Pentland Firth Tidal Energy Project
Grid Options Study

Prepared for:
Highlands and Islands Enterprise

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Executive summary

This report examines the grid connection works required to connect 1,000MW to 1,700MW of marine energy in the Pentland Firth by 2020. The focus is on the local grid works required to connect and transport the energy to the wider transmission system rather than on the wider system itself. In broad terms the targets are found to be challenging but achievable.

The marine energy resource is located in the Pentland Firth between Orkney and mainland Scotland and the existing grid in the immediate vicinity is poor, being limited to 11kV lines with some 33kV grid further away. The existing 132kV transmission system approaches as close as Thurso. All in all this leaves the area poorly served by suitable grid infrastructure.

Even with upgrades, the existing distribution grid cannot accept more than around 26MW. This is limited locally by voltage and thermal issues on lines and at substations. The connectable capacity can be extended through the use of innovative practices such as generator constraint and voltage control allowing access to non-firm grid capacity. Together with an upgrade of a key line to Gills an estimated 145MW can be connected by around 2013.

To extend the capacity further requires new lines and substations. To achieve 1,000MW by 2020 is possible by new grid infrastructure on the mainland only. For 1,700MW it appears necessary to take 132kV grid infrastructure to Orkney. In all scenarios it is difficult to develop eastern resource areas without major new lines across the region – a scenario which is likely to be difficult from a consenting perspective. A possible future DC link to the north east mainland coast from the Moray coast offers a potential solution however.

In assessing grid options XE has paid note to environmental sensitivities, offshore conditions (particularly harsh in the Pentland Firth), likely locations for marine energy projects, the limited opportunities for beach landings of cables and minimisation of the overall impact of new build grid infrastructure.

In regards to Orkney, whilst expensive to develop new subsea cable routes to and grid infrastructure on the islands, this does offer connection options for the northern Pentland Firth, some potential for strengthening island supplies, potential for other generation interests and the potential to open up a mainland-Orkney ring system.

Total grid development costs are estimated at £150-435 million depending on the scenario of which around 7-25% is directly chargeable to the projects. Individual connection costs at distribution level are from around £150k upwards with an annual use of system charge of up to £5.52 per kW per annum. At transmission level, connection costs can be low (around £150-250k per project) but incur annual use of system charges of £22.26 per kW per annum on the mainland up to an estimated £40-50 per kW per annum offshore or £61 on Orkney.

Change to the regulatory frameworks is required to facilitate access to the wider transmission system, is ongoing and it looks possible that wider transmission system capacity will become available. The regulatory frameworks are also important if transmission charges are to be moderated. Participation is important for Pentland Firth marine generators.

Key local grid issues are how the more major grid work will be set in motion early enough to give timely delivery after smaller projects have made use of the limited existing system and how requirements will be coordinated to allow a cost efficient and targeted set of grid works rather than an ad hoc delivery on demand.

A general summary is contained in Section 8 with recommendations in Section 9. The following Figure 1-1 provides a graphic overview of the grid options.

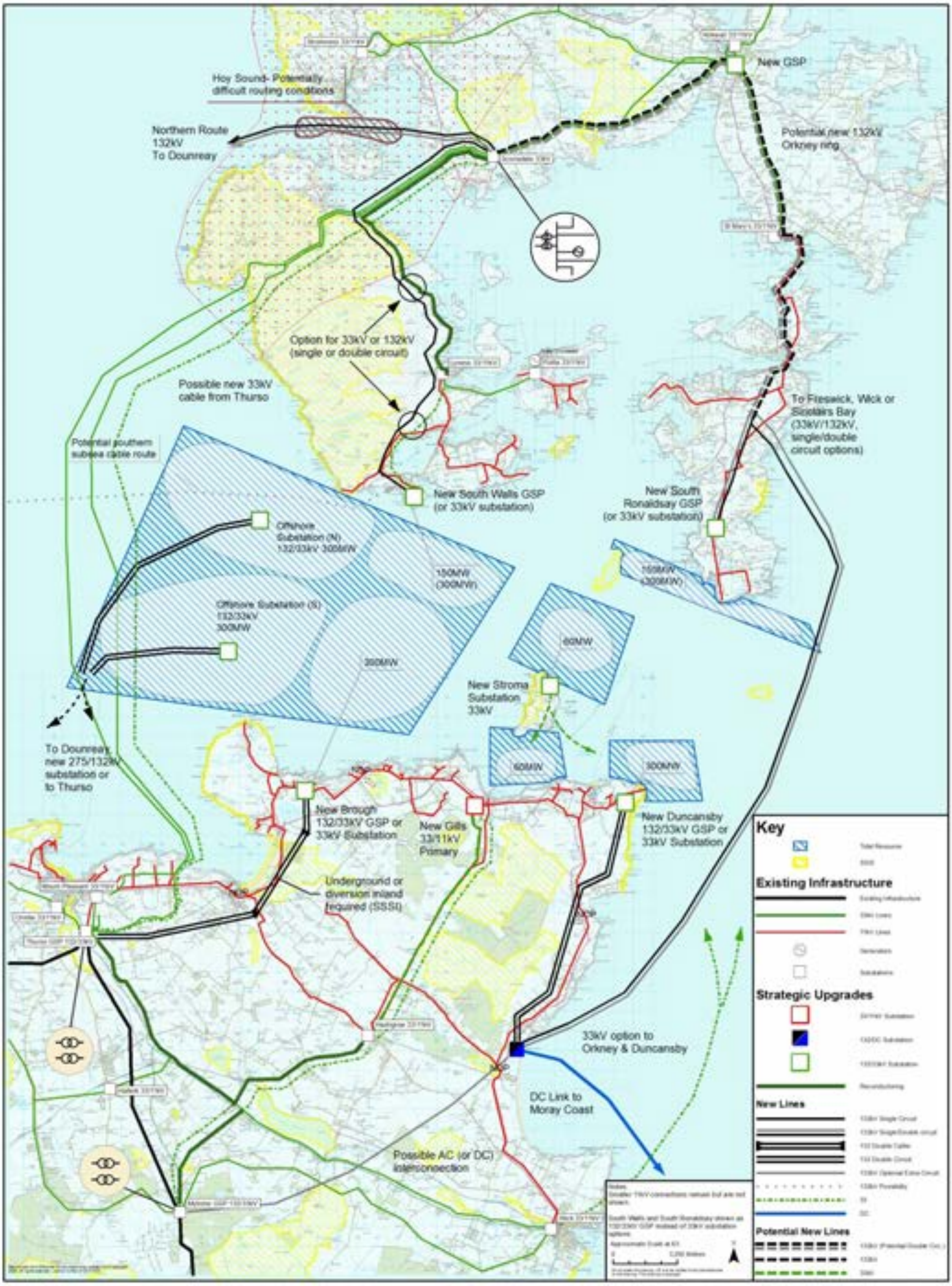

Figure 1-1: Overview of grid options for Pentland Firth marine energy

Glossary

Acronym	Full term
AC	Alternating Current
BERR	(Department of) Business, Enterprise and Regulatory Reform
BWEA	British Wind Energy Association
CAES	Compressed Air Energy Storage
CAP	CUSC Amendment Proposal
COWRIE	Collaborative Offshore Wind Research Into the Environment
CUSC	Connection and Use of System Code
DC	Direct Current
DECC	Department of Energy and Climate Change
DEFRA	Department for Environment, Food and Rural Affairs
DNO	Distribution Network Operator
DSM	Demand Side Management
DVAr	Dynamic reactive compensation system
EC	European Commission
EMF	Electro-Magnetic Field
EU	European Union
FREDS	Forum for Renewable Energy Development in Scotland
GB	Great Britain
GSP	Grid Supply Point
HIE	Highlands and Islands Enterprise
ICRP	Investment Cost Related Pricing
IVR	Inline Voltage Regulator
MESPG	Marine Energy Spatial Planning Group
NaS	Sodium Sulphur
NiCd	Nickel Cadmium
NOP	Normally Open Point
OFGEM	Office for Gas and Electricity Markets
OFTO	Offshore Transmission Owner
ONAN	Oil Natural Air Natural
RPZ	Registered Power Zone
SAC	Special Area of Conservation
SCADA	Supervisory Control And Data Acquisition
SEA	Strategic Environmental Assessment
SHEPD	Scottish Hydro Electric Power Distribution
SHETL	Scottish Hydro Electric Transmission Limited
SPA	Special Protection Area
SQSS	Security and Quality of Supply Standard
SSSI	Site of Special Scientific Interest
TAR	Transmission Access Review
TNUoS	Transmission Network Use of System
TO	Transmission Owner
UK	United Kingdom
WG	Working Group
XE	Xero Energy Limited

1 Introduction

1.1 General

This report has been written by Xero Energy (XE) on behalf of Highlands and Islands Enterprise (HIE) to provide guidance on grid connection of marine energy projects in the Pentland Firth area.

The Pentland Firth region is one of the most powerful marine energy resources in Europe, notably for tidal energy. It is bounded by the Orkney Islands and mainland Scotland. Resource estimates for wave and tidal vary from 150MW up to 1,000MW in the Scottish Government‘s Marine Renewables Strategic Environmental Assessment although a 1,837MW target appears to be a commonly quoted figure as the total available capacity. In truth, the resource, its environment and the issues in exploiting it are complex and probably still not very well understood. Whatever the resource, it is a key area of interest for tidal development and one the region wishes to capitalise on. Wave energy is also of interest to this study but less so and tends to be more important to the fringes of the Pentland Firth and further afield.

The Scottish Government has set a target that 50% of Scotland‘s electricity (as a proportion of whole demand) should come from renewable sources by 2020, with an interim target of 31% by 2011. It is estimated that the 2011 target will require around 5,000MW of capacity to be installed and recently, First Minister Alex Salmond has described the Pentland Firth as the ‗powerhouse‘ of Scotland [1].

In addition, the United Kingdom (UK) Government has agreed with the European Union to provide 15% of its total energy (electricity, heat and transport) from renewable sources by 2020. The UK‘s 15% target means that by 2020 around 40 per cent or more of the UK‘s electricity must come from renewable energy sources. It is estimated that approximately 20% of the UK electricity demand could be provided by marine energy sources.

A proposal has been put forward within the Scottish Government to revise the current Renewables Obligation (Scotland) to include greater incentives for marine energy [2]. Under the new regime an electricity generator would obtain five Renewable Obligation Certificates for each MW of installed wave capacity and three for each MW of tidal capacity. This proposal would strengthen the marine sector and would attract more investors.

In addition, The Crown Estate has announced a round of leasing opportunities for a defined area of the Scottish seabed called the Pentland Firth Strategic Area [3]. This includes an area around the Orkney Islands, the Pentland Firth and a coastal area along the North Sutherland coast. The Crown Estate is currently seeking expressions of interest with a closing date of April 2009. Developments in the Pentland Firth area will thus commence in earnest shortly.

Much of the regulatory structure that unpins the marine sector development in the Pentland Firth flows from the Scottish Marine Bill [4], which ties in closely to the Marine and Coastal Access Bill from the Department for Environment Food and Rural Affairs (DEFRA) [5].

The region itself has a strong history in marine technology and renewable energy developments. Apart from various wind, wave and tidal projects at various stages it already supports the Environmental Research Institute in Thurso, the International Centre for Island Technology in Stromness and the European Marine Energy Centre in Orkney. Regional socio-economic development is an important issue and development of marine energy offers many potential opportunities from manufacturing through to construction and operation. Not only this, but Scotland is seen as a world leader in marine energy and there is a will to maintain and capitalise on this position.

1.2 Grid related background

Development of the marine energy potential of the Pentland Firth area will be critically dependant on the availability and creation of grid capacity.

1. A first tranche of small projects is likely to be connectable using the existing grid with some minor works. These will make use of the existing 11kV and 33kV networks but be bound by the capability and location of the grid.

2. A second tranche will extend the usability of the existing grid by innovative and proactive measures such as generation and grid management through Renewable Power Zone (RPZ) type measures and limited reinforcements.

3. Building on the above will be a third tranche taking advantage of strategic reinforcements and extensions of the grid.

4. Ultimately, larger scale developments are likely to take advantage of transmission developments to the region specifically for the projects, together with other transmission work to facilitate transport of energy away from the area.

Each of the stages will take progressively longer to realise and in keeping with this will release progressively more MW capacity. In the same way as the proposed marine energy development scenarios ramp up capacity with increasing acceleration, so do the natural and progressive stages of grid development and connection.

Despite the above, it is a fact that at the time of writing and for the immediately foreseeable future the contracted queue of generation in the North of Scotland is more than can be accommodated by the grid as currently planned for upgrade. New applicants for connection are in general now being given connection dates of “beyond 2018”.

All developments in the Pentland Firth, virtually irrespective of size, will therefore be critically dependant on the developing regulatory regimes for onshore and offshore transmission and distribution, the movement and management of the queue of generation for connection, the progress of transmission and distribution reinforcement works and commercial understanding of the strategies required to achieve connection.

Despite its overarching importance, the development of the wider transmission system and regulatory regime is largely outside the scope of this report. Some comment is however made on regulatory issues in Section 6 and wider transmission developments in Section 5 with a view to establishing whether capacity will become available to Pentland Firth projects on the wider transmission system and if so within what timeframe.

This report focuses more locally on the mainland and Orkney region around the Pentland Firth in terms of grid with the aim being to connect projects to the local grid and ensure there is a path back to the wider transmission system. This in itself is a challenge. Access into the wider transmission system is clearly also a challenge but only partly within control of Pentland Firth projects and hence is not the key focus of this work.

1.3 Development scenarios

HIE has, as a result of discussions with the marine energy industry from February to July 2008, produced two scenarios for development of tidal energy in the Pentland Firth. The scenarios are intended to reflect the potential growth in marine energy developments in both tidal and wave technologies from small devices, through progressively larger projects to major developments over longer timeframes to 2020 and beyond.

The scenarios were developed prior to The Crown Estate announcement of sea bed leasing focussed on the region which may mean that the level of interest, particularly in the early stages, is higher than given in the scenarios. It should also be noted that The Crown Estate has defined a 10MW limit for the initial pre-commercial arrays and subsequent bands of scheme sizes up to 300MW for commercial arrays. This was not known at the time of the scenario development although this may not restrict the ambitions of project developers.

Initial developments in the scenarios include single devices, probably around 0.5 – 1MW. Such projects are already under development and are an essential part of prototyping and proving technology for increasing scales of development.

Small arrays in the order of 5 – 10MW will likely follow, reflecting the need for understanding of array engineering, performance and economics. This is expected to lead on to larger arrays, followed by major projects over much longer timeframes.

The 10MW upper bound reflects the limit at which a project is currently termed a Large Power Station and bound to strike an agreement with the transmission system operator regardless of whether it is distribution connected or not.

It is expected that single devices and small arrays will be located close to the mainland and Orkney shores with major projects, and possibly large arrays, located further out in areas such as the channel between Stroma and Swona. The following definition of scheme size has been identified by HIE and used by XE in this study.

- Single device—typically 0.5 - 1MW
- Small array—typically up to 10MW
- Large array—typically up to 30MW
- Major project—greater than 30MW

The following tables present development scenarios to 2020 of 1,000MW and 1,700MW as provided to XE by HIE. These are the scenarios that this grid study considers.

Year	Total installed to year end, MW		Description of possible device arrangements installed in period
	Annual	Cumulative	
2009	12	12	1 x 2 + 2 x 5
2010	30	42	2 x 5, 2 x 10
2011	30	72	2 x 5, 2 x 10
2012	30	102	2 x 5, 2 x 10
2014	80	182	1 x 30, 1 x 50
2016	118	300	1 x 30+, 1x 50+
2020	700	1000	5 – 10 x 50+

Table 1-1: Marine energy development – 1,000MW development scenario

Year	Total installed to year end, MW		Description of possible device arrangements installed in period
	Annual	Cumulative	
2009	12	12	1 x 2 + 2 x 5
2010	30	42	2 x 5, 2 x 10
2011	40	82	4 x 10
2012	100	182	2 x 50
2014	400	582	2 x 50, 2 x 100+
2016	400	1000	2 x 50, 2 x 100+
2020	700	1700	5 – 10 x 50+

Table 1-2: Marine energy development – 1,700MW development scenario

1.4 Scope of study

In general terms the scope of this study is to take the current grid in and around the Pentland Firth and apply successive tranches of generation developments to grid connection, development, innovation, and strategic reinforcement to deliver the marine energy development scenarios as outlined in Section 1.3. This loosely means achieving connection of a few tens of MW in the next two to three years to 2011/12, a few hundred MW by around 2015, and at least 1,000MW by 2020.

The main sections of this report that describe the work undertaken and how the marine energy development scenarios may be achieved in terms of grid connection are as follows:

Section 1 Introduction (this section).

Section 2 Background studies
A review of existing reports, studies, and workstreams to understand the historic and ongoing frameworks that the grid options study and the development of marine generation in the Pentland Firth region must develop from, the resource location and physical constraints.

Section 3 Existing grid
A study of the existing grid to identify opportunities for single devices and smaller arrays over short time horizons where issues with major grid upgrades and consents can largely be avoided.

Section 4 Extension by innovation
An investigation of the various innovative practices that can be applied to the marine generation and the grid to obtain further increments in capacity.

Section 5 Strategic reinforcement
A view of the strategic transmission and distribution system upgrades and extensions that can be undertaken and that involve longer timeframes, more risk, higher consenting issues, more cost, BUT will be required to significantly develop the resources of the Pentland Firth region.

Section 6 Regulatory review
A review of the existing regulatory system and the potential future changes that will be an essential part of freeing up and creating capacity for projects.

Section 7 Blueprint
All of the preceding sections are collected together in this section to create a connection options blueprint for the delivery of Pentland Firth marine energy.

Section 8 Summary
This section presents a general summary of the report with conclusions.

Section 9 Recommendations
This section sets out specific recommendations on how the grid work can be implemented to facilitate the development targets (the blueprint) and on the further work that is required.

2 Background studies

2.1 Introduction

This section provides a summary of relevant data from reports forming the background to HIE‘s Pentland Firth Tidal Energy Project and indeed a background to this report concerning grid connection.

To be able to gain an understanding of the context surrounding project development within the Pentland Firth region, XE undertook an investigation of existing studies and reports that pertain to exploitation of the resource and the physical and environmental constraints in and around the area. This task was conducted to develop an understanding of what grid works would or wouldn‘t be possible from an environmental standpoint, which regions of the seabed and land needed to be avoided, to better understand the various risks to grid works, and to define the offshore development regions within the Pentland Firth where grid works would need to facilitate project development and power off-take.

The background study review looks at a number of papers ranging from regulatory to early feasibility to technical studies. The scope of the background study also takes guidance from various political sources (including Scottish Government targets, The Marine Supply Obligation, etc), although does not explicitly review the documents in detail. A brief summary of these is contained within the introduction of Section 1.

The summary of this background study work concludes that there are a number of physical and environmental constraints that will dictate, constrain and lead much of the onshore and offshore grid works needed for marine renewable development. XE has also reported separately to HIE with a more detailed and wider ranging report on the issues [6].

It is worth noting that the Scottish Government‘s Marine Renewables Strategic Environmental Assessment (SEA) produced in 2007 is by far the most valuable source of information for this report and this section concentrates on drawing out its key points for this grid study. A brief review of other reports and developments is given in Appendix A.

2.2 Resource development areas

In order to provide some locational context to this examination of requirements for grid infrastructure, and in the absence of any detailed resource assessment of the area, XE has used the SEA [7] as a starting point. The SEA identifies the Pentland Firth as having up to 1000MW of exploitable resource based on high level information in terms on resource assessments and the baseline environment. XE understands HIE has developed scenarios of 1,000MW and 1,700MW based on industry appetite.

XE has then estimated the available capacity in each of the tidal resource regions identified in the SEA (as a percentage of entire Pentland Firth resource based on area). This can be seen in Figure 2-8 and although only a rough estimate is extremely useful in understanding what level of grid infrastructure located where is likely to be required to exploit the developable resource locations.

The westernmost region constitutes around 80% of the resource by area and may be a major zone for exploitation requiring significant grid infrastructure. Given the targets for 2020 this could mean 800-1,200MW suggesting major new 132kV infrastructure, high voltage developments or even DC. This area is also very significant in that it contains the bulk of the wave energy resource which continues out from the western Pentland Firth.

The other areas are small by comparison but nonetheless represent significant regions which are each likely to be exploitable by strategic grid development at either 33kV or 132kV.

An examination of the Orkney Harbours tidal map [8], which provides a time based prediction of the tidal currents, suggests that it is not clear as to which areas will be most developed as all do show strong tidal currents at different times. Additionally, there are eddies, dead zones and whirlpool effects, all of which are significant and suggest a lot more work is required to understand the resource.

