cannot accommodate an 18-24 month delay to run a competitive process.

Finally, and as highlighted within our Competition Strategy, given that Ofgem and the ESO are still at the very early stages of developing potential early and late competitive models, and the absence of the required CATO legislation, significant further work will be required before any decision can be made on the application of any new competition model to these projects.

6 Conclusion

This paper provides justification to establish a reactive compensation substation including a double busbar connected onto the 275kV circuit between the existing Tummel and Braco West substations on the Beauly to Denny overhead line (OHL).

The primary driver for this reinforcement is the load related requirement for renewable generator connections in the local area.

Following optioneering and detailed analysis, the proposed scope of works is:

- Establish a new 400kV GIS substation on the Beauly – Denny 275kV circuit at a site 3km south east of the existing Tummel 275kV substation, Kinardochy substation.
- Equip the substation with 400kV capable GIS switchgear and busbar and operate initially at 275kV.
- Install reactive compensation at the new Kinardochy substation comprising of a STATCOM with a range of +/-225MVAr, and a 100MVAr MSCDN, and operate initially at 275kV.
- OHL diversion works and installation of two terminal towers to turn the Beauly – Denny circuit into Kinardochy substation.

The cost to deliver the preferred solution is £106.04m and the works are planned to be completed in 2024.

The Kinardochy Reactive Compensation project is above both Ofgem's early and late competition threshold. The project is not flagged as suitable for early competition or for late competition, as detailed in Section 5 Detailed Analysis of the EJP.

7 Price Control Deliverables and Ring Fencing

As set out in our Regulatory Framework paper (section 1.12 and Appendix 3) we support a key principle from Citizens Advice – one that guarantees delivery of outcomes equivalent to the funding received - to ensure that RIIO-T2 really deliver for consumers. At the project level this means that if we don't deliver the output, or a materially equivalent outputs, we commit to returning the ex-ante allowance for the output not delivered.

This means that if the funding for Kinardochy Reactive Compensation project should be ring-fenced and if it does not go ahead, we will return the allowances £106.04m in full (minus any justified preconstruction expenditure).