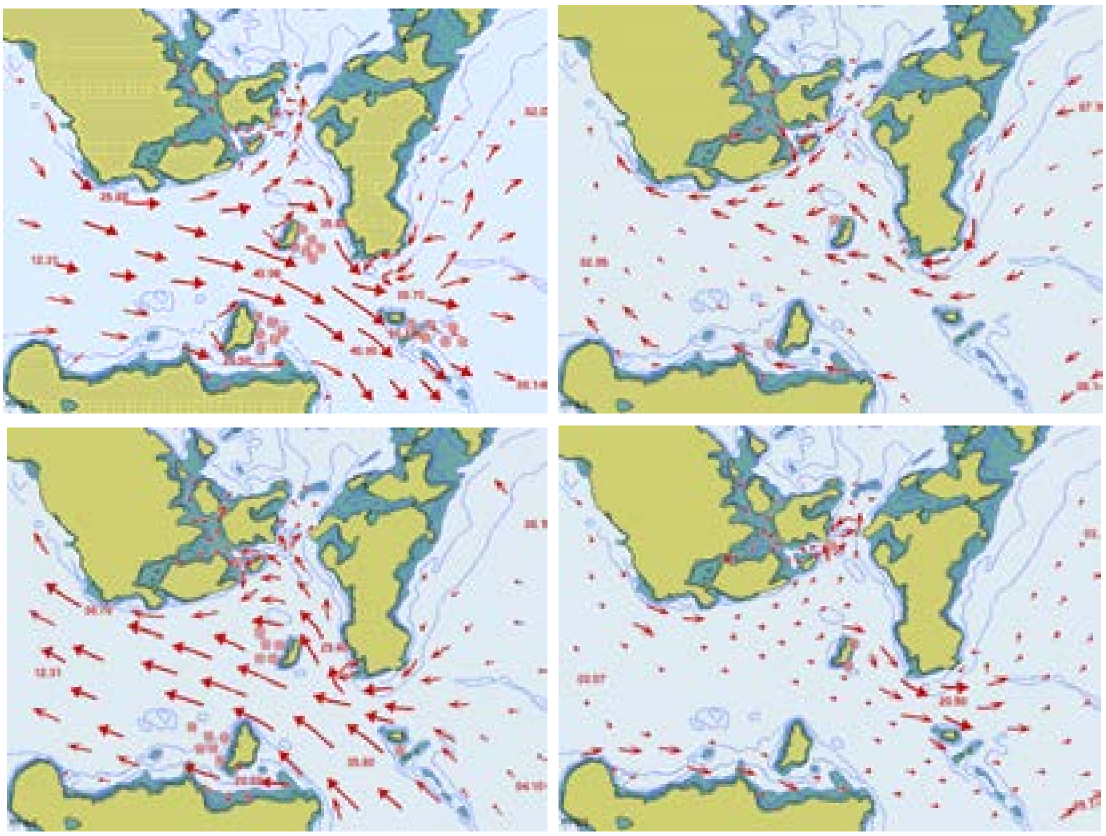

Figure 2-1: Tidal currents in the Pentland Firth (03 November 08) [8]

2.3 Scottish Government Marine Renewables SEA

2.3.1 Introduction

The Marine Renewables SEA [9] that was commissioned by the Scottish Government (published in 2007) looked at the Scottish coastline within 12 nautical miles from the north-eastern tip of the mainland, along the north coast and down the west to the Solway Firth and including the Orkney and Shetland Islands. For the purposes of this report, only the sections of the SEA that discussed relevant aspects in and around the Pentland Firth region are reviewed.

The initial assessment (Section C) carried out in the SEA consisted of an assessment of all the potential factors that require consideration during the site selection for, and development of, marine renewable devices. The SEA report segments that relate to this grid study are reviewed below along with the general constraints model (Section D) that brings together all of the physical and environmental restrictions that limit the total exploitable resource and help define both the development areas of interest and the key considerations of grid developments.

2.3.2 Water depths – working difficulties

Water depth is briefly covered in Section C1 of the SEA under bathymetry [10], see Figure 2-2. Water depth will be an important factor to consider for offshore works - particularly any offshore substations where deeper water will tend to drive costs up. Figure 2-2 identifies a number of items including the tidal resource (light solid green areas), wave resource (green hatched areas), as well as bathymetric lines that provide a rough gauge for water depth in the region. The light grey lines, close to the shore of the mainland and Orkney represent 20m depth while, the blue lines represent 50m depth.

The SEA quotes the water depth through the Pentland Firth as around 60m at a distance of 5-10km offshore which primarily relates to the central channel through the Pentland Firth. As XE later suggests, offshore substations may be desirable so this is an issue worthy of further and more detailed clarification. Locating such a structure in significant water depth will entail significant cost and it will be advantageous to take a view on water depth in consideration of location for key pieces of grid infrastructure.

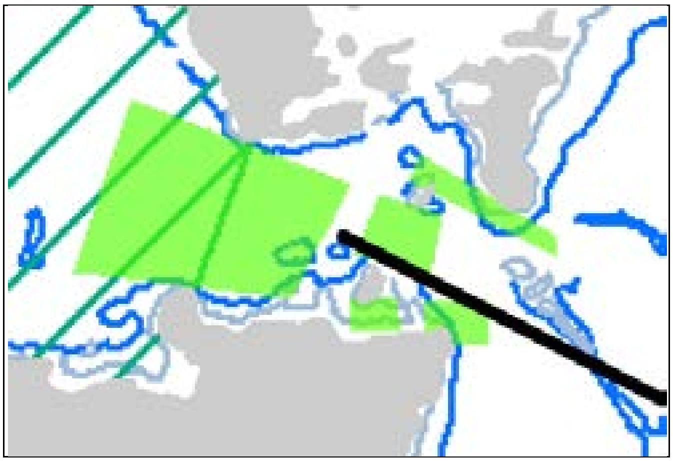

Figure 2-2: Bathymetric chart [10]

⇒ Water depths in the central areas of the Pentland Firth are relatively deep (c. 60m) and will make offshore works difficult and expensive. This area should as far as reasonably possible be avoided.

2.3.3 Geology – cable and structure installation issues

Section C2 of the SEA [11] discusses the geological considerations that relate to marine energy development, Figure 2-3. The authors comment that there are currently no offshore geological conservation sites, however this may change with the finalisation of the Marine and Coastal Access Bill [5]. The geological description of the seabed along the Pentland Firth is as follows:

- There is bare rock and rock outcrops on the seabed along the Pentland Firth where the fast tidal currents have removed surface sediments. The bare rock and rock outcrops are shown as the dark region in Figure 2-3 and are a significant issue making cable installation and protection very difficult and expensive. In addition to cables, foundation installation will require significant works, involving expensive drilling techniques, and locating of offshore structures with significant foundations such as offshore substations, will be an issue.

- The fast tidal currents also point to a natural phenomenon known as scour which occurs around the edges of foundations of seabed installations, and can affect cable burial. This also suggests the installation of structures and subsea cable installation in the Pentland Firth will be a challenge for both project developers and grid works. On the western extremes where wave energy is more important the seabed conditions are more favourable.

- Beaches are small along the coastline with some larger inter-tidal sand flats. These sand flats are likely to be the most attractive options for cable landing on the mainland. Surveys need to be conducted to identify which of these beaches or flats are suitable for cable landing. XE notes there are existing cable landings at Murkle Bay near Thurso, and Rackwick on Hoy (Orkney). Various cables interconnect the Orkney Isles which may be relevant to the development of marine energy sites in the Orkney Islands but are less critical to the Pentland Firth region.

- Between the Pentland Firth and the south of the Orkney Isles the coastline is predominantly rocky and exposed to harsh wave action, both poor conditions for cable landings.

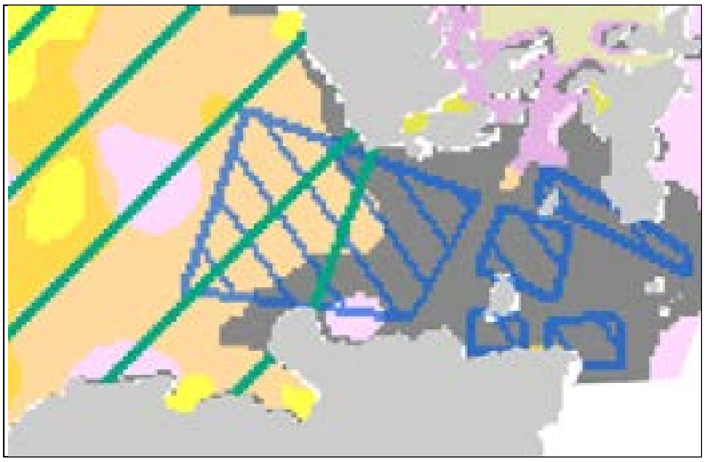

Figure 2-3: Seabed Surface Geology [11]

⇒ Key issues are the identification of scour, rock outcrops, and solid and exposed rock, all of which suggest cable installation is best avoided in the Pentland Firth and establishing offshore substations is likely to be problematical.

2.3.4 Existing cables and pipelines – obstacles

Section C12 of the SEA [12] discusses existing cables and pipelines. Cables and pipelines present obstacles and are sensitive to damage which could result in gas/oil leaks and interruptions to electricity/telecommunications. Therefore the International Cable Protection Committee suggests that offshore wind farms be sited at least 500m from existing subsea cable or pipeline routes. This recommendation has been embraced by the SEA, and in lieu of further study, can be taken forward as the minimum distance required between existing infrastructure and any new tidal/wave devices.

As can be seen in Figure 2-4 there is little existing infrastructure (in green) currently placed within the Pentland Firth (most likely due to the difficult marine conditions along the seabed). Indeed, the key existing cable obstacles are the 33kV grid cables from Thurso to Orkney on the western extremity, thereby avoiding the worst of the seabed conditions. Since the SEA was conducted, new fibre optic cables have been laid between Dunnet Bay, on the mainland, and Skaill Bay, Orkney [13].

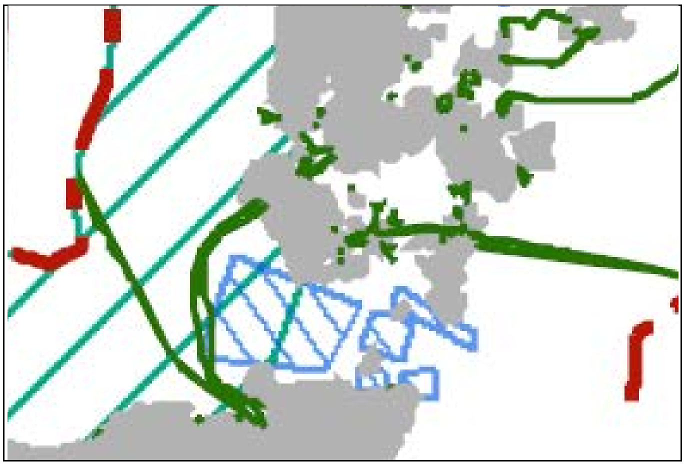

Figure 2-4: Existing cable and pipeline obstacles [12]

Avoiding existing infrastructure should not be difficult as long as adequate separation remains between existing and new installation works and proper mitigation is employed during cable routing. In cases where cables must cross other cables and pipelines, crossing agreements will need to be put in place although XE notes that standard forms are available and commonly used. Crossings will add time and cost but are not a major barrier.

⇒ The key existing cables and pipelines that need to be avoided or approached with caution are the 33kV cables that interconnect Thurso with Orkney.

2.3.5 Shipping and navigation

The Pentland Firth is an identified region with a large volume of offshore traffic shown in Figure 2-5. With high vessel density along the Pentland Firth, the deployment of wave or tidal devices and offshore substations would increase the risk of collision. Main shipping lanes affect all of the resource areas, cutting some of them in half.

Fishing activity as well as anchoring from shipping, ferries and other sea users all present risks to subsea cables. XE suggests that cable burial will need careful examination in this respect and indeed when considering other factors in and around the Pentland Firth. The impact that tidal and wave device deployment has on navigational risk must be considered, particularly in this region of high vessel activity. Consultation with the Maritime and Coastguard Agency would be advised in this respect.

Shipwrecks are not discussed in any length in the SEA but are also shown on Figure 2-5 as dots. There are numerous shipwrecks to be avoided. This can be ensured by adequate use of charts and surveys and should not be a major issue.

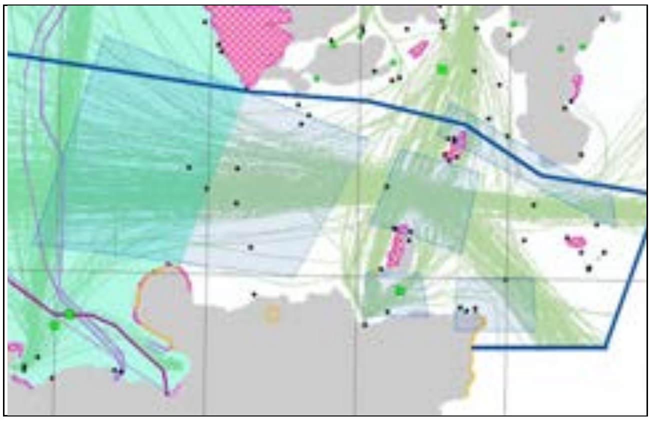

Figure 2-5: Shipping and shipwrecks [7]

⇒ Vessel activity is a key factor through the Pentland Firth and main corridors are probably best avoided. Shipping, fishing, ferries and other sea users presents risks of collision hazard with structures and risks to cables from anchoring and other activity. Cable burial will be an important consideration.

⇒ The impact on navigational risk from device deployment must be assessed as part of any project environmental assessment. Particularly for projects located in the Pentland Firth.

2.3.6 Electromagnetic fields (EMFs)

Section C18 of the SEA [14] is based largely on the Collaborative Offshore Wind Research Into the Environment (COWRIE) investigations into the effect of electromagnetic fields on fish [15] [16] [17]. The general conclusion from the reports cites there are several different species of fish in the UK that are affected by artificial EMFs in various ways from the cellular to the behavioural level. The impact on most electro-receptive fish and mammals is minimal or non-existent however.

There is some mitigation that may be required to avoid any adverse impact of artificial EMFs on a number of sensitive species. The suggested mitigation methods include:

- Transforming the generated power from 33kV to 132kV hence reducing the current carried through the subsea cables, and in turn the electromagnetic fields.

- Burying the cables to a depth of 1m below the seabed to mitigate the impact of some of the most intense magnetic fields (and induced magnetic fields).

- Armouring submarine cables with permeable material and installing cable sheath with high conductivity which is shown to reduce the electromagnetic field strength outside of the cable.

Given the above comments, and that new 11kV, 33kV and 132kV cables will be required, EMF's do warrant consideration. However, burial is often, where possible, specified to 1m or more and armouring and sheaths are common, particularly in areas of risk such as the Pentland Firth. XE suggests that EMFs are not therefore likely to be a major issue.

⇒ Cable specification for works in and around the Pentland Firth can, and most likely will, help mitigate EMF issues to a large extent and this is not likely to be a significant limiting factor.

2.3.7 Onshore issues – environmental designations

Section C20 of the SEA assesses the visual and ecological impact (amongst other factors) of the necessary (grid) works [18]. The most significant consideration for onshore grid work is conservation areas (Sites of Special Scientific Interest (SSSIs), Special Areas of Conservation (SACs), Special Protection Areas (SPAs), etc), Figure 2-6. These regions are effectively ‗no-go' zones for onshore grid works, or at least very sensitive, and therefore they will act as fundamental limitations to any cable or line routing and major issues for consenting.

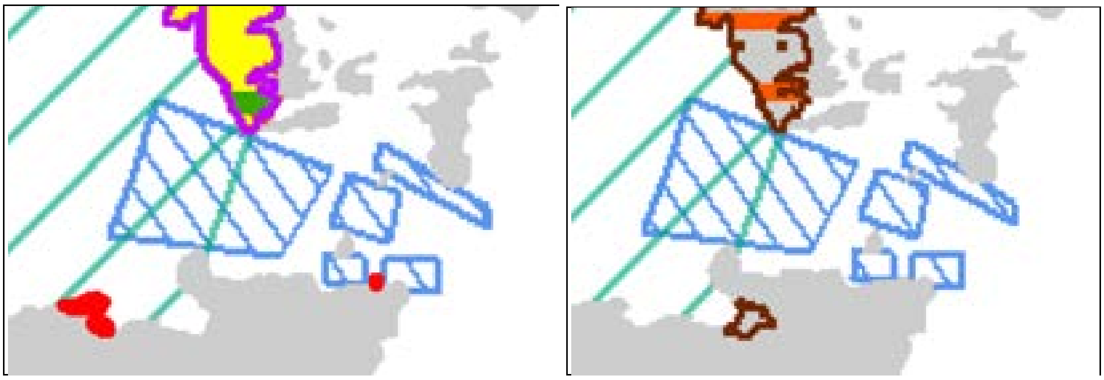

Figure 2-6: Environmentally designated sites [11]

The SEA conclusion from Section C20 is that if alleviating measures are employed then the impact on most environmental aspects is minimal. In undertaking this work XE has paid note to the Holford rules (as mentioned in the SEA) in attempting to minimise consenting issues at reasonable cost. XE has kept all new lines, where possible, to wood pole constructions and notes that undergrounding is possible at additional cost. Some new infrastructure is unavoidable and new substations are required as well as modifications to existing sites.

XE also notes that other onshore areas also contain conservation designations and XE has included these in its own summary Figure 2-8, although these were not included in the SEA.

Scottish Natural Heritage produced a consultation in the summer of 2008, proposing to extend the current ‗North Caithness Cliffs' SPA designations offshore by 2km [19]. This proposal may impact cable routing or project positioning for marine renewable developments in the Pentland Firth. This proposed extension is not included in Figure 2-8.

⇒ Onshore conservation areas exist in and around the Pentland Firth and will need consideration (avoidance) in routing new lines and establishing new substations.

⇒ To reduce impact XE has given consideration to wood pole overhead lines only and notes undergrounding is also possible at additional cost. Upgrades allowing maximum use of existing infrastructure have been considered and new substations kept as far as possible to a minimum by creating connection hubs around the coast rather than many smaller connections.

⇒ Other designated areas exist and constrain works, shown in XE‗s Figure 2-8.

⇒ Future changes to marine SPA designations may impact cable routing and/or project locality.

2.3.8 Onshore issues – geological interest areas

Section C2 of the SEA identifies the regions on land that are protected for their geological interest, Figure 2-7. The report concludes by suggesting the most appropriate mitigation method for sites of special geological interest is to avoid them completely, therefore having obvious implications for onshore cable routing and landing. If avoidance is difficult then the crossing means is important and disturbance or destruction is the critical issue to be avoided.

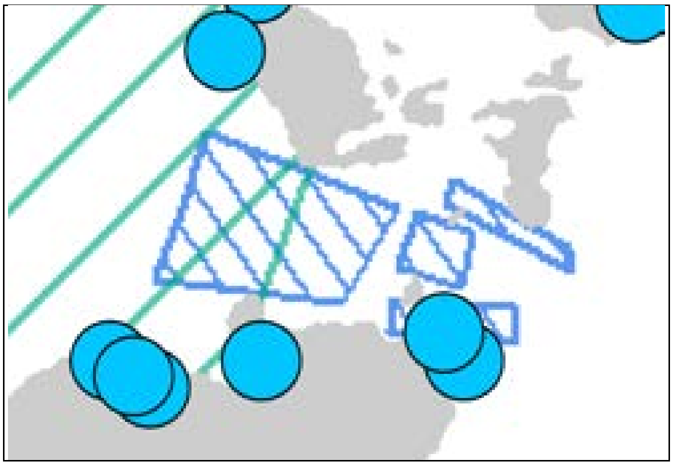

Figure 2-7: Confirmed geological interest areas [11]

⇒ Additional issues are encountered environmentally by crossing special geological interest areas.

2.3.9 Offshore structures - visibility

According to the SEA it is considered a major issue to have structures surfacing and rising 10m above sea level between 0-5km offshore and a moderate issue to have them 5-10km offshore. As XE has considered offshore substations this will be a factor in their design and consenting although probably not a barrier.

⇒ Offshore substations will be visible from shore and hence visual impact will be a consideration in their design although probably not a critical factor.

2.4 Marine Energy Spatial Planning Group

Ongoing work by The Marine Energy Spatial Planning Group (MESPG) is seeking to produce an integrated framework for the marine sector based upon the production of the following.

- Locational/planning guidance.
- Streamlined regulation.
- Scientific and environmental research (to better understand the interface between new technologies and the marine environment).

Activities based around anticipating consenting issues and establishing streamlined consenting guidelines will support and accelerate the sustainable development of the marine renewables industry for Scotland.

Through the activities of MESPG, the Scottish Government intent is to further the work done in the SEA by producing a route map that will inform the wider actions set out below.

- **Research and Data Gaps.** MESPG will establish research priorities, identifying the data and knowledge gaps which need to be tackled and the most appropriate means of doing so.
- **Monitoring.** The Group will establish guidelines for monitoring the effects of wave and tidal devices in the environment.
- **Strategic Locational Guidance.** The Group will commission a detailed analysis and map of the marine resource.
- **Environmental Impact Assessment.** The Group will offer comment on the production of guidance for developers on the compilation and scope of project level EIAs.
- **Mitigation.** The Group will consider number of possible ways in which the effects of marine devices on the environment might be mitigated, as identified by the SEA.
- **Grid.** The Group will ensure that issues affecting marine development specifically are considered fully and properly.

2.5 Section summary

Having reviewed documents ranging from early feasibility studies to technical studies, XE has been able to draw a number of conclusions. A summary of the key details that relate to the Pentland Firth and are relevant to this study are outlined below with reference to XE's Figure 2-8 (overleaf) which draws all the issues together along with (a non-exhaustive survey of) additional onshore designations. The issues and constraining factors that have been identified from this review can be separated into four different areas: project/resource location, offshore conditions, cable landing issues and environmental constraints.

2.5.1 Project resource and locations

No background work examined states how much tidal resource can be developed in any one location in the Pentland Firth. Therefore, XE has taken a view on the most likely areas of development for the purposes of analysis. The region of identified capacity is based largely on knowledge of shipping lanes [20] and conservation areas [11] as well as the identified tidal resource [7]. XE has concluded that there are five distinct areas that could provide development opportunity for tidal stream devices (see Figure 2-8) and has indicated potential resource according to area. For wave energy the western extremities of the Pentland Firth are more important and this starts to pick up on the westernmost resource area.

2.5.2 Offshore conditions

Much of the seabed through the Pentland Firth is a hard rocky surface, hence subsea cable burial/protection and offshore substation installation will be very difficult and expensive compared to more favourable conditions such as sand and gravel. On the eastern and western edges of the identified tidal resource [7] the subsea surface is described as ‗gravelly sand' or ‗sandy gravel'. Installation work would be easier in these regions, although any development would have to avoid other cables in the same area. The westernmost region becomes increasingly important for wave energy, suggesting installation works would be easier than for the key tidal energy areas. Water depth reaches 60m at 5-10km offshore presenting additional costs for installation works due to depth and challenges for offshore substations.

2.5.3 Cable landing

For cable landing, sheltered sand bays are not readily available in and around the Pentland Firth area. Apart from standard maps, no literature has been reviewed that documents the coastline along the north east coast of mainland Scotland or southern coasts of the Orkney isles. Some potential landing sites for cables appear evident but it is recommended that this information is obtained through a thorough survey of the coast.

2.5.4 Environmental constraints

There are areas around the coast where a submarine cable landing can be assumed difficult, if not impossible, due to environmental designations, as shown in Figure 2-6 and Section C2 of the SEA [11]. Therefore, these areas have been effectively excluded from consideration for grid cable routes. Figure 2-7 shows areas of geological interest where works would be very sensitive. However, the Geological Review Site specification is somewhat ambiguous and needs confirmation. In addition to these coastal areas are onshore environmental designations, also a constraining factor on routes and substation locations.

2.5.5 Note on grid issues

As a final point of note, all of the documents that have been reviewed indicate that grid capacity is one of, if not *the*, major hindrance to the exploitation of commercial scale marine energy. This concerns both the regulatory regime and the physical capability of the grid itself. These issues are already well understood by XE and commented on in this report.

2.5.6 MESPG

The MESPG will be an important coordinating body for marine energy and will need to be involved in further work and ongoing processes. The MESPG is currently progressing work on the Marine Spatial Plan for the region.

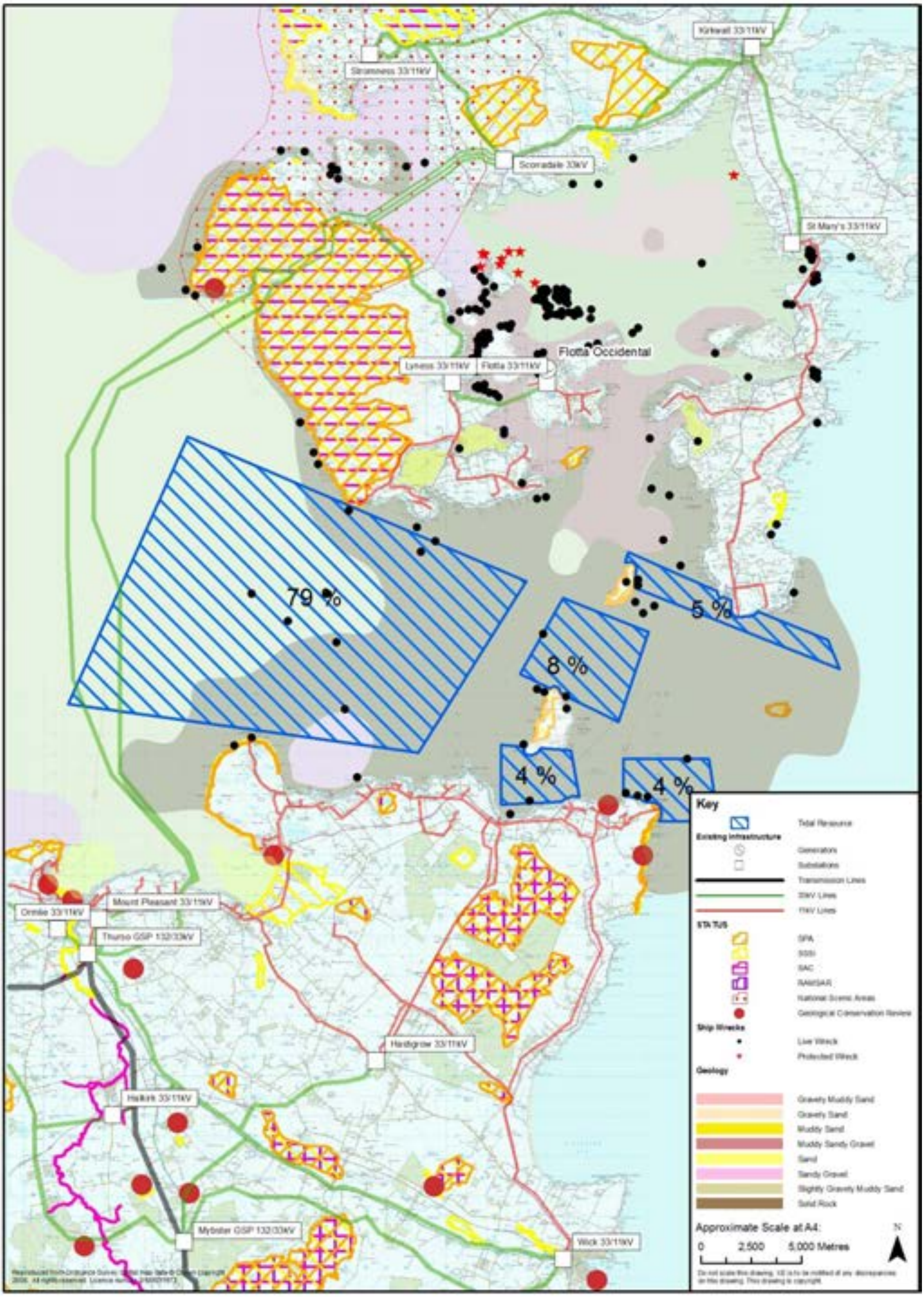

Figure 2-8: Physical and environmental constraints map of the Pentland Firth with resource

2.5.7 Recommendations for further work

Even with the existing reports and assessments that are currently in the public domain, there is still a considerable amount of detailed analysis work that is required to ensure that stakeholders in the Pentland Firth can move forward confidently in developing the region for marine renewables. Below is an outline list of recommendations for further work that is required to help develop marine renewables (and onshore and offshore grid works) in the Pentland Firth region.

- Detailed bathymetry report of the Pentland Firth
- Detailed investigation of tidal resource.
- Detailed geological assessment of the coastline and seabed along the Pentland Firth.
- Survey of suitable cable landings – north coast of the mainland and southern coast of Orkney Islands.
- Comprehensive shipping/navigation risk assessment.

Many of these assessments may be carried out by individual project developers. However, considering the initial phase of development is focused on single demonstration devices, developers may not have the resources to complete such studies. The MESPG is likely to be an important stakeholder in helping to coordinate and progress the above recommendations.

3 The existing grid

3.1 Introduction

This section of the report reviews the existing grid with a view to identifying opportunities for single devices (0.5 – 1MW), smaller arrays (c. 10MW), and, if possible, larger arrays (up to 30MW). This initially considers the existing grid as is, then extends the analysis to relatively minor local upgrades but not distinct new infrastructure (covered in the strategic review of Section 5). This limited approach is undertaken to keep costs, works and issues with consents as low as reasonably possible and timeframes short for these small projects.

The review examines:

- The locality of the existing transmission and distribution grid in relation to likely project locations and the coast.

- Planned and possible future developments.

- Likely connection points for Pentland Firth projects, available capacity and related issues, notably cost, timeframes and consenting.

In assessing potential connection points XE has undertaken a technical analysis which assesses the MW capacity the grid can accept. The methodology has been discussed and agreed with the transmission grid owner Scottish Hydro Electric Transmission Ltd (SHETL) and the distribution grid owner and operator Scottish Hydro Electric Power Distribution (SHEPD) and is therefore robust against headline issues. More detail on the study methodology is contained in Appendix B.

All connection costs quoted in this section are for connection to the points specified and include the metering switchgear for the project. Once connected Use of System charges also apply as set out in Section 6. More information on the cost methodology is contained in Appendix B along with an explanation of timeframes and consents assessments.

XE has obtained a complete set of 11kV to 132kV data for the region with which to undertake the connection analyses. This is built up of data from [21] and [22] and data provided to XE by SHEPD. It is however important to realise that the technical studies cannot be exhaustive within the budget of the study and ultimate connection will depend on further study work and formal processes with SHEPD and/or SHETL and National Grid.

As with all areas of the grid study, the actual connections that will be realised will also be affected by other interests outside the control of the Pentland Firth generation.

3.2 The existing transmission grid

Figure 3-1 shows the main existing transmission system in the north of Scotland. It can be seen that the north coast is served by a single 275kV transmission line to Dounreay and a double circuit 132kV line to Thurso and on to Dounreay where the two interconnect. Both systems originate from Beauly near Inverness.

There is currently no transmission system to Orkney or closer into the north east of Caithness. The transmission system is effectively the transport system out of the region for generation and is particularly relevant for larger developments (e.g. larger than 10MW) which may wish to access it directly or need to obtain and agreement with the transmission system operator regardless. This is more relevant to medium and longer term timeframes.

Information on planned transmission reinforcements and possible major new transmission developments is contained in Section 5.2. Figure 3-1 only shows the transmission system as is at present.

Smaller and near term projects will wish to access the local distribution system which will be closer and more cost effective.

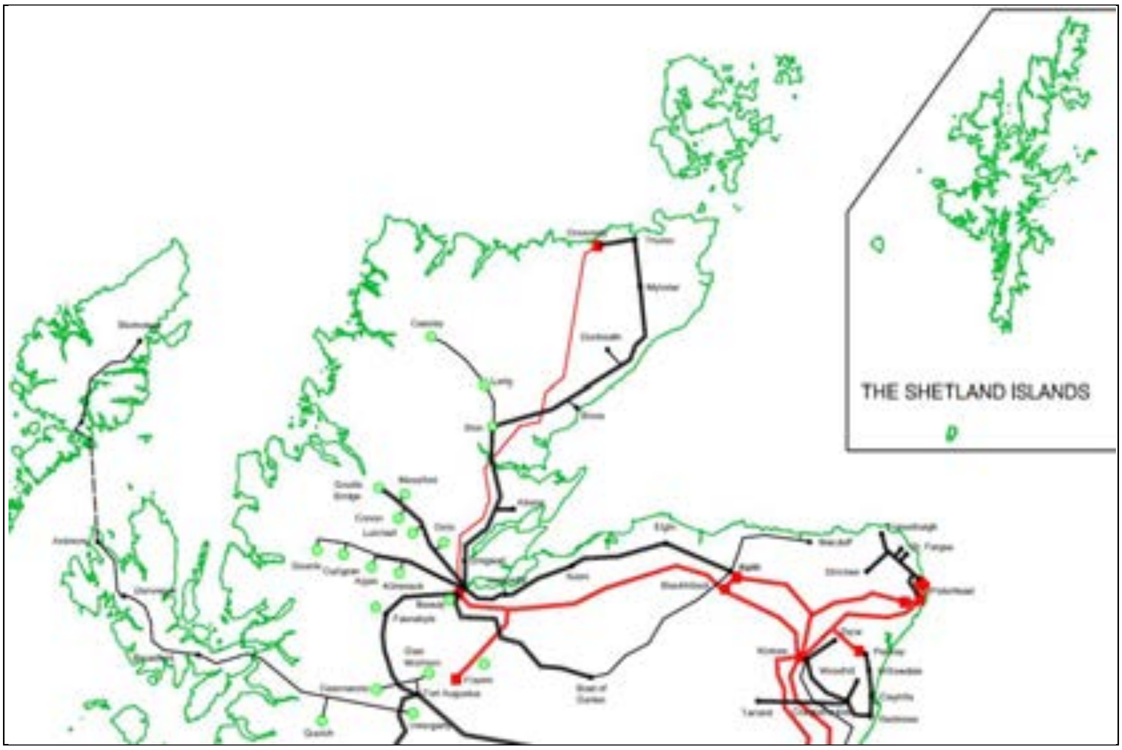

Figure 3-1: North of Scotland and Orkney transmission system [22]

3.3 The existing mainland distribution grid

The north east mainland distribution system is shown in Figure 3-2. Shown in green are the 33kV lines and in red the 11kV lines. The 132kV transmission system is shown in black. The 33kV system is primarily used to transport power around the region from the main interconnections at transmission to the 11kV system. The main interconnection substations to transmission are termed Grid Supply Points (GSP) and the main interconnection substations from the 33kV network to the 11kV network are termed primary substations.

As can be seen from Figure 3-2 the mainland region is mainly supplied by 11kV network, the weakest high voltage normally operated by SHEPD. It is supplied from Thurso 132/33kV GSP and a system of 33/11kV primaries. Of these, the primaries at Mount Pleasant and Hastigrow are most relevant as they supply the 11kV network in the region east of Thurso. Thurso GSP also provides two 33kV circuits to Orkney which run overhead to Murkle Bay before going subsea to Orkney.

The 11kV network is loosely split between three different circuits in the north east, one from Mount Pleasant 33/11kV Primary, and two from Hastigrow 33/11kV Primary. Wick Primary is supplied from Mybster 132/33kV GSP and so ultimately connects back to the same transmission system but via a different route. Points on the network where the lines are split are termed Normally Open Points (NOP) and these can be closed to alter the network topology.

There is some 11kV and 33kV network west of Thurso but it is further away geographically, difficult to access due to cable landing problems and environmental designations and therefore of much less interest. These networks may however be of some interest to wave energy projects that are not within the bounds of the Pentland Firth itself.

The 33kV system is of primary interest to small and medium sized projects but is relatively far from the project development area. This is unfortunate as the 11kV network is effectively used to supply end consumers and as such is used to low power levels. It is very sensitive to changes in power flows, notably those arising from generation, and cannot readily accommodate much generation. This leaves a gap in terms of local grid in that only connections for very small projects are readily available.

An electrical diagram of the Thurso 33kV grid, showing its interconnection to the 132kV transmission system, and 33/11kV primary substations is given in Appendix C.

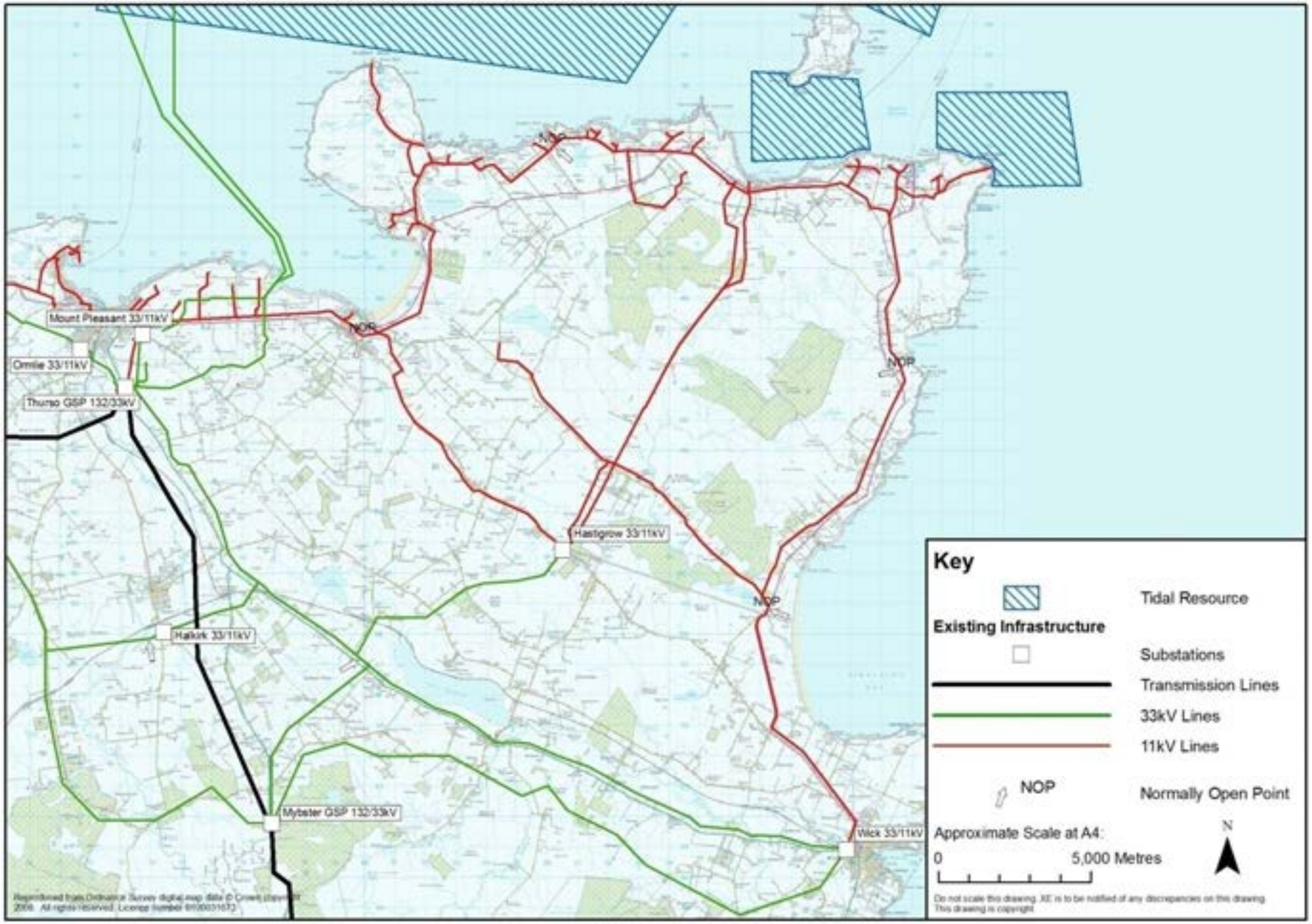

Figure 3-2: Mainland distribution system

3.4 The existing Orkney distribution grid

The Orkney grid is effectively built up of a 33kV ring system around the northern isles and two 33kV lines to the southern isles which are of main interest. The Orkney 33kV system is supplied by way of two subsea cables from Thurso which run to Scorradale via Hoy. The system is a complex mix of generation and demand and currently runs at its limits in terms of allowable generation. A Renewable Power Zone (RPZ) has been put in place to allow more generation to connect by way of managing the distribution grid and generation. The RPZ is discussed further in Section 4.2.1 and participation in it is a pre-condition to any new generation on Orkney for the time being.

The existing Orkney distribution system is shown in Figure 3-3. The incoming 33kV cables from Thurso pass through voltage regulators at Scorradale, where there is also a Dynamic reactive power control system (DVAr system).

Scorradale is directly connected to Kirkwall. The main circuits of interest to the Pentland Firth generation are one 33kV circuit from Scorradale on Hoy to Lyness and then subsea to Flotta and one from Kirkwall to St. Mary‘s Primary and thence at 11kV right down to the southern tip of South Ronaldsay. St. Mary‘s Primary already has 0.85MW of wind generation connected in the 11kV network.

In regards Hoy and Flotta there is a very small primary substation at Lyness and a larger one on Flotta. There is already 2MW of wind generation connected at 11kV to Flotta Primary and a further 10.5MW from Flotta Occidental connected to the 33kV system. The 11kV system extends from Lyness down on to South Walls via a short subsea section, and prior to this, splits to the southern tip of Hoy, both being part of the same feeder.

Both 33kV and 11kV systems are of interest to Pentland Firth tidal generation, but as noted earlier, the Orkney system is effectively full in regards generation and hence anything new must participate in the RPZ as a pre-condition. This means some degree of generation management and thus curtailed or lost export energy from time to time.

An electrical diagram of the Orkney 33kV grid, showing its interconnection to Thurso, and 33/11kV primary substations is given in Appendix C.

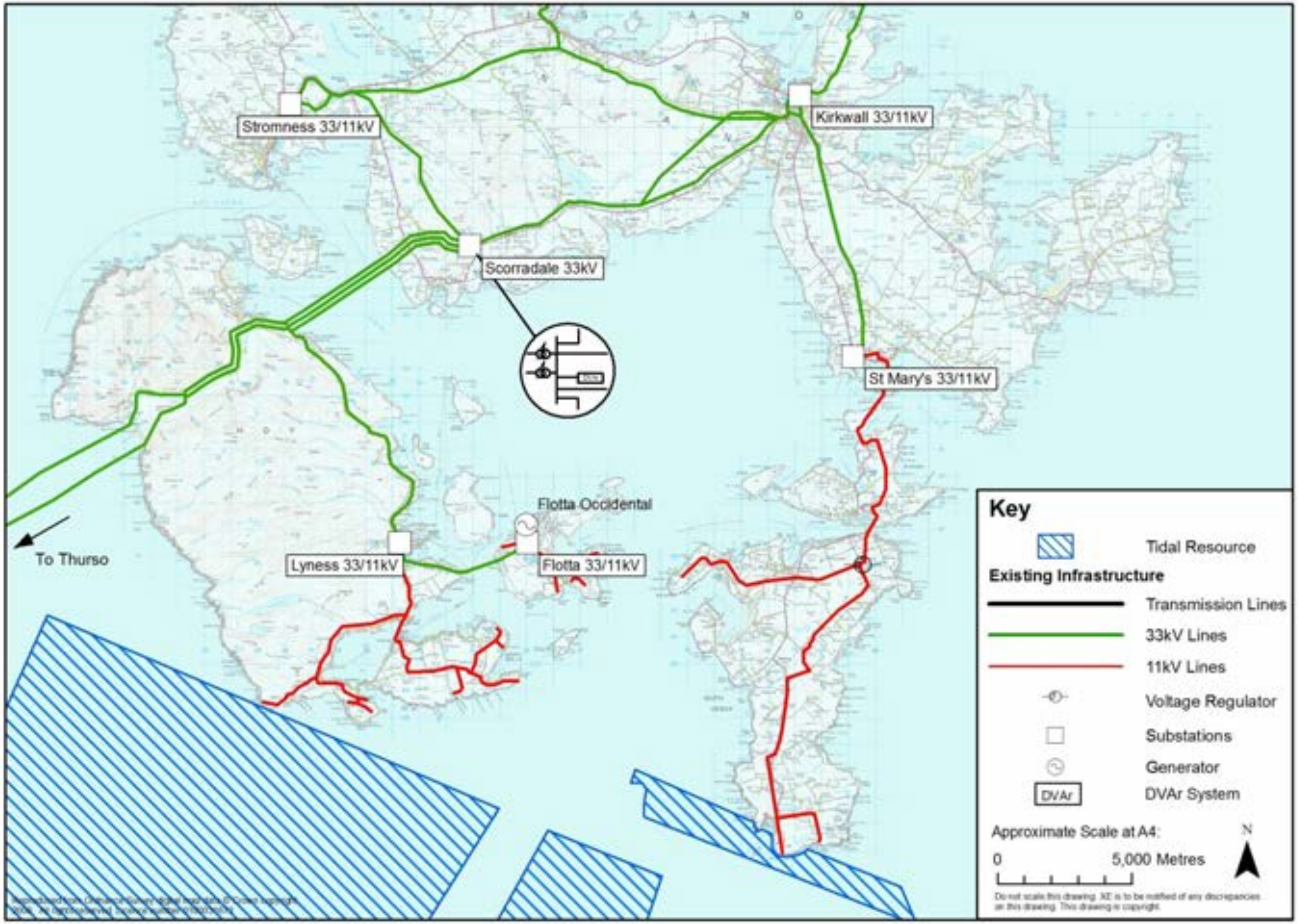

Figure 3-3: Orkney distribution system

3.5 Available capacity without upgrades

XE has examined connections to the existing 11kV and 33kV networks to the east of Thurso and the southern extremes of Orkney to assess the connectable capacity without upgrading the existing grid.

3.5.1 Mainland

Due to the distance from the shore to the primary substations which feed the 11kV network, the 11kV lines are long and voltage rise is a limiting factor. Depending on the exact point of connection, XE‘s studies show connectable capacity generally varies between about 100kW and 300kW. XE has varied the generation power factor to increase the connectable capacity, i.e. an import of reactive power has been used to assist with voltage. Closer to Thurso, the situation is more amenable, with the connection of 1MW possible via the 11kV lines near Murkle Bay albeit at some distance from the project locations.

Connections to the 33kV network are limited to Thurso GSP, the lines feeding Orkney at Murkle Bay, or the line feeding Mount Pleasant Primary, all some distance from the offshore project locations.

XE‘s analysis shows no capacity is available on the 33kV overhead lines which go subsea from Murkle Bay to Orkney due to the abundance of generation already on Orkney.

At Mount Pleasant Primary, up to 15.6MW is available at either 11kV or 33kV and is limited by the 33kV overhead line rating back to Thurso GSP. An 11kV busbar connection is however disproportionately expensive over a 33kV option.

At Thurso GSP itself there is some 26MW of firm capacity back through the 33/132kV transformers, 86MW non-firm according to [21]. Firm is the capacity that can be secured during an outage of a transformer or incoming circuit and as noted in the appendices it is normal to design for firm capacity only. XE has used this figure but it is important to note that it does not take full account of any generation added under the Orkney RPZ (up to 15MW) and any other connection applications in process with SHEPD at time of writing. Depending on whether projects are indeed realised under the RPZ, the actual capacity at Thurso could be much less.

The potential connections and connectable capacity are shown in Figure 3-4 and detailed in Table 3-1. Connections are shown graphically in the Figure with the study point shown as a dot on the grid lines and the region it is representative of shown as a “shape”. This graphically shows the capacity that can be connected somewhere within the area bounded by the shape.

Connection point geographic location	Voltage	Capacity [MW]	Approx costs [£k]	Grid issues & Consents
Duncansby Head	11kV	0.15	160	Voltage limit
Gills Bay	11kV	0.24	160	Voltage limit
Scarfskerry NOP east	11kV	0.16	160	Voltage limit
Scarfskerry NOP west	11kV	0.27	160	Voltage limit
West Brough	11kV	0.35	160	Voltage limit
Dunnet Head Lighthouse	11kV	0.24	160	Voltage limit
Mains of Murkle	11kV	1.42	160	Voltage limit
Orkney cable pothead	33kV	0	260	Thermal limit due to Orkney gen‘
Mount Pleasant Primary Substation	11kV	15.6	402	Thermal limit of 33kV line
	33kV	15.6	260	Thermal limit of 33kV line
Thurso GSP	33kV	26.5	533	Firm thermal capacity of 132/33kV transformers

Table 3-1: Possible connections to the existing mainland distribution system

As connections to the same grid line (feeder) and or substation are largely mutually exclusive, the table shows the interdependent connections by way of double line grouping, e.g. Duncansby Head, Skarfskerry east and Gills Bay are a group. This means that these connections cannot be used together as they affect each other.

All connections are achievable with an approximate 12 month timeframe due to the low levels of work and consents. Quoted costs are the costs for metering switchgear and associated equipment for a single project.

Consents are indicated by a green colour for a low level of issue as per the methodology of Appendix B. This is on the basis that no significant new works are required.

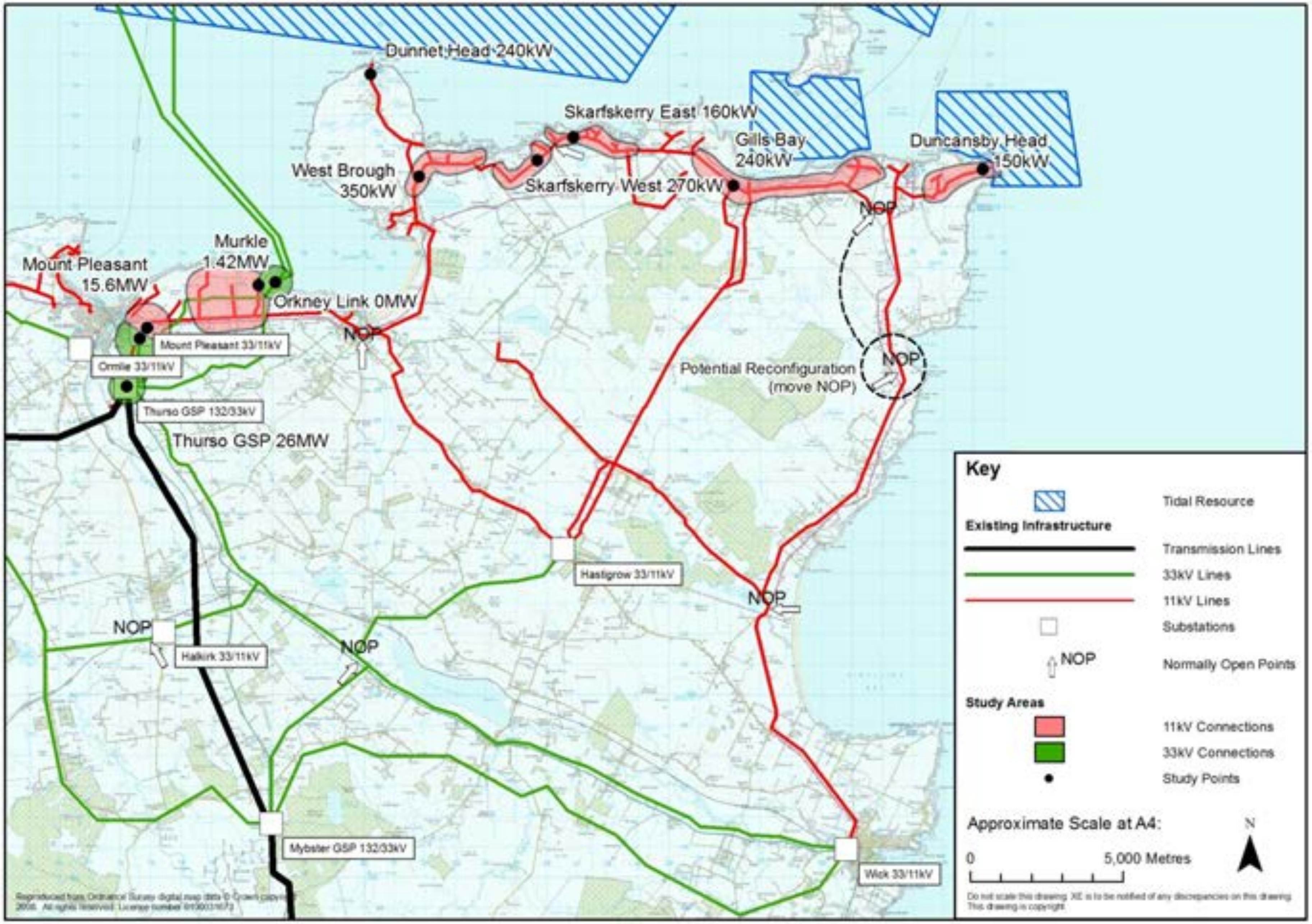

Figure 3-4: Possible connections to the existing mainland distribution system

3.5.2 Orkney

XE has examined connections to the existing 11kV and 33kV grid on the southern end of Hoy and South Walls, and the 11kV network at the southern end of South Ronaldsay.

As with the mainland, 11kV connections are limited by voltage rise issues. On South Ronaldsay connectable capacity is around 270kW although the circuit already uses a voltage regulator. Hoy cannot accept any generation as the lines are single phase only and South Walls can accept up to 200kW. As with the mainland, XE has used generation power factor to limit voltage rise. Flotta also contains 11kV network but is relatively far away and has not been examined.

A connection further inland could be made to the 33kV line around Lyness or to the 11kV side of Lyness Primary, or even on Flotta. Existing generation limits connectable capacity on the 33kV line to around 1.5MW depending on Flotta's operating power factor range. The Lyness Primary transformer rating limits connectable 11kV capacity to around 1MW. Upgrades are required to install a more significant amount of generation. Lyness is however quite far from the offshore region of interest. Flotta is even further away and for this reason has not been examined (the connectable MW is the same in any case).

The potential connections and connectable capacity are shown in Figure 3-4 and detailed in Table 3-2.

Connection point geographic location	Voltage	Capacity [MW]	Approx costs [£k]	Grid issues Consents
Melsetter, Hoy	11kV	0	n/a	Single phase line only
Aithsdale, South Walls	11kV	0.20	160	Voltage limit
Lyness Primary	11kV	1.00	200	Thermal limit of Lyness transformer
Lyness lines	33kV	1.50	260	Thermal limit of 33kV line
Burwick, S. Ronaldsay	11kV	0.27	160	Voltage limit

Table 3-2: Possible connections to the existing Orkney distribution system

As connections to the same grid line (feeder) and or substation are largely mutually exclusive, the table shows the interdependent connections by way of double line grouping. This applies to 11kV and 33kV connections on Hoy and 11kV connections on South Ronaldsay.

All connections are achievable with an approximate 12 month timeframe due to the low levels of work and consents required except they must join the Orkney RPZ.

Consenting issues are shown as green for a low level of issue. As with the mainland connections, the quoted costs are the costs for metering switchgear for a single project.

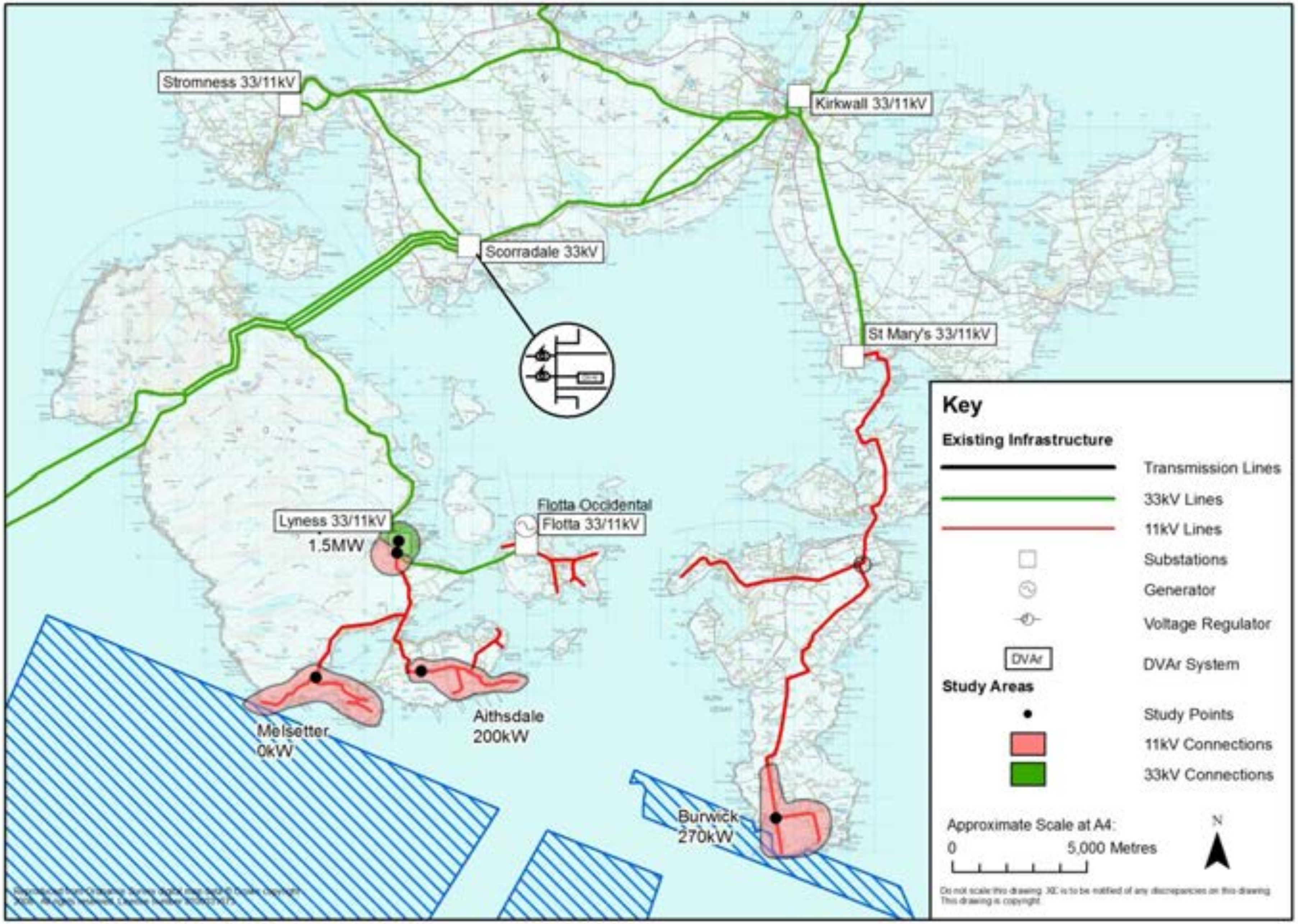

Figure 3-5: Possible connections to the existing Orkney distribution system

3.6 Available capacity with upgrades

This section re-examines the same connection points to the existing distribution systems of the mainland and Orkney but this time targets upgrade works to increase the connectable capacity. All upgrades are chosen on the basis that they are relatively straightforward, avoid new infrastructure (new lines or substations), and are acceptable to SHEPD. For the main this means uprating lines by reconductoring, upgrading substation transformer capacity, and installing voltage regulators on the 11kV systems. These upgrades also target the main constraining factors. XE has used standard SHEPD conductor sizes for line uprating (e.g. giving a maximum 30MVA or so at 33kV), standard SHEPD transformer sizes, and proven and installed voltage regulator technology as described in Section 4.2.5. Long 11kV lines with many customers are not upgraded as the benefits are marginal, costs relatively high, and customer disruption an issue.

3.6.1 Mainland

Connectable capacity can be roughly doubled by installation of voltage regulators, thereby improving prospects from Duncansby Head through to Dunnet Head. Capacity at Murkle Bay is increased to around 2.8MW but is relatively far from the offshore development area.

Further increases in capacity can be obtained by reconductoring the 11kV lines but this is disproportionally expensive and provides only more marginal increases in capacity. The exception is the 11kV line from Hastigrow to Gills Bay which, with an upgraded line as well as the installation of a voltage regulator could increase capacity to around 1.5MW in the vicinity of Gills Bay. This reinforcement also increases connectable capacity at other points such as Skarfskerry east to around 0.4MW. The utility of this reinforcement hinges on moving a small number of consumers from the main 11kV line between Hastigrow and Gills to allow a higher voltage rise.

The Orkney 33kV overhead lines are convenient to the shore at Murkle Bay but increasing their overall rating to 30MVA apiece only releases an additional 6.3MW or so.

Closer to Thurso, Mount Pleasant Substation could support up to 26MW if its 33kV feeder were upgraded over the short distance back to Thurso GSP. There is little point in connecting at 11kV as this would additionally require a transformer upgrade.

The grid transformers at Thurso ultimately limit the maximum amount of generation on the distribution system. To increase connected generation further, it is necessary to either swap the transformers for larger ones, or less likely, introduce more transformers. Replacement of the two 60MVA units with two 90MVA units would provide an additional 30MVA of firm capacity at Thurso GSP extending overall firm export capability to 56MVA.

XE has not examined system reconfigurations in any detail but notes there is some potential to optimise the 11kV system configuration depending on the locations that generators are developed in. The total connectable capacity will not be significantly different however. Probably the most useful reconfiguration would move the easternmost open points to allow Duncansby Head to be fed from Wick thereby removing dependency on the 11kV system via Gills where it could be severely limited by other connections. This is shown on Figure 3-6.

Upgrades, costs, capacity, consents and issues are set out in Table 3-3.

Connection point geographic location	Voltage	Suggested upgrade	Cost [£k]		Capacity with upgrade [MW]	Grid issues consents
			Total capital	To project		
Duncansby Head	11kV	Voltage regulator (switch to Wick)	260	222	0.30	Voltage limit
Gills Bay	11kV	Voltage regulator	260	234	0.48	Voltage limit
	11kV	Voltage regulator plus line upgrade	950	853	1.50	Voltage limit
Scarfskerry NOP east	11kV	Voltage regulator	260	226	0.32	Voltage limit
	11kV	Voltage regulator plus line upgrade	950	656	0.40	Voltage limit
Scarfskerry NOP west	11kV	Voltage regulator	260	236	0.54	Voltage limit
West Brough	11kV	Voltage regulator	260	244	0.70	Voltage limit
Dunnet Head	11kV	Voltage regulator	260	233	0.48	Voltage limit
Mains of Murkle	11kV	Voltage regulator	260	210	2.84	Voltage limit
Orkney cable potheads	33kV	Reconductor 33kV line	635	343	6.27	Thermally limited by line ratings and Orkney export
Mount Pleasant Primary Substation	11kV	None worthwhile	n/a	n/a	n/a	n/a
	33kV	Reconductor 33kV line	370	307	26.0	Limited by Thurso transformer capacity
Thurso GSP	33kV	Replace transformers with 90MVA units	3,033	1,872	56.0	Limited to upgrade capacity

Table 3-3: Possible upgraded connections to the mainland distribution system

All connections require a low level of consents (green) as no new lines or substations are required and for the most part timescales are in the order of 12 months.

Upgrade of transformer capacity at Thurso GSP is a more serious proposition and is likely to have an approximate 24-36 month timeframe.

Capital costs of the upgrades are given but it should be noted that the cost to projects is shared with SHEPD. The estimated shared cost to the project is also given.

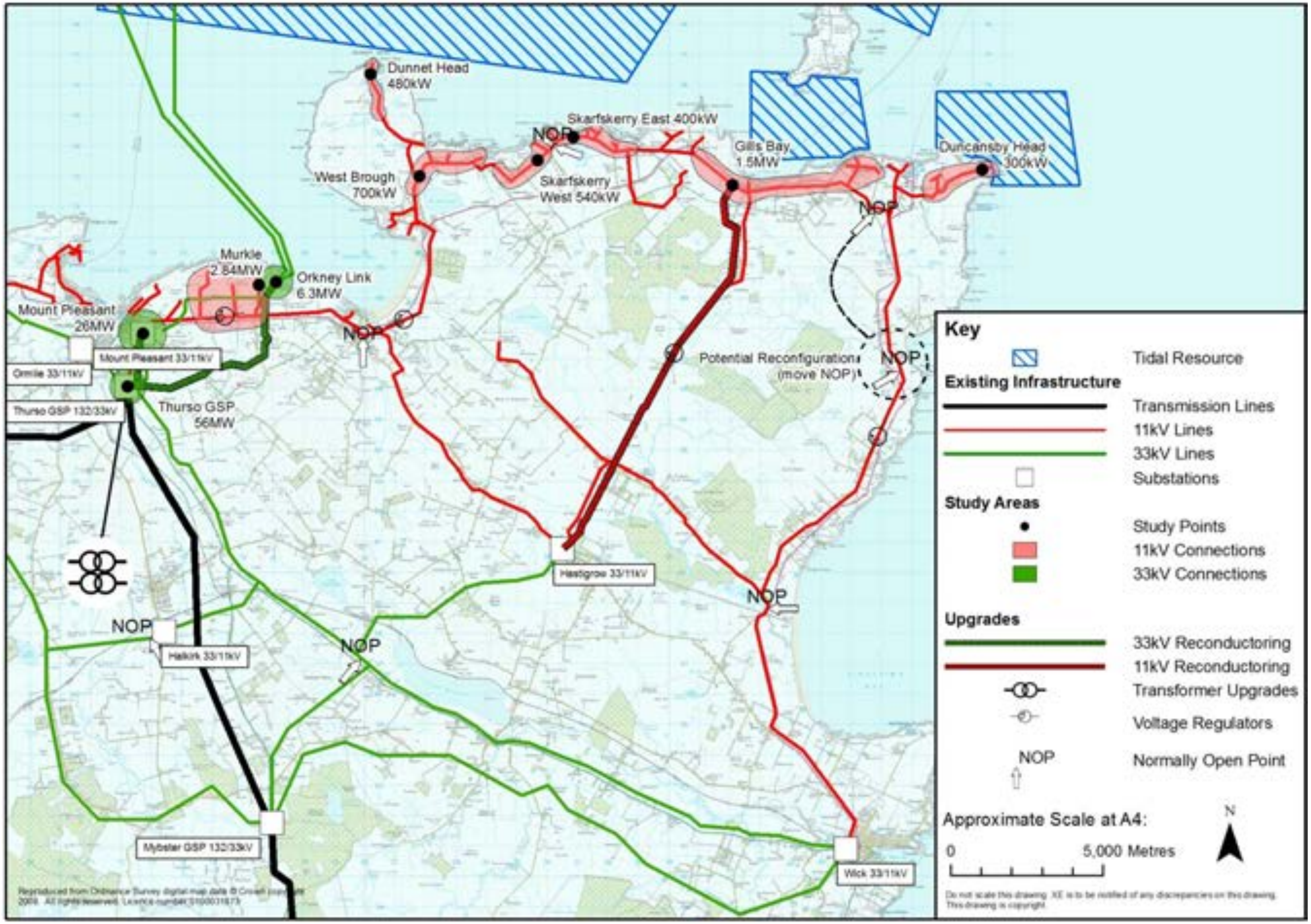

Figure 3-6: Possible upgraded connections to the mainland distribution system

3.6.2 Orkney

As with the mainland, connectable capacity on the 11kV connections can be roughly doubled by installation of voltage regulators. Capacity on Hoy requires a line upgrade to three phase operation followed by the installation of a voltage regulator. South Walls is raised to 400kW.

The South Ronaldsay 11kV system is very long with many existing consumers and an existing voltage regulator. This means to further increase capacity would require extensive reconductoring and disruption to consumers and would be expensive with only marginal benefits. For these reasons XE has not considered upgrades as worthwhile.

Further capacity increments can be achieved on Hoy and South Walls by reconductoring the 11kV lines at least in part. This is worth considering as the lines are relatively short (compared to the mainland or South Ronaldsay). Capacity at either connection could be raised to around 1MW which is the limit on the 33/11kV transformer at Lyness.

Further 11kV capacity increases can be gained by replacing the Lyness 33/11kV transformer although the 33kV line draws a limit at around 1.5MW (possibly more depending on minimum load and Flotta's generation power factor).

Increasing the capacity further, or for a 33kV connection at Lyness, requires reconductoring of the 33kV lines back to Scorradale at considerable expense. This includes a subsea section from Hoy to Scorradale on mainland Orkney. Export capacity could be increased to a theoretical 18MW but this would be severely restricted within the RPZ which can allow a maximum 15MW and within which this capacity is already being signed up.

The upgraded Orkney connections are shown in Table 3-4 and Figure 3-7.

Connection point geographic location	Voltage	Suggested upgrade	Cost [£k]		Capacity with upgrade [MW]	Grid issues consents
			Total capital	To project		
Melsetter, Hoy	11kV	Line upgrade to 3 phase	130	130	0.21	Voltage rise
		Voltage regulator plus line upgrades	230	230	0.42	Voltage rise
		Voltage regulator, line upgrades and Lyness transformer upgrade	710	710	1.5	33kV line rating
Aithsdale, South Walls	11kV	Voltage regulator	100	69	0.39	Voltage rise
		Voltage regulator plus line upgrades	1,138	937	1.0	Lyness transformer
		Voltage regulator, line upgrades and Lyness transformer upgrade	1,488	1,268	1.5	33kV line rating
Lyness Primary	11kV	Lyness transformer upgrade	510	170	1.5	33kV line rating
Lyness lines	33kV	Reconductor 33kV line	6,161	6,007	< *18*	RPZ limits
Burwick, South Ronaldsay	11kV	none	n/a	n/a	n/a	Voltage rise

Table 3-4: Possible upgraded connections to the Orkney distribution system

The 11kV connections require a low level of consents and timescales are in the order of 12 months.

Upgrade of the 33kV system from Lyness is extensive and requires installation of new subsea cable to Scorradale. Timeframes are likely to be extended although 24-36 months may still be possible depending on the lead time for the subsea 33kV cable.

As with the mainland, there is a degree of cost sharing of upgrade as indicted in Table 3-4.

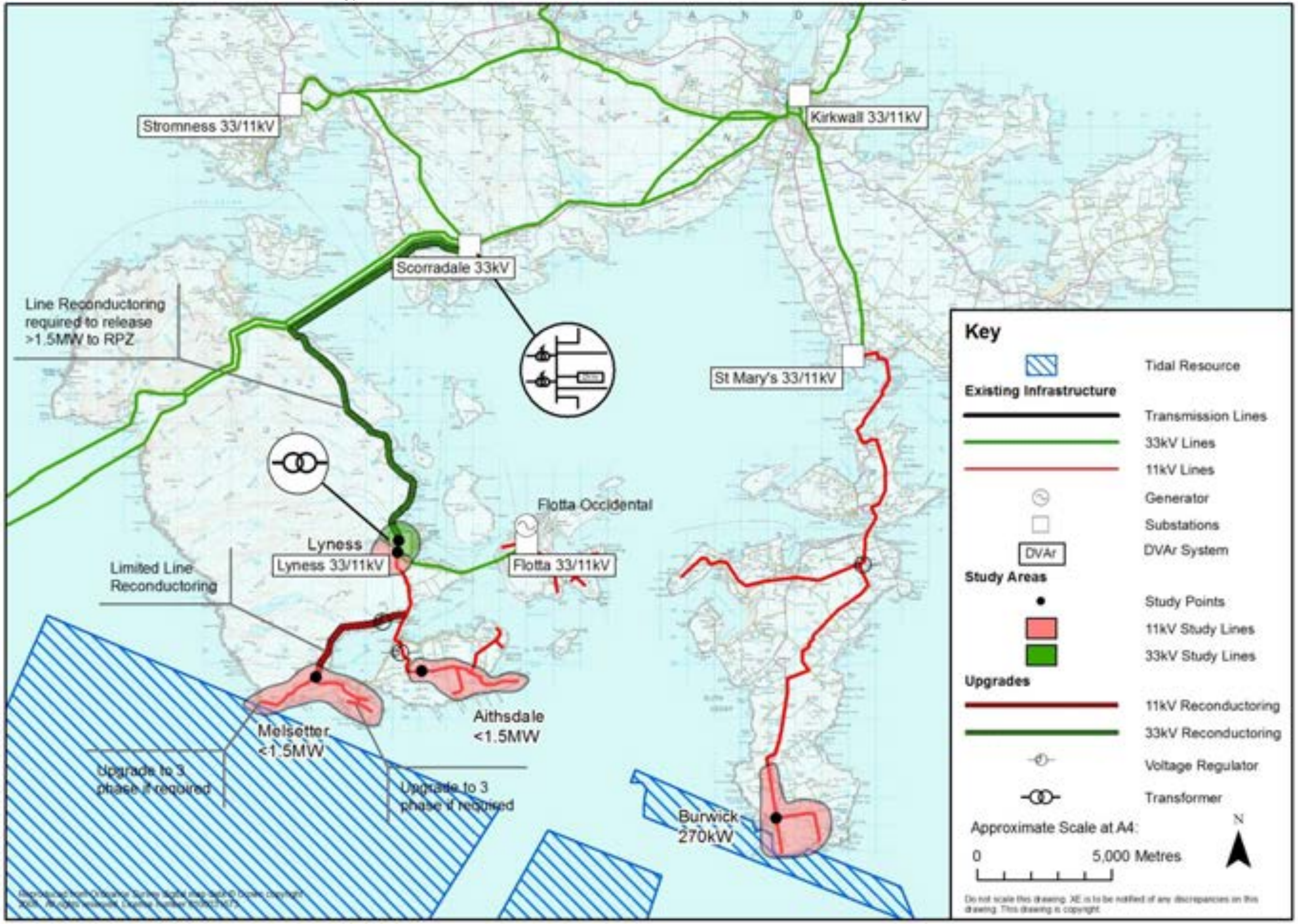

Figure 3-7: Possible upgraded connections to the Orkney distribution system

3.7 Section summary

This section of the report has examined the available capacity in the existing mainland and Orkney grid, particularly for smaller distribution connected projects. The rationale has been to minimise works and issues with consents by simply connecting to the grid as is, then increasing connectable capacity by upgrading the existing grid without recourse to new lines or substations. This means the connections are generally achievable within a 12 month timeframe without major consenting issues.

As can be expected, 11kV connections are primarily limited by voltage rise issues and 33kV connections by thermal (MW capacity) issues. Sensible upgrades are therefore combinations of line and transformer upgrades and installation of voltage regulating devices such as inline voltage regulators (see also Section 4.2.5).

Even with upgrades the connectable capacity is only around 5MW in the immediate coastal 11kV networks, about 3MW in the mainland and around 2MW on Orkney.

If longer routes are taken from the offshore development areas to the area around Murkle Bay and Thurso, up to 26MW total is available but this requires quite long connections from the offshore area to the grid. This might be affordable for a larger project.

Orkney capacity is also extendable to around 15MW+ in theory but only by very expensive (multi million pound) reinforcement of the 33kV system which in any case leaves the connection very heavily constrained by wider Orkney RPZ issues. All Orkney connections are dependant on participation in the RPZ and may therefore suffer constraint regardless of upgrades.

Thurso GSP currently has a firm export limit of some 26MW [21] which is the ultimate limiting factor for all the connections (i.e. the sum total of Orkney and the mainland). Transformer upgrades at Thurso would attract a capital cost of around £3M and a two to three year timeframe. It is important to note that the capacity at Thurso does not fully include Orkney RPZ generation and any projects currently in the connection process with SHEPD at time of writing. The capacity at Thurso could therefore be close to zero and transformer upgrades could be necessary immediately.

This section has shown that fast and easily achievable connectable capacity is severely limited locally and thus wider works are absolutely necessary to exploit the Pentland Firth tidal energy resource.

Wider works will mean new lines and substations with more cost and more consenting issues and it would therefore appear prudent to start their development as soon as possible.

The next section of the report examines the use of innovation to extend the connectable capacity of the above connections to the existing system further in lieu of wider works. This can be viewed as a short term measure to extend capacity.

4 Extension by innovation

4.1 Introduction

This section of the report examines the scope for innovation in extending the capacity that can be connected to the distribution system. There is also potential for some innovative technologies to be applied to new strategic grid works as examined in Section 5.

There are potentially almost limitless innovations that can be brought forward but absolutely critical is understanding that grid practices tend to be conservative and the scope to readily innovate is limited. The commercial frameworks to facilitate innovations are not well developed or understood and the poor uptake of RPZs is a case in point. This section therefore splits the innovations into three categories of which the first two are of most interest:

- Acceptable to the grid now and therefore immediately of use, e.g. voltage regulators.
- Acceptable to the grid with some effort and therefore useful over short to medium time horizons, e.g. RPZ schemes.
- Novel and developing technology likely to be implementable with considerable effort, marginal cost benefits and/or over long timeframes, e.g. hydrogen storage.

The review concentrates on the best candidates from the first two categories noting that wider grid system developments and targeted strategic reinforcement will be a more certain mechanism to release capacity, particularly the larger capacities sought. A reliance on innovation alone would likely lead to incremental increases in capacity with less certainty but would not deliver larger MW targets.

Notwithstanding the above, comments in this section provide an understanding of the potential additional MW capacity that each innovation can release, identify the key readily realisable innovations, and, those worthy of more detailed investigation for longer term implementation. The following assessment criteria are used:

- Realisable MW capacity as far as it may be quantifiable.
- Likelihood that the project will deliver the extra capacity.
- Cost of implementation if known.
- Likely timeframes for implementation.

The different categories are assessed in view of the Pentland Firth grid as follows:

Rating	MW potential	Likelihood of realising potential	Cost (per MW)	Timeframe
Unknown				
Low	< 1MW	Unlikely	> £100k	> 5 years long
Good	1MW - 10MW	Possible	£10k - £100k	< 5 years medium
Very good	> 10MW	Likely	< £10k	< 1 year short

Table 4-1: Innovation assessment criteria

4.2 Short to medium term electrical/grid innovation

This section of the report looks at those innovations that are particularly likely to be of use.

The use of such technology in RPZs is one useful reference. The main commercial mechanism for development is through combination with the Innovation Funding Incentive. An RPZ is simply a term for a funded –trial” of innovative and new technology on the distribution system. There are currently only three RPZs in the UK:

- Orkney 33kV RPZ.
- Skegness 132kV RPZ.
- Martham 11kV RPZ.

To qualify as an RPZ, the Distribution Network Operator (DNO) must employ new methods or technologies to increase local generation capacity.

Another useful reference is The Distribution Working Group (previously the Distribution Generation Coordination Group) new technologies report [23], identifying a number of technologies that are being developed in the UK and world-wide that have the potential to allow more generation to connect to the distribution network.

The innovations considered are set out in the following sub-sections.

4.2.1 Generator constraint against (firm) thermal capacity (Orkney RPZ)

The Orkney RPZ employs a number of different technologies together to squeeze more out of the local 33kV grid with constraint of generation the key technique. SHEPD has already installed a dynamic reactive compensator and shunt reactors at Scorradale Substation to control the voltage. The RPZ however also increases connectable generation capacity by constraining generation against the thermal capacity of the subsea interconnectors to Thurso and also between the islands. Under the RPZ, the system is configured to operate both Thurso cables at full rated (non-firm) capacity. If one of the cables should fail, the scheme is designed to quickly trip off sufficient generation to maintain safe operation on the limits of the remaining cable. The combination of these technologies will increase the overall connectable capacity by 15MW [24] at an estimated cost of £200,000 (about £13k for every extra connectable MW).

The time required to implement this technology into other distribution grids throughout the UK is estimated to be around 12-24 months [25]. This timeframe is highly dependent on the level of input from the DNO and developers, as opposed to the time required for the actual system study and equipment installation. The level of increased capacity that the system can release is difficult to estimate as every single distribution network varies, although in general it is suggested to double the available capacity.

- Generation constraint against firm capacity can release multi-MW.
- The likelihood that this technology can deliver extra capacity is high.
- The cost of releasing extra capacity is relatively low (£13k per MW on Orkney).
- The deliverable timeframe for implementing this technology in other regions is estimated (by Smarter Grid Solutions Ltd) as within 12-24months.

4.2.2 Dynamic Line Rating (Skegness/Boston RPZ)

E.ON Central Networks has implemented a dynamic line rating scheme on the Skegness to Boston section of its 132kV grid triggered by increasing levels of wind generation. The line rating is based on rarely occurring worst case conditions meaning that the rating is overly conservative for most of the year. This scheme calculates the real time rating of the line based on current weather conditions which releases increased capacity for most of the year. The scheme has released 90MW [26] of new generation capacity at a cost of £270,000 (£3k per MW).

This innovation is limited by the actual network make-up and the ability to measure temperature at enough points along lines. To overcome this, E.ON is developing techniques to estimate line rating based on variables such as line sag.

- Dynamic line rating can release from a few MW (11kV) to tens (132kV).
- Measurement and estimation issues mean deliverability is variable.
- Costs can be very low. (Boston-Skegness cost £3,000 per MW)
- As the method examined in this report is still under development, it is not expected to be immediately available but may become so within a few years.

4.2.3 Generator dependant substation voltage control (Martham Primary RPZ)

EDF Energy has installed an automated voltage control system that alters the primary substation on-load tap changers according to generation export, demand and voltage. Since installing the equipment in 2005, EDF has been successfully controlling the voltage for the 11kV Martham network [27]. The solution was employed to prevent voltage problems resulting from the installation of an extra 1.5MW of wind generating capacity. The GenAVC™ system used has been stated as costing £180,000[28]. Subsequently, the system has been deployed elsewhere in EDF's network, releasing 3.8MW of capacity for the same total cost (£47k/MW). It has been estimated that from assessment through to installation, the system can be installed as fast as within 22 weeks [29] although XE considers this rather optimistic. The achievable output from implementing this technology varies from location to location but a potential to double [29] or even triple the generating capacity has been given.

GenAVC™ is known as a Micro Grid Controller, and is one of two devices under development in the UK - the other is ABB's AuRA-NMS™ [30], similar but still in development.

- Generation dependant substation voltage control can release several MW per feeder.
- The likelihood that this technology can deliver is high considering that there are existing, operational examples of the technology.
- The cost of extra capacity can be moderate to relatively high (between £50-120k per MW thus far).
- This technology can deliver quickly.

As voltage constraints are critical to the earliest developments for the Pentland Firth this technology could be used to extend immediately connectable capacity on the 11kV networks particularly.

4.2.4 Generation constraint against voltage

In the analysis of Section 3, XE has already used generation power factor as a means to control or limit voltage rise on the 11kV connections. This is a static technique commonly applied to such connections and is assessed against worst case conditions which means that for most of the time the line is safely operating well away from the limiting case. In theory then, additional generation could be connected provided it was prepared to be dynamically constrained according to actual conditions.

In such a case the level of generation that can be connected is simply limited by the line rating but increasing the level comes with increased cost of constraint and an economic breakpoint is reached. It is very difficult to simply assess where this lies but as with other innovations a ―double capacity” rule is probably not unreasonable. Numerous, but case specific, assessments have been made, e.g. [31]. In its crudest form this simply requires a voltage dependant relay at the point of connection of the generator to trip it off if voltage should rise too high. This can be extended with controllable generators to a more dynamic scheme with low implementation costs. Power export control is now a common practice on wind farms in the UK and could be extended to tidal technologies for voltage regulation purposes.

- Generation constraint against voltage could release hundreds of kW per 11kV connection for Pentland Firth generation.
- The likelihood that this technology can deliver extra capacity is high.
- The cost of releasing extra capacity can be very low (a few thousand pounds).
- The deliverable timeframe for implementation could be immediate.

XE is not aware of this being used in the RPZs as yet but assumes it could be part of GenAVC^{TM} or AuRA-NMS^{TM} type systems or used as a low cost stand alone method.

4.2.5 Inline Voltage Regulators

Inline Voltage Regulators (IVR) are essentially 1:1 ratio transformers that include on-load tap changers to control voltage rise/drop. They are traditionally used to bring voltage levels back within limits at the base of very long distribution feeders. However, they can also be used to regulate voltage rise that occurs when generation is installed [32]. This is a particular problem for the 11kV connections of Section 3. An IVR can generally double the export capacity that is allowable on long feeders. One example of utilising this technology is in North Wales where, Scottish Power installed an IVR on an 11kV feeder [33]. This size of a single phase unit is estimated to cost around £30,000 [34].

- Inline Voltage Regulators can roughly double available capacity per installation.
- The likelihood that this technology can deliver is high.
- The cost is moderate to high at around £100k+ per installation.
- Inline Voltage Regulators are immediately available and are already used.

For most of the Pentland Firth cases examined the use of IVRs means only a few hundred kW per installation at 11kV. XE has already assumed the use IVRs in Section 3.6 as SHEPD has indicated their acceptability.

4.2.6 New conductor types

New conductors are becoming available for overhead lines and offer increased ratings, thereby allowing more generation onto them. These are typically high temperature low sag designs and current types being trialled by various network operators include GAP, AAAC and AZTSR. There is potential for the new conductors to both extend the capabilities of the existing network, albeit with reinforcement works, and extend the capabilities of new strategic work as outlined in Section 5. This is in part dependant on successful trials and uptake as approved conductors by the various DNO and transmission system operators and owners.

- New conductors can increase line capacity by a few MW.
- The likelihood that this technology can deliver is high.
- The cost is likely to be a moderate increment for new works.
- The technology is in use but unlikely to be widely used for a few years.

4.2.7 STATCOMs and similar

A STATCOM device can generate or absorb reactive power by utilising capacitors, reactors and power electronic switches. Within its operating bounds, the STATCOM can help to maintain power/voltage quality and stabilisation. If this technology were to be implemented into a distribution network to allow more generation to be installed, it would be eligible for RPZ status. Currently there is a small scale STATCOM device used on Orkney to control the voltage on the local distribution network although this was installed in response to problems with loads and not generators. Currently, STATCOM devices are expensive at around £1M for a 10MVAr device. This technology is likely to be relatively expensive with only limited relevancy to Pentland Firth generation.

4.2.8 Superconducting Fault Current Limiters

These have the potential to allow more generation to be connected to transmission and distribution systems where fault current levels are an issue [35]. XE has surveyed the mainland and Orkney fault levels and switchgear ratings and found issues are unlikely for the foreseeable future although notes that issues could arise later with increased generation in the network. As yet this technology is not available for use on UK distribution grids although there is significant ongoing worldwide research into this area.

4.3 Other innovation

4.3.1 Local high energy users

Providing demand for electricity close to generation removes the need for far-reaching transmission and distribution reinforcements. The main issues here are ensuring that high energy demand users will locate close to the generating site and ensuring the demand profile fits closely with the generating profile. The investment bank Morgan Stanley recently announced that it is looking to build a data centre in Caithness along with tidal energy capacity that will be used to power the site [36]. The project, proposed to be implemented by 2011, is expected to cost around £250-£300 million. Currently this is the only known example of a high energy user planning to locate near to marine resource in the UK.

This is not an innovation that can be generically applied as it is case specific. However, encouraging demand to locate in the north east mainland and Orkney regions could, dependant on exact location, assist with connectable capacity, and would assist with wider transmission issues.

4.3.2 Demand Side Management

Active Demand Side Management (DSM) is not currently used by DNOs in the UK. Historically however, low cost off peak tariffs such as Economy 7 have been effective at reducing peak demand and levelling load profiles. Currently there are a collection of examples around the world of DSM, utilising ‗Smart Meters' to encourage use at times of low demand as well as providing data feedback to the network operators. Currently, the Office of Gas and Electricity Markets (OFGEM) is conducting ongoing trials of smart meters (in conjunction with DNOs) although this is focused more on demand and carbon emission reduction [37].

Smart Meters are considered throughout industry as a path to implementing widespread DSM. The largest, most developed smart metering project is ENEL'S Telegestore program, in Italy. The program has seen smart meters installed into nearly 30 million Italian homes [38], resulting in flatter daily and weekly load profiles. ENEL has achieved this by providing a number of tariffs that are designed to encourage use at times of low demand. This can help generation in relieving problems such as voltage rise which are in part demand dependant.

The use of demand control has been examined in detail in the past to alleviate issues such as voltage rise [39] but not as far as XE is aware been implemented. XE considers there is merit in examining this innovation further as a means to mitigate voltage and thermal issues but would not expect any substantial progress in the near future in regards Pentland Firth related issues.

4.3.3 Storage

Storage offers benefits of being able to shape and form both generation and demand to overcome various issues including those of connectable generation capacity. Whilst much work is ongoing with storage, it is generally still regarded as expensive with limited and often site specific use. Whilst some trial applications could be developed for Pentland Firth purposes it is unlikely to offer any major breakthroughs over and above those from other innovations, changes in the regulatory regime and ongoing grid work. A brief summary of storage technology in contained in Appendix D.

4.3.4 Hydrogen

As with storage, there is much interest in hydrogen but prospects for affordable and useful application in the near future are probably limited. It is possible that some additional capacity might be released through the use of hydrogen technology but this is likely to be limited to demonstration projects and prototyping efforts rather than any large scale works. XE considers that concentrating on new grid infrastructure and changes to the regulatory regimes will be the key for delivering Pentland Firth marine energy capacity. A brief review of hydrogen is contained in Appendix D.

4.4 Section summary

Innovative techniques and equipment do have the potential to increase grid connectable capacity for Pentland Firth generation. It is difficult to quantify costs and the amount of additional generation that the innovations can release as this is largely case specific. However, in general it appears that a doubling of capacity is possible and in some cases a tripling – perhaps where innovations are used together.

Similarly, the cost of innovations is difficult to assess but of those surveyed there appears plenty of cost effective techniques that cost anything from just a few thousand pounds to implement up to £50k-120k per additional MW released. Many rely on periodic constraint or disconnection of the generation according to network conditions and this is an additional cost that needs to be borne in mind.

Many are implementable in very short to immediate timeframes and others within 2-3 years.

In particular, those techniques alleviating voltage rise issues are particularly relevant to 11kV connections for small projects and single generators and include:

- Voltage dependant generator constraint
- Inline voltage regulators
- Generator dependant substation voltage control

XE has already used inline voltage regulators in the Section 3 analysis but suggests there is scope for further capacity extension by at least a factor of 2, certainly at low cost and very effectively by voltage dependant generation constraint.

Those techniques alleviating thermal capacity issues are particularly relevant to 33kV and above and include:

- Thermal loading dependant generator constraint
- Dynamic line rating
- New higher rating line conductors

Dynamic line rating and use of new conductors are likely to be useable within the next few years, adding additional capacity by extending line ratings although are to some extent more useful on new build lines. Generator constraint allows more generation on a line provided it is constrained according to its balance against demand loading. Loads on the grids examined in Section 3 tend to be low and thus this offers limited opportunity.

More interesting is the use of constraint to access non-firm capacity at substations. This could be used to avoid, or at least defer, transformer upgrades at Thurso and Mybster GSPs. This could create an additional 60MW of non-firm capacity at both and save around £6M in upgrades. XE has assumed this innovation is adoptable in the strategic work of Section 5 where new build is for the most part used only by Pentland Firth generation.

The thermal innovations are also applicable to new strategic works as discussed in the following Section 5. Other innovations exist but are less likely to deliver additional generation in the Pentland Firth.

Total extendable capacity by innovation is summarised in Table 4-2 and, perhaps conservatively, estimated at around 8-10MW on the 11kV and 33kV lines. However, constraint to access non-firm capacity could also avoid transformer upgrades at Thurso and latterly Mybster and more significantly allow access to a further 60MW or so of capacity at each. For Thurso this is 60MW above the non-upgraded 26MW (86MW grand total).

Connection point geographic location	Voltage	Suggested upgrade	Capacity with upgrade [MW]	Extension by innovation [MW]	Grid issues consents
Duncansby Head	11kV	Voltage regulator	0.30	0.60	Voltage rise issue
Gills Bay	11kV	Voltage regulator	0.48	1.0	Voltage rise issue
		Voltage regulator plus line upgrade	1.50	3.0	Voltage rise issue
Scarfskerry NOP east	11kV	Voltage regulator	0.40	0.80	Voltage rise issue
Scarfskerry NOP west	11kV	Voltage regulator	0.54	1.1	Voltage rise issue
West Brough	11kV	Voltage regulator	0.70	1.4	Voltage rise issue
Dunnet Head Lighthouse	11kV	Voltage regulator	0.48	1.0	Voltage rise issue
Mains of Murkle	11kV	Voltage regulator	2.84	~ 4	Thermal limit reached
Orkney cable potheads	33kV	Reconductor 33kV line	6.27	6.27[i]	n/a
Mount Pleasant Primary Substation	11kV	None worthwhile	n/a	-	n/a
	33kV	Reconductor 33kV infeed	26.0	30[i]	Access non-firm Thurso capacity by generator constraint
Thurso GSP	33kV	~~Replace transformers with 90MVA units~~	56.0	86 (grand total)	Generator constraint avoids £2.5M transformer replacement
Orkney					
Melsetter, Hoy	11kV	Line upgrade to 3 phase	0.21	0.42	Voltage rise
		Voltage regulator plus line upgrade	0.42	0.84	
		As above plus transformer upgrade	1.5	1.8	33kV line rating
Aithsdale, South Walls	11kV	Voltage regulator	0.4	0.8	Voltage rise and Lyness transformer
		Voltage regulator plus line upgrade	1.0	1.2	
		As above plus transformer upgrade	1.5	1.8	33kV line rating
Lyness	33kV	Reconductor 33kV line	*< 18*	*< 18*	RPZ limits
Burwick, S. Ronaldsay	11kV	none	0.2	0.3	Voltage rise

Table 4-2: Summary of extended capacity through innovation

[i] This assumes new conductor types and dynamic line ratings are not applied else could be raised.

5 Strategic reinforcements

5.1 Introduction

This section of the report extends the analysis of Section 3 and Section 4 by examining which more significant grid work can be undertaken to facilitate ongoing connection of larger capacities and more major projects above 30MW, ultimately achieving 2020 goals. This section therefore takes a strategic view of the local transmission and distribution systems as follows:

- Upgrades at key substations to release more capacity to the wider grid, e.g. at Thurso.
- Development of new overhead line routes (or new underground cable routes) at 33kV and 132kV and above into the Pentland Firth area.
- Establishment of new substations to act as hubs for connections, e.g. new 132/33kV GSPs, 33kV switching stations, plus a new 132kV marshalling station.
- Wider transmission works that will be required to release capacity in the north of Scotland.

All the works set out have been discussed with SHETL and SHEPD as realistic, achievable and cost effective means to release significant additional capacity.

The work in this section focuses in part on local 33kV and 132kV infrastructure as this is most appropriate for release of capacity to the wider transmission system using lower environmental impact overhead wood pole lines, or underground circuits.

Heavier infrastructure (275kV, 400kV and DC) presents very significant consenting issues but may be needed to provide access to the grid for major developments - to release 1,000-1,700MW will require thorough upgrade and use of the onshore grid and use of future developments such as a subsea link from the north coast south. Examination of such developments is in part outside the scope of this report, constituting major and wider transmission system developments. However, they are clearly of fundamental importance and XE gives consideration to and discusses those proposals most likely to be realised. As development of this infrastructure is key to reaching 2020 targets and the options are limited, it is useful to start with this and let it in part guide the preceding developments. The wider transmission system is discussed in Section 5.2.

All of the above lead to a set of grid works that involve longer timeframes, more risk, higher consenting issues and more cost, BUT are required to significantly develop the resources of the Pentland Firth.

As with the grid connection options in other sections of this report the works eventually undertaken will be led by the generation developments and consideration of how this can be coordinated into an efficient build up of grid infrastructure is important.

Further afield, and possibly important closer to 2020, there are workstreams investigating an offshore supergrid which could impact on the Pentland Firth region. This includes work by the Scottish Government [40] and work by the transmission companies which at the time of writing is still in progress.

5.2 Wider transmission system developments to 2020

This report and the connection of Pentland Firth generation are premised on two key factors:

- Ongoing reinforcement, upgrade and development of the transmission system, and,
- Change in the regulatory regime to allow more renewable capacity to access it.

This section looks at planned and potential reinforcements of the wider transmission system as they are relevant and could be at least in part a result of demand for capacity from the Pentland Firth and thus led by it.

As set out in Section 3.2, the north coast is served by a single 275kV transmission line to Dounreay and a double circuit 132kV line to Thurso and on to Dounreay where the two interconnect. Both systems originate from Beauly near Inverness. There is currently no transmission system to Orkney or closer into the north east of Caithness. The transmission system is effectively the transport system out of the region for generation.

The current system is planned for some upgrade works for the period to around 2017. These are mainly required for new wind projects. The key northern works as have been planned are discussed below and illustrated in Figure 5-1.

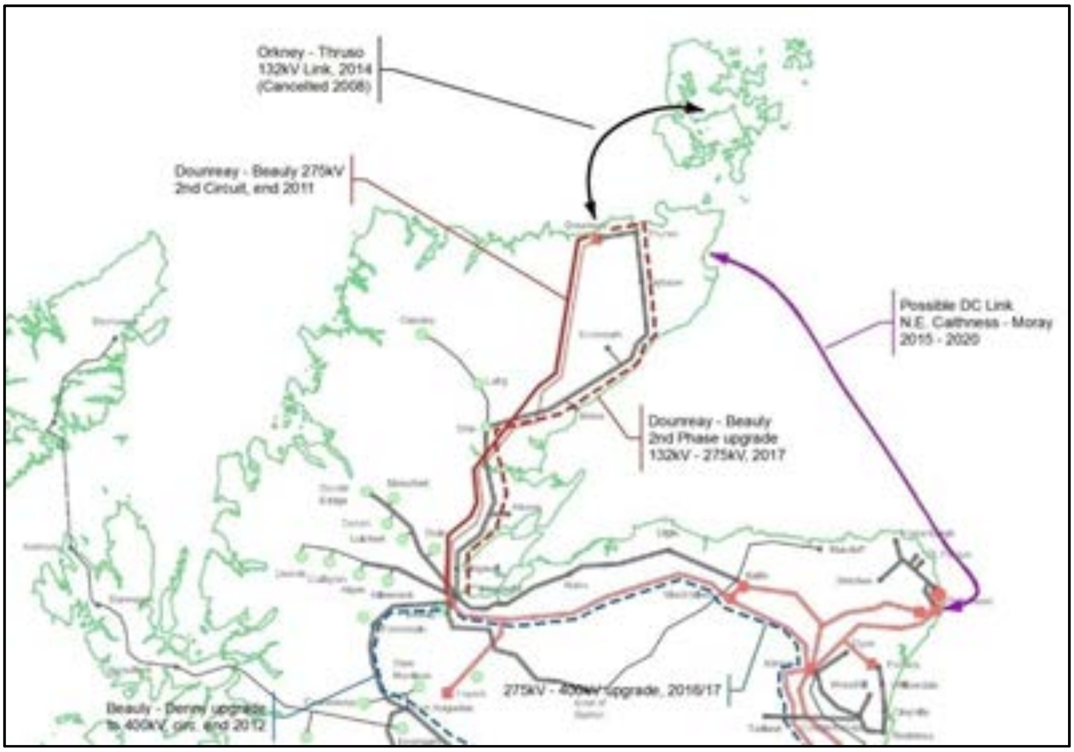

Figure 5-1: North of Scotland transmission system – planned and potential upgrades

5.2.1 Beauly-Dounreay phase 1

The existing Beauly to Dounreay 275kV line is a single circuit only strung on one side of the towers. Beauly-Dounreay phase 1 effectively consists of two parts which will add a second 275kV circuit to the tower line to give approximately 1,000MW total capacity. This is low environmental impact work as no significant new works are required along the tower line route. The result is a significant upgrade that is achievable in short time frames.

Additional work is associated with the second circuit addition and includes the installation of phase shifting quadrature boosters on the Shin 132kV circuits at Beauly, the upgrade of Dounreay‘s existing 150MVA 275/132/kV transformer to a standard 240MVA unit, and the addition of a second 275/132kV 240MVA transformer.

All works are currently tabled for completion by the end of October 2011 but are dependant on upgrades further south including the Beauly to Denny line and likely to slip a year or more.

5.2.2 Beauly-Dounreay phase 2

Beauly-Dounreay phase 2 is a more serious proposition. This reinforcement involves a complete rebuild of the 132kV double circuit between Beauly and Dounreay via Thurso to 275kV. In terms of consenting issues this is more akin to the current and ongoing Beauly-Denny upgrade which, if finally consented, will have taken around 10 years from start to finish. Apart from rebuilding the 132kV double circuit tower line to 275kV, various substation works are required including the creation of 275/132kV substations at Alness and Mybster, and proposed conversion of Thurso GSP to a 275/33kV substation. Other substation works are required over and above this.

The completion date is tabled as the end of November 2017 at present. The work is dependant on Beauly-Dounreay phase 1 and Beauly-Denny.

Given the level of works required and the likely issues with associated consents, a 2017 date is not unreasonable but could easily slip. In discussions, SHETL has suggested that a DC link from Caithness to the south could be a more attractive option although given the suggested scenarios for the Pentland Firth XE suggests both are probably necessary.

Ultimately the need for either will be driven by the changes in the existing queue of generation and the requirements of the Pentland Firth and it is possible that any combination of the two could go forward.

As part of the works examined in this report involves 132kV system extension from Thurso or thereabouts, an upgrade to 275kV would create some issues. XE considers that a 132kV system would likely be maintained if in demand, i.e. by the Pentland Firth, and that the planned 275kV upgrades could interconnect by way of a new 132/275kV substation.

In total, the phase 1 and phase 2 Beauly-Dounreay works will deliver approximately 1GW of firm capacity from the north coast to Beauly further south. There are still severe limitations on transport through this system and Beauly onwards. Further capacity would need a more complete upgrade, probably to form a 400kV ring effectively from Beauly to Denny in the Central Belt and back to Beauly via the north east of Scotland. This would require a further complete line rebuild on at least the Beauly-Dounreay line although the upgraded 132kV could be built to a 400kV specification in anticipation.

5.2.3 Future DC options

The possibility of a DC interconnection from a point in Caithness to Moray has been discussed with SHETL. This could be developed as an alternative to Beauly-Dounreay phase 2 or as a complimentary reinforcement.

Unlike a further upgrade of the Beauly-Dounreay-Thurso system to 400kV, the DC option provides an entirely separate third circuit / path from the region south. It also completely avoids the bottleneck of Beauly.

Further advantage may be gained by avoiding the need for onshore consents for much of the DC work. Only the converter stations and onshore route sections will be relevant to onshore consenting issues. Given typical consenting timeframes for typical onshore works, such as Beauly-Denny, this gives the DC option much benefit.

An issue for an eastern DC connector is however its justification and where and how it will fit into the existing transmission and/or distribution system. The former will need financial commitment from sufficient projects unless up front grid developments become allowed. The second issue arises since bringing the DC interconnector to Caithness for Pentland Firth generation will mean it is relatively remote from the existing Beauly-Dounreay-Thurso transmission system. To get the most out of the DC interconnector it should ideally interconnect to the existing transmission system as well as facilitating off-take of Pentland Firth generation. This requires some thought but there is clearly scope for an interconnection across Caithness to Mybster and/or via an Orkney 132kV ring or indeed continuation of the DC link across Caithness.

For present purposes this report assumes the DC terminal station will be located north of Wick, probably close to a beach landing at Sinclair‘s Bay (or Freswick Bay).

Assuming a landing via Sinclair‘s Bay and location of a new DC to AC converter station just inland, this could provide several hundred MW or more of capacity by way of 132kV and/or 33kV lines out to the northern coast. As set out in Section 5.3 this would be well placed to exploit the south eastern most resource and Gills Bay area resource.

DC systems such as ABB‘s voltage source converter ―Light" technology can be developed in modular fashion and thereby a modest DC interconnector, e.g. 350MW, could be upgraded with additional converter modules and cables as required at a later date. There is much material in the public domain on such systems, e.g. [72].

Development of the main transmission system to this far north east corner also opens up possibilities for onward interconnection to Orkney via an eastern route, probably at 33kV or 132kV and as discussed in Section 5.3.

5.2.4 Orkney 132kV extension

A transmission system extension to Orkney has been planned for some time. However, at the time of writing this report the single onshore wind farm driving this has terminated its grid connection agreements and this reinforcement is therefore no longer in progress. XE is not aware of any project, or collection of projects, that as yet will bring it back to planning.

Despite this, the extension is worthy of discussion as the Orkney 33kV system from Thurso GSP is full and already operating under an innovative RPZ scheme to allow further generation. Clearly, if the transmission extension to Orkney were to come back to planning it could have important implications for not only Orkney generation but for developments in the Pentland Firth which might have a preference to land power on the Orkney side.

The previously planned extension was for a 132kV double circuit over approximately 80km total route length from Dounreay 132kV Substation to Kirkwall on Orkney where a new 132/33kV GSP substation was to be established. The 132kV system was then to be extended as a double circuit to St Marys where a new 132/33kV substation was to be created. The anticipated completion date was October 2013. Other works at the various substations, including reactive compensation plant were included.

The reinforcement would have provided around 250MW+ of non-firm capacity, about half as firm. It would have provided an opportunity to SHETL to relieve pressure on the Orkney system from generation and improve supply quality. It would have provided some potential opportunity for Pentland Firth generation to export via Orkney on a non-firm basis.

Notwithstanding the RPZ generation, there appears to be only one known generation project which is queued with grid for connection and in need of some form of reinforcement works, i.e. Stromness Wave Farm [41]. At 20MW it seems unlikely that 132kV infrastructure would be considered. Some comment on this has been made in Section 5.3.

5.3 Local strategic developments 2012-2020

This section considers developments at 33kV and 132kV, voltages that are both present in the mainland region and which can be used to release tens of MW at 33kV and hundreds at 132kV. The ultimate realisation of 2020 targets of 1,000-1,700MW will also rely on wider infrastructure developments and this has been briefly examined in Section 5.2.

At 33kV and 132kV all overhead circuits can be built on wood poles or indeed undergrounded at additional cost. This helps to reduce the environmental impact and consenting issues. New substations are also required for the strategic works and these will also attract locating and consenting issues. In some cases an offshore substation is worthy of consideration.

All costs are based on typical equipment and works costs as understood by XE and identified by SHEPD and SHETL, and set out in the charging documents [42] and [43]. Costs are defined by local requirements but are generic for a study at this level. All costs are quoted in capital at present (2008) prices. It is assumed that projects will connect to the specified works and as the number of projects and exact arrangements cannot be defined the cost for project metering switchgear is not included. This is unlike the costs provided in Section 3. For guidance, XE suggests a cost of £150-250k is allowed by projects for a single 11kV or 33kV connection respectively at the specified new substations. For 33kV grid infrastructure the costs of the grid works are payable by the project(s) although in some cases are shared with SHEPD. For cases where projects are connecting to 132kV grid no such infrastructure charge is applied. Use of System charges apply in operation in all cases.

Timeframes are indicated based on typical periods for design, consenting, equipment lead times and construction timeframes. Equipment lead times can be very significant for major equipment such as high voltage cables and transformers (2-3 years).

Consenting timeframes are set to a default period of 6-18 months depending on the infrastructure and issues anticipated. It is beyond the scope of this report to examine consenting issues in any detail and time slippage beyond that assumed due to consenting issues is always a real possibility. There is also no guarantee that consents will be obtained. XE has provided typical achievable timeframes to build local infrastructure if consenting is not a major problem and as such these represent the best achievable timeframes. A colour code is used to indicate the potential seriousness of consents with green for relatively straightforward to red for likely to be problematic.

Timeframes are also dependant on the ability of the wider transmission system to accept the export power. A fundamental assumption of this report is that this is possible and a combination of regulatory regime change, grid reinforcement, and reduction in the level of generation seeking connection does facilitate this. If this assumption was not made then the connectable capacity would be very small until close to 2020.

More information on the analysis methodology for capacity, costs, timeframes and consents in contained in Appendix B.

A summary is presented here starting with 33kV infrastructure to deliver tens to a few hundred MW and is followed by 132kV infrastructure which together with wider transmission developments may deliver hundreds to the thousand plus MW required.

5.3.1 Mainland

5.3.1.1 Hastigrow-Gills at 33kV

The 11kV line from Hastigrow Primary to Gills is already built to a 33kV specification. It is therefore an immediate candidate for upgrade to 33kV to release more capacity. The work can be divided into several phases depending on offshore developments but could ultimately release from 8MW up to 60MW with an additional circuit.

- Phase 1. This involves some reconfiguration work at Hastigrow, moving a small number of consumers from the existing 11kV line, and establishing a new 33/11kV primary substation at Gills before operating the line at 33kV. With some 11kV reconfiguration, supply in the area is improved. The capacity released is 8MW.

- Phase 2. Reconductoring the line from Gills back to Hastigrow will increase its rating and the capacity to around 17MW (limited by the line to Thurso). Consideration needs to be given to the 33/11kV transformer(s) at Gills and whether connections are to be 11kV or 33kV with 11kV triggering upgrade. This applies to future phases also.

- Phase 3. A further increase in capacity to around 30MW could be achieved by reconductoring to Thurso GSP. This would be reliant on transformer upgrades at Thurso (or generation constraint) due to the currently limit on firm capacity.

- Phase 4. A second 30MVA 33kV circuit is added to increase export away from Gills to around 60MW. This circuit would connect to the Mybster GSP 33kV system and export via Mybster via a short upgraded section of line. This would additionally be reliant on Mybster 33/132kV transformer upgrades as capacity at Mybster GSP is currently zero (or again, generator constraint could be used to access non-firm capacity).

5.3.1.2 Mt. Pleasant-Murkle-Brough at 33kV

The 33kV system at Mount Pleasant could be extended to the Orkney cable transition at Murkle Bay and onwards to the Brough/Skarfskerry area. This could alternatively be brought straight from Thurso although this would require works within Thurso GSP. This could be tied to the existing Orkney circuits by way of a new switching station at Murkle Bay to give additional switching capabilities in case of faults. For projects however, the new 33kV grid is still relatively far from the offshore development area and it may be attractive to bring the 33kV extension round to the Skarfskerry/Brough area. A single 33kV circuit would give up to 30MW and a double 60MW (both non-firm).

5.3.1.3 Thurso-Brough at 132kV

The large area to be developed off Dunnet Head could contain 80% of the tidal resource (by area), of which most would be landed on the mainland. This is likely to mean 800-1,360MW by 2020 depending on the scenario. There is therefore a need to tackle this area with larger infrastructure from a number of different points. A 132kV extension to Skarfskerry/Brough would be a suitable approach, as would be offshore substations, discussed in the following sections. A 132kV wood pole circuit could release around 150MW, a double 132kV circuit around 300MW. A new GSP would be established at Skarfskerry/Brough which could provide 33kV connection points for various projects. This would likely replace any 33kV extension to the area.

5.3.1.4 Thurso GSP

Thurso GSP is currently run with two 60MVA 132/33kV transformers. These currently have around 26MVA of spare firm capacity available (86MVA non-firm). The preceding 33kV extensions from Thurso/Mount Pleasant and Hastigrow would demand up to 90MVA or so. Increasing transformer rating to 120MVA would almost achieve this and given demand offset and generation diversity might be acceptable with some precautions. Access to non-firm capacity via generation constraint may also be possible, see also Section 4.2.1.

5.3.1.5 Mybster GSP

To take Hastigrow-Gills above 30MVA XE has suggested a second circuit to Mybster GSP. Mybster GSP currently has no firm capacity and so transformer upgrades are required. These are already under consideration by SHETL/SHEPD and could be achieved similar to Thurso transformer upgrades or potentially avoided if generator constraint is acceptable in accessing the non-firm capacity.

5.3.1.6 Offshore 132/33kV substations

In developing the large area off Dunnet Head XE suggests offshore substations may be required unless all the development takes place very close to shore. A typical 132/33kV offshore substation, as seen on various offshore wind projects, could release in the order of 300MW or more by way of a double circuit (non-firm) 132kV extension from Thurso or thereabouts.

XE notes that previous plans for a 132kV link to Orkney were brought from Dounreay. This is more distant for the substations and would entail more cost, although plans to upgrade the existing onshore 132kV system to 275kV by 2017 will affect the choice. The substations could be brought from Dounreay or near Thurso via a 132kV switching station which could later be upgraded to a significant 275/132kV transformer substation.

Given the offshore geology, shown in Figure 2-8, XE suggests the substations can be located on more favourable seabed towards the western end of the offshore area. This means that more eastern parts of the largest resource area can be developed by way of a Skarfskerry/Brough substation and/or a similar development around South Walls on Orkney.

5.3.1.7 New Thurso 132kV switching station

It is noteworthy that the 132kV system may be upgraded to 275kV by 2017 [44], and indeed, to meet the 2020 targets this may be essential. Reinforcements at Thurso GSP, and 132kV system extensions will be required for the Pentland Firth generation scenarios. XE suggests it is worth considering a 132kV marshalling switching station which could be interconnected to a future 275kV system. There are various options which would be dictated by transmission considerations, the level of generation, and the presence of a possible eastern DC interconnector.

5.3.1.8 Duncansby Head/John O' Groats at 33kV or 132kV

The area to be developed around Duncansby Head is relatively remote electrically. Depending on development scenarios a 33kV substation established in the area could be sufficient. The existing 33kV system is relatively far away and would need upgrading if it were extended. More interesting and perhaps more attractive is the prospect of a new High Voltage DC link being established in the area. This is discussed in Section 5.2.3 of this report.

A 33kV extension to the Duncansby Head region could release 30MW on a single circuit, or 60MW on a double circuit (both non-firm). A new 33kV switching station would be established. Alternatively, if the area was likely to warrant further capacity, and perhaps to allow some off-take from other areas of interest such as the area north of Stroma, a 132kV wood pole circuit and new 132/33kV substation could be built out to release up to 150MW. A double circuit could double this. There is also a possibility to take the 132kV circuits up the coast subsea if consenting issues were serious.

5.3.1.9 Stroma at 33kV

Access to the central resource in the Pentland Firth could be achieved by way of a subsea cable to Stroma and a sensitively sited 33kV switch house on the island avoiding its western environmental designations. The 33kV system could be connected back to the new Gills Primary. A second or even third 33kV circuit could be developed from Stroma to a new Duncansby 33kV switching station or 132/33kV GSP as and when possible. Off-take to South Ronaldsay could also be an option at some point.

5.3.1.10 System interconnections

It is beyond the scope of this report to suggest how SHETL or SHEPD may ultimately wish to develop the grid over and above the connections examined herein but a level of interconnection is desirable from a security perspective. In particular this may involve interconnection between an eastern DC station and the 132kV and/or 275kV grid to the west.

XE has discussed these issues with SHEPD and SHETL. From a transmission system perspective it is desirable to run the DC link across to the existing transmission system, probably near Mybster, by underground DC cable to provide a strong tie in. However, to develop the John O'Groats / Duncansby Head and Stroma area more fully would require new (AC) 132kV infrastructure back across the region. In addition, the development of a potential 132kV (or 33kV) eastern subsea cable route to South Ronaldsay on Orkney would also require further build across the mainland. There is therefore a need to carefully consider the best way to develop the eastern marine energy resources whilst achieving a satisfactory level of transmission system interconnection. For the purposes of this study XE has assumed the DC converter station will locate on the east coast and provide an AC 132kV connection.

5.3.2 Mainland summary

Table 5-1 below summarises the strategic grid work that can be undertaken to release capacity to the mainland for Pentland Firth generation. All connections are given costs based on generic metrics, MW capacity based on non-firm capacity over single or double circuits, best timeframes based on what is achievable provided consents are not problematical and wider system transmission issues do not act as a barrier. Incremental costs are indicated by a "+". With the exception of Thurso and Mybster transformer works, and Gills works, all distribution costs are attributable solely to the generation. Gills costs are shared although the bulk of the cost will be attributed to the projects and is thus not shown separately.

Consent risk is indicated in colour and escalates with voltage and requirements for new lines and substations. Clearly, consents are a major issue and slippage of timeframes is possible, if not likely, in all cases. All costs assume overhead lines are used where practical.

In the case of works to Duncansby Head, the tabled connections are brought out from a potential DC link and dependant on its timeframes. A temporary lower capacity alternative in the shorter term would be to build out a 33kV connection from the upgraded line to Gills. The works, capacity and timeframes are shown graphically on Figure 5-2.

Connection works Best date	Capacity [MW]	Approx costs [£k]	Works and consents	Best timeframe
Gills 33kV upgrade phase 1	8	1,060	Revised consents for overhead line, works at Hastigrow plus new Gills primary substation.	2-3 years
Gills phase 2	17	+690	As above plus reconductoring.	
Gills phase 3	30	+1,015	As above plus reconductoring to Thurso. Thurso transformer upgrades required.	2-3 years
Gills phase 4	60	+4,113	As above plus new 33kV circuit to Mybster. Mybster transformer upgrades required.	2-4 years
33kV extension to Murkle and on to Brough	30	4,048	New overhead line from upgraded Mt Pleasant (or Thurso) line to Murkle and onwards to Brough. New 33kV station at Brough. Thurso transformer upgrades required.	2-4 years
2nd 33kV circuit	60	+3,737	As above plus new circuit from Thurso.	
Thurso 132/33kV transformer upgrade	As required	3,033 (1,872 shared)	New transformers and associated works for above 33kV options.	2-3 years
Mybster 132/33kV transformer upgrade	As required	3,033 (1,872 shared)	New transformers and associated works for above 33kV options.	2-3 years
132kV extension to Brough	150	15,194	132kV works at Thurso. New 132kV wood pole line to Brough. New 132/33kV GSP at Brough.	4-5 years
2nd 132kV circuit	300	+10,941	As above plus new circuit from Thurso plus additional transformer capacity at Brough.	
132/33kV offshore substation (each)	300	79,299	132kV works at Thurso or Dounreay. New 132kV subsea cables to 132/33kV offshore GSP.	4-6 years
132kV switching station	n/a	7,600	132kV switching station near Thurso to facilitate 132kV grid extensions.	4-5 years
Duncansby Head 33kV	30	2,591	New single wood pole 33kV circuit from DC converter station.	2015-2020 (DC)
	60	+1,725	As above plus second circuit.	
Duncansby Head 132kV	150	9,251	New wood pole 132kV line from DC converter station plus new 132/33kV GSP at Duncansby.	2015-2020 (DC)
	300	+8,516	As above plus second 132kV circuit and additional transformer capacity at Duncansby.	
Stroma 33kV	30/60	5,500/ +4,691	New 33kV circuits to new Gills Primary and later Duncansby 33kV or 132kV development.	4 years +

Table 5-1: Mainland strategic summary

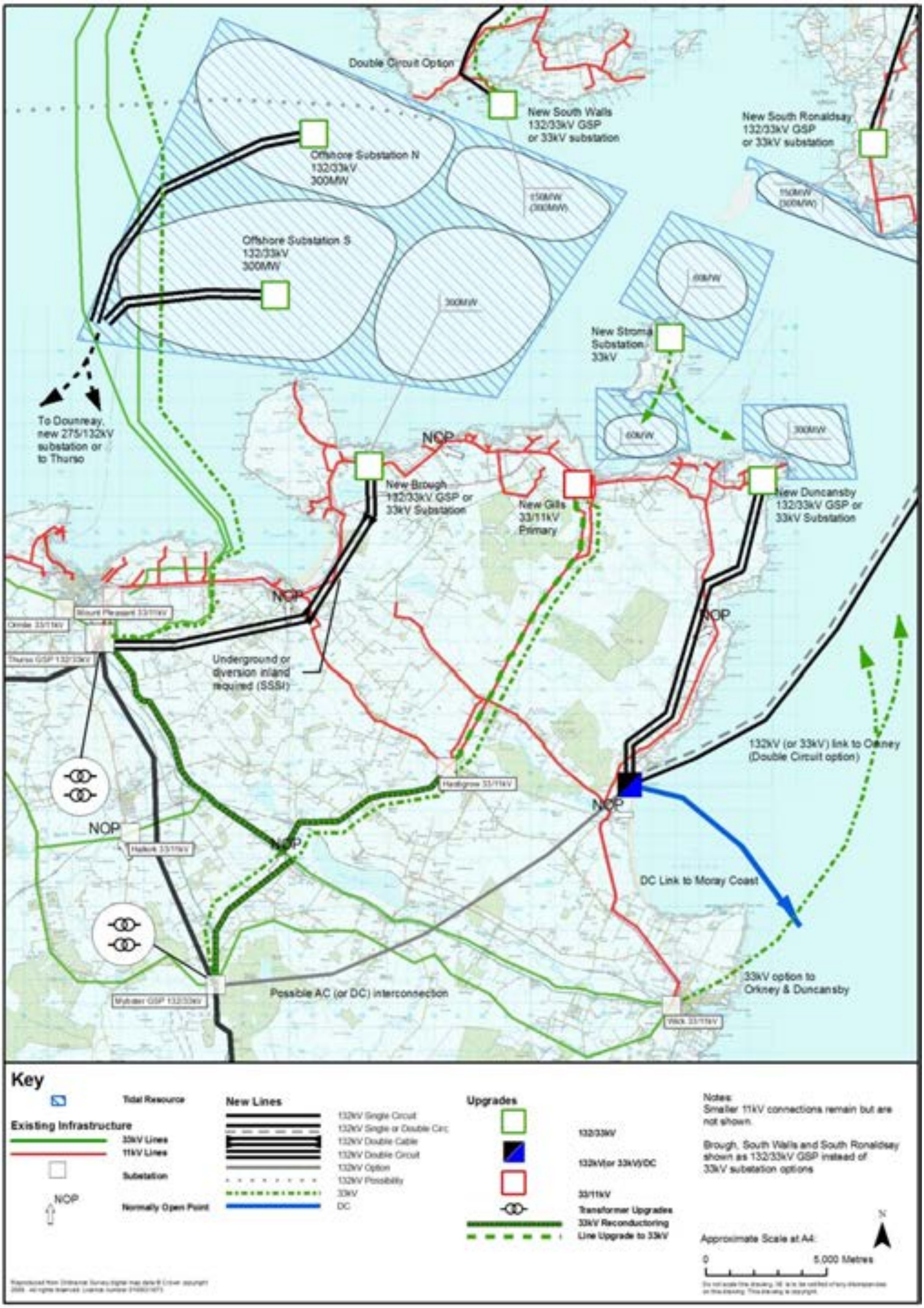

Figure 5-2: Mainland strategic summary

5.3.3 Orkney

Marine energy off-take to Orkney is expected for projects located closer to Orkney. However, this has disadvantages. First, the power is taken north and must be brought back south to the mainland by new grid infrastructure. Second, accessibility for subsea cables is relatively limited, and third, costs will be high for subsea routes. These are reasons why offshore substations as discussed in Section 5.3.1.6 may prove attractive – they avoid a need to land cables on Orkney and get the generated power back to the mainland directly.

Orkney is probably only to be preferred for landings where off-take to the mainland is impractical and/or simply too expensive. This is particularly the case for the north western development area off Hoy and the north eastern region off South Ronaldsay.

Taking major new infrastructure to Orkney also offers SHETL/SHEPD an opportunity to develop the island system and release further capacity from the currently constrained Orkney system. This is not a focus of this report but is significant and XE has given consideration to creating an Orkney-mainland loop, potentially at 33kV, but particularly at 132kV.

Except for very small developments joining the existing Orkney RPZ, all new works are dependant on new subsea cables from the mainland to Orkney. These could be at 33kV from Thurso following the existing cable route or 132kV from Dounreay. The potential development of an eastern mainland DC converter station also opens interesting possibilities to develop an eastern 33kV or 132kV subsea link, probably landing on South Ronaldsay and possibly continuing to mainland Orkney.

5.3.3.1 South Walls (Hoy) at 33kV

The existing circuit from Scorradale to Lyness and then Flotta currently contains 12.5MW of generation and with extension to the area around South Walls could accept up to 1.5MW into the Orkney RPZ. Upgrade of the existing circuit back to Scorradale could release up to 18MW but would be severely constrained under the RPZ. With the installation of a new 33kV subsea cable circuit from Thurso to Scorradale this 18MW could be realised. Further capacity would require a complete new circuit to Thurso. This option has serious consenting issues on Hoy. There may be some potential to land a cable from Thurso close to South Walls but the offshore route appears difficult and warrants further investigation.

5.3.3.2 South Ronaldsay at 33kV

The existing 33kV system on Orkney heads south from Kirkwall but stops on mainland Orkney at St. Mary‘s. To develop generation on South Ronaldsay requires a 33kV extension from St. Mary‘s to establish a new 33kV switching station on South Ronaldsay. This would require sea crossings and release approximately 18MW, limited by the Kirkwall-St. Marys circuit rating. The generation would be severely constrained by the RPZ.

To extend capacity to a maximum 29-30MW, it would be necessary to upgrade the St. Marys circuit, upgrade from Kirkwall to Scorradale and install a new subsea cable from there to Thurso. This would also be contingent on Thurso transformer upgrades.

An alternative to the above is to develop a new 33kV switching station on South Ronaldsay but off-take the generation to the north eastern mainland by way of an eastern 33kV subsea cable route, possibly to a new DC converter station on the mainland. Timeframes would be dependant on the DC converter station meaning this is a longer term (2015-2020) option. The only other 33kV eastern option is to bring a cable from Wick but this would also require upgrades between Wick and Mybster as well as Mybster transformer upgrades.

5.3.3.3 Dounreay-South Walls 132kV

Work on a Dounreay to Orkney 132kV link had already started but is now understood to be cancelled following termination of the wind farm driving it. The link was to create a new 132/33kV GSP at Kirkwall and then terminate at St. Mary's. This is a substantial part of the way to South Ronaldsay (see Section 5.3.3.4).

To develop generation off Hoy the 132kV link need only land at Scorradale and double back to South Hoy. This dog leg adds additional cost but provides significant additional benefits to SHETL in extending the 132kV system to mainland Orkney, strengthening the island and potentially developing a complete 132kV Orkney ring with a potential eastern route. Subsea cable routing north of Hoy is likely to be problematic as it will need to go through a strong tidal area where rock may be exposed. This will need further examination.

Once on Hoy a new 132kV wood pole line would be built, hugging the eastern side to avoid the Hoy environmental designated areas as far as possible. Proximity to the designations is likely to be a consenting issue nonetheless. The line would terminate in a new 132/33kV GSP around South Walls to allow an off-take of some 150MW for a single circuit. A double circuit would release 300MW.

As with 33kV development to South Walls there is some possibility of a direct subsea cable route into South Walls which could provide good cost savings and potentially open a southern Orkney ring system.

5.3.3.4 South Ronaldsay 132kV

A new 132/33kV GSP established on South Ronaldsay could off-take 150MW from the north eastern offshore development region. The landings for cables from this region are likely to decide the exact location given the rocky coastline. To establish the GSP would need either a substantial development from Dounreay via mainland Orkney or via the potential southern route. An alternative is the development of an eastern 132kV subsea route from a new mainland DC converter station. A landing is expected to be feasible mid-way up South Ronaldsay and the GSP developed at the southern end. Timeframes for both are likely to be long. Upgrading the South Ronaldsay to eastern mainland circuits to double circuit could increase capacity to 300MW and this might assist in exploiting the central resource area.

5.3.3.5 132kV Orkney ring

It is possible to link a 132kV circuit from Scorradale to South Ronaldsay. This might be undertaken as a general reinforcement, but would also permit export from both South Walls and South Ronaldsay through a single cable to either Dounreay or eastern mainland. Firm capacity would be around 150MW, non-firm 300MW with a single circuit ring in place.

Initial export, probably to Dounreay, could be shared by Hoy and South Ronaldsay generation and a second eastern route developed later.

The 132kV ring could also be upgraded to a double circuit allowing more capacity to be brought from Orkney or the Pentland Firth via the Orkney Islands. Firm capacity would be around 300MW, non-firm 600MW.

The possibility of a southern ring may also exist. This would provide good cost savings but needs further examination in terms of landing around South Walls and it would not bring wider benefits to Orkney and other Orkney wind and marine generation.

5.3.4 Orkney summary

Table 5-2Table 5-1 below summarises the strategic upgrades that can be used to release capacity in the southern Orkney region for Pentland Firth generation. All connections are given costs based on generic metrics, MW capacity based on non-firm capacity over single or double circuits, and timeframes based on what is achievable provided consents are not problematical.

The 33kV works include elements of cost sharing. For the most part the cost savings for projects are relatively small and the total capital cost is effectively the project cost. An exception to this is the South Walls strategic upgrades on the Lyness 33kV line and back to the mainland. The estimated cost to the projects is given in brackets.

As with the mainland, consent risk is indicated in colour and escalates with voltage and requirements for new lines and substations. Use of an eastern subsea route to a new mainland DC converter station is time limited by the establishment of the DC station. As with the mainland, consents are an issue, especially on Hoy, and slippage of timeframes is possible in all cases. The works, capacity and timeframes are shown graphically on Figure 5-3.

Connection works Best date	Capacity [MW]	Approx costs [£k]	Works and consents	Best timeframe
South Walls 33kV (1)	*~ 1.5*	1,592	Extend 33kV system from Lyness. RPZ contingent.	2-3 years
South Walls phase 2	*< 18*	+810 (+486 shared)	Upgrade from Lyness to Scorradale. RPZ contingent and severely constrained.	
South Walls phase 3	18	+21,980 (+13,188 shared)	As above plus new 33kV subsea cable to Thurso plus Thurso transformer upgrades.	4-5 years
South Ronaldsay 33kV extension	*< 18*	2,286	New 33kV line/cable from St Marys to South Ronaldsay. RPZ contingent & heavily constrained.	2-3 years
South Ronaldsay 33kV upgrades to Thurso	30	+23,830	As above plus upgrade from St Marys to Kirkwall, onwards to Scorradale plus new subsea cable to Thurso. Thurso transformer upgrades required.	4-5 years
New 33kV eastern link to South Ronaldsay: i. from Wick	30	23,591	Install new subsea cable to South Ronaldsay and reinforce from Wick to Mybster GSP. Upgrade Mybster GSP transformer capacity.	4-5 years
ii. from DC station	30	20,126	Install new subsea cable to South Ronaldsay from mainland DC station.	2015-2020 DC
Thurso 132/33kV transformer upgrade	As required	3,033	Uprated transformers or new transformers and associated works for above 33kV options.	2-3 years
Mybster 132/33kV transformer upgrade	As required	3,033	Uprated transformers or new transformers and associated works for above 33kV options.	2-3 years
132kV extension to South Walls	150	66,812	Works at Dounreay. Subsea 132kV cable to Scorradale. 132kV line/cable to South Walls. New 132/33kV GSP at South Walls.	4-5 years
2nd 132kV circuit	300	+66,075	Complete second circuit from Dounreay plus additional transformer capacity at South Walls.	
132kV extension from Scorradale to South Ronaldsay	150	18,659	New wood pole 132kV circuit to Kirkwall-St. Marys-South Ronaldsay. New 132/33kV GSP on South Ronaldsay	4-5 years
New 132kV eastern link to South Ronaldsay	150	40,698	132kV subsea cable from DC converter station to South Ronaldsay. New 132/33kV GSP at South Ronaldsay if required.	2015-2020 DC
2nd 132kV circuit	300	+39,963	Complete second circuit from DC converter station plus additional transformer capacity at South Ronaldsay if required.	
New Orkney GSP (for SHETL/SHEPD)	*90*	*4,000*	*Establish new GSP at Scorradale or Kirkwall to strengthen Orkney system.*	*4-5 years*
	180	*7,266*		

Table 5-2: Orkney strategic summary

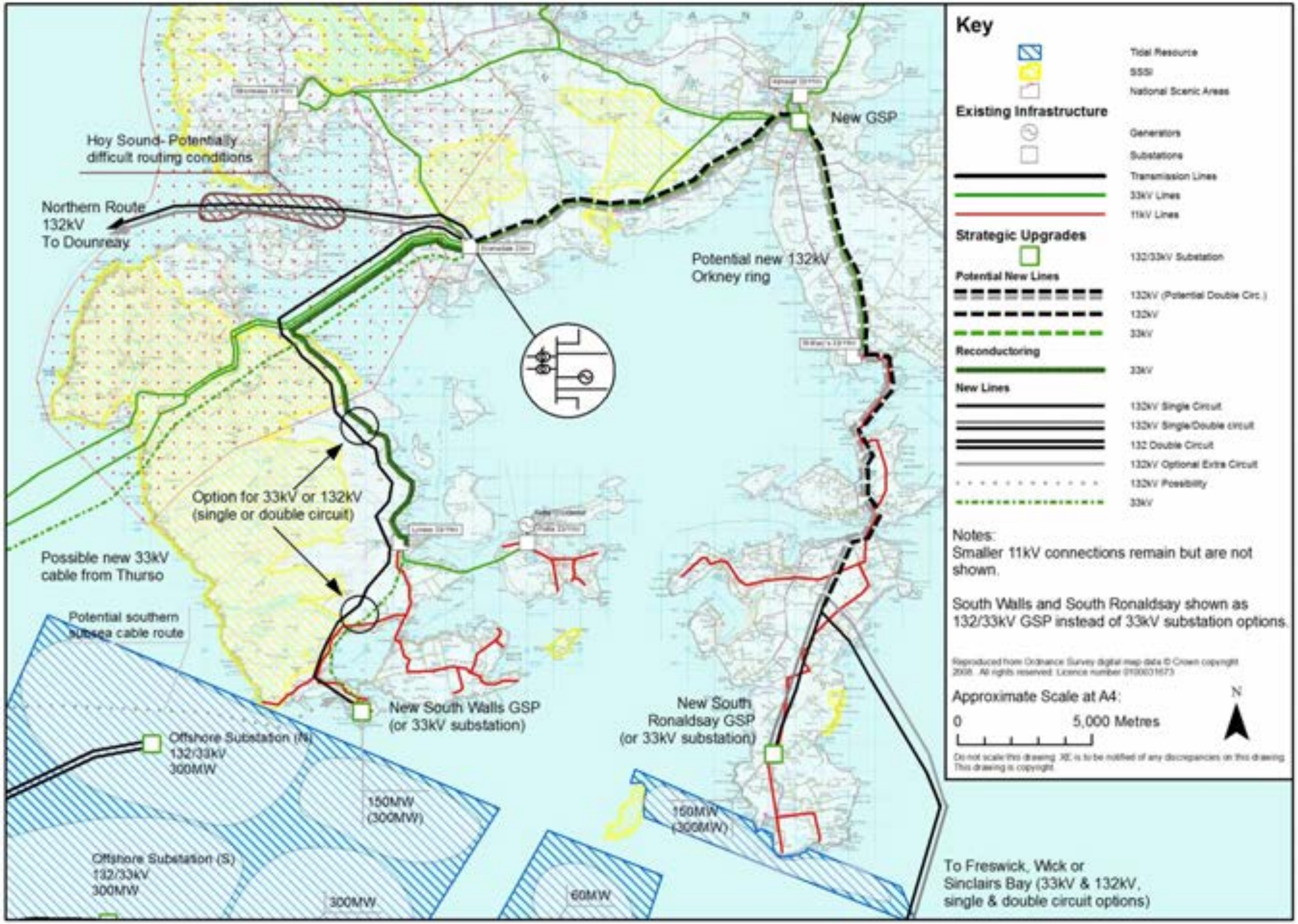

Figure 5-3: Orkney strategic summary

5.4 Section summary

This section of the report has examined the optional works required to ultimately deliver the targets of 1,000MW or 1,700MW of Pentland Firth tidal generation by 2020.

To deliver the targets a significant amount of new grid infrastructure will be required. This could be on Orkney as well as the mainland, therefore driving a need to take new subsea cables to Orkney at either 33kV, or more likely 132kV.

XE has attempted to develop the grid sensibly and efficiently to keep all developments to sensible sizes and has used wood pole overhead lines to reduce consenting issues. Despite this, consents will be a major factor and could push all timeframes back considerably.

A key strategic upgrade is the Hastigrow to Gills line on the mainland. This is built to 33kV specification but currently operated at 11kV. Uprating operation to 33kV could progressively allow from 8MW to 30MW from Gills with only upgrades and a new Gills Primary substation. Consents are fairly low and the work would improve local electricity supplies. It could be in place within two years. A second circuit from Gills to Mybster could add another 30MW but would constitute a later addition.

By contrast all other works that can release tens to hundreds of MW of capacity require new lines and substations with timeframes of 3-5 years at best.

For many of the works there will be a choice as to whether they should be built at 33kV (slightly less local impact, cheaper and faster but less capacity – typically 30/60MW) or at 132kV (more local impact, more cost and slightly longer timeframes but more capacity – typically 150/300MW). There is a trade off here with smaller initial marine energy developments likely to trigger 33kV works which may then be usurped within a few years by a need for 132kV. This would be inefficient and needs careful consideration.

As Orkney presents major reinforcement issues, it is likely that the mainland will see most of the initial developments. Anything on Orkney will require new subsea cables which will drive longer timeframes and higher costs. However, it seems that works on Orkney may be necessary, possibly forming a later development stage, and providing interesting possibilities for other generation, not just Pentland Firth marine energy.

Wider transmission system developments, apart from being required to take power away from the region, will effect development. A potential eastern DC connection may offer opportunities to significantly develop the area around Duncansby Head on the mainland, and, develop eastern subsea cable routes to South Ronaldsay. This will provide off-take from South Ronaldsay and present a possible opportunity to create a mainland-Orkney ring system.

It may not be practical or cost effective to take off all of the region‘s marine energy by way of onshore infrastructure and particularly for the large western resource area, offshore substations may present a good option. They are expensive but allow access to the middle area of resource without an overabundance of onshore infrastructure, consenting issues, and overabundance of offshore to shore cabling.

Figure 5-4 presents a graphical overview of the possible grid development options.

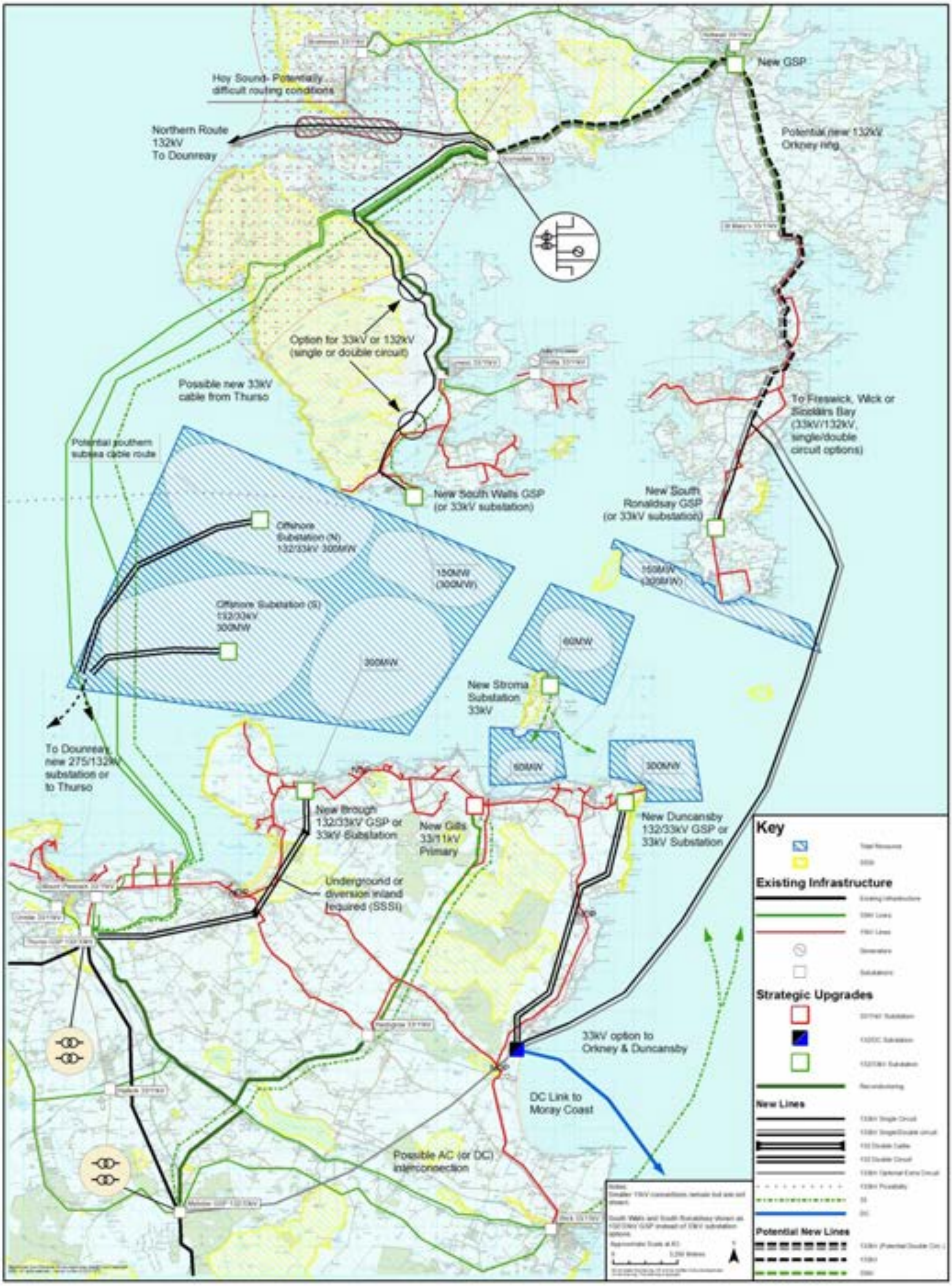

Figure 5-4: Overview of potential strategic grid to meet 2020 targets

6 Regulatory issues

6.1 Introduction

This section of the report examines the impact of the regulatory regime on the wider (and local) transmission system in freeing up capacity for Pentland Firth generation. As part of this, a brief review of the queue of generation waiting to connect in Scotland is also undertaken.

Regulatory change is seen as an essential part of the process for facilitating access of Pentland Firth generation to the wider transmission system, without which prospects for major developments are poor. It also has a role to play in delivering the more local infrastructure which has been the focus of this report. Regulation of the electricity network has a bearing on:

- Which projects can connect.
- When projects can connect.
- The level of utilisation of the existing system.
- How much new capacity can be progressed by the Transmission Owners (TO).
- How much different users pay for connection to, and use of, the electricity network.

It is however important to keep in mind that regulatory changes cannot create new capacity where it is physically impossible to provide it and cannot speed up the consenting process, which is a matter for the government and the public.

With regard to the wider system key regulatory workstreams such as the Transmission Access Review (TAR) [45] are examining issues such as new transmission access products which would enhance the utilisation of the existing system thereby allowing more generation to use the system by methods such as sharing of capacity. Most controversially, it is also exploring the option of removing all existing access rights and auctioning them.

An integral part of TAR has also been the evolution of the existing "locational" charging regime for transmission access. Charging is a major issue, especially for northern generators such as those in the Pentland Firth, where locational charging results in very high costs to use the transmission system once connected. Notionally separate to TAR, there has also been parallel work on charging arrangements for offshore connections and the Scottish Government has put forward a proposal which seeks to charge for access on a non-locational basis, see later Section 6.5.6. This would result in lower costs to generation in the Pentland Firth.

Another key issue for the Pentland Firth is the delay in getting connected and being able to use the transmission system due to the existing GB queue of generation already waiting to be connected and gain access to use the system. This has arisen due to various reasons but the basic issue is that provision of transmission capacity can only be examined once projects have formally come forward and entered into agreements which require underwriting of some of the costs. Generally speaking, by the time projects can afford to fund reinforcements, there is insufficient time to plan and develop the necessary grid works for them to be ready in time for the generator.

Finally, the Regulator and the TOs are looking at whether the TOs might be less risk-averse in the provision of new infrastructure. This means allowing the TOs to invest in advance of generators' underwriting the investment, a potentially key issue for timely delivery of grid capacity to the Pentland Firth at a local level.

The remainder of this section considers some of the workstreams on access reform. It is not exhaustive and only key workstreams are considered.

In discussing each key workstream, XE has used a colour code to highlight the most important ones for delivery of Pentland Firth marine energy. The colour code is as follows:

- Key workstream likely to deliver additional transmission capacity in the near to medium term.
- Workstream likely to be of some benefit but not necessarily significant, perhaps having wider