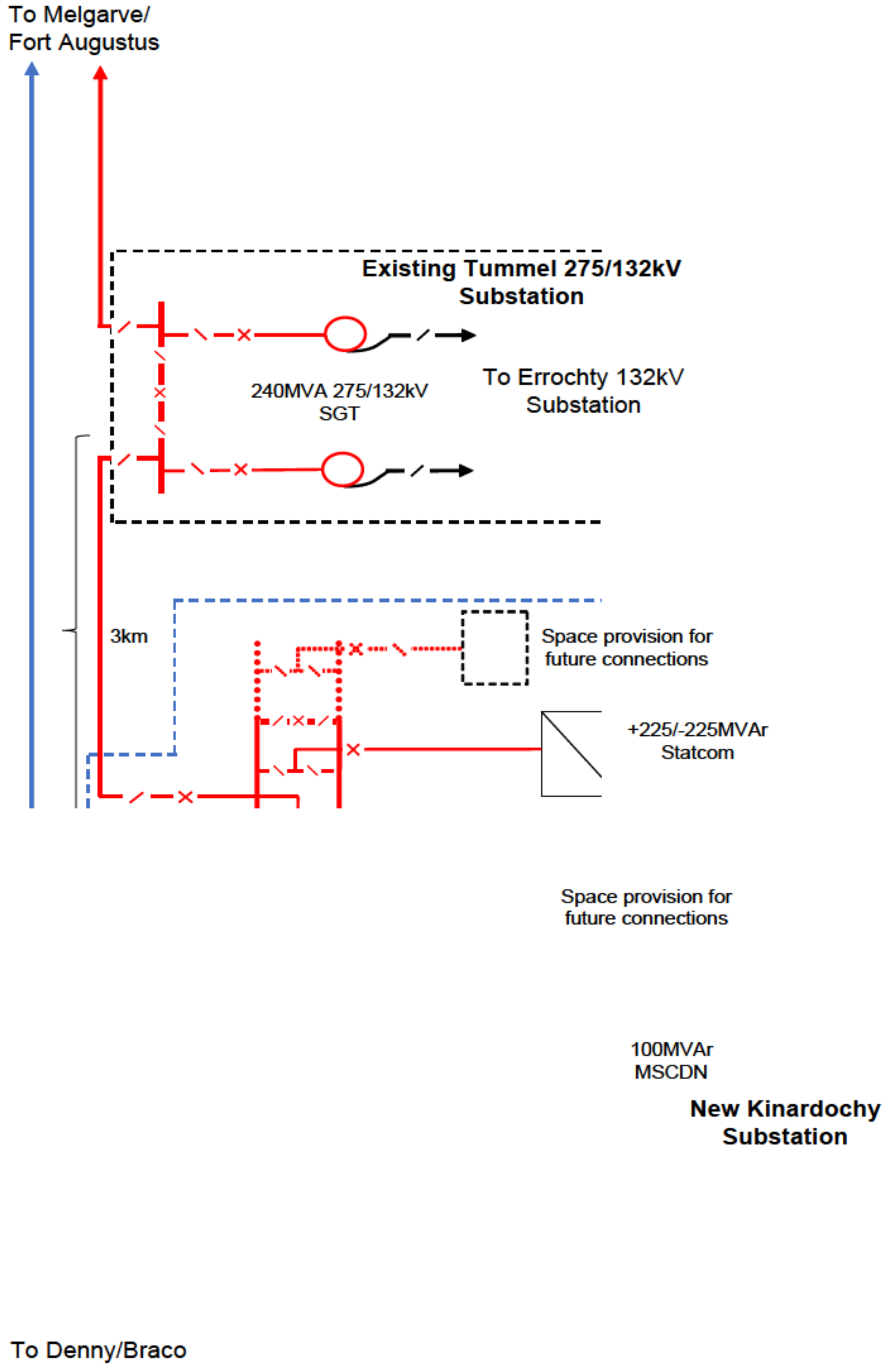
It also means that we commit to delivering +325/-225MVAr of reactive compensation for the costs of £106.04m. If we do not deliver that +325/-225MVAr of reactive compensation, or a materially equivalent output, we commit to returning a proportion of the ex ante allowance. The detailed methodology should be decided at when developing the Close Out methodologies but should apply the same principles of uncertainty mechanisms - that any under delivery should be material.

8 Outputs included in RIIO T1 Business Plan

There are no outputs associated with this scheme included in our RIIO T1 plans.

Appendices

APPENDIX A: Kinardochy Substation Proposed SLD



APPENDIX B: NGESO Statement of Support

[redacted]

From: [redacted]
Sent: 29 November 2019 11:22
To: [redacted]
Cc:
Subject: [EXTERNAL] EXT || 275 kV Reactive Power Compensation on the Beauly Denny circuit

WARNING: this email has originated from outside of the SSE Group. Please treat any links or attachments with caution.

[redacted]

[redacted]

We understand you are looking for a statement from ESO regarding 275 kV Reactive Power Compensation on the Beauly Denny circuit. Our initial views are:

1. If it has been identified as an enabling works for a few contractual generation connections, then it will be your TO's call to plan the delivery to ensure our future network operation are compliant with SQSS with the consideration of any uncertainly in customer connection process.
2. From voltage regulation perspective, we have done a preliminary system study, we can see under certain generation scenarios including the existing and contractual ones in that region, when exporting a credible level of generation from the north west of Scotland, especially with 400 kV circuit outages between Fort Augustus and Denny, the system operation would benefit from the reactive power support from this new Reactive Power Compensation.

Trust it helps, please do let us know if you need more information or have any question.

Thanks.

[redacted]
Network Performance and Risk Manager
Networks
Electricity System Operator
nationalgridESO

[redacted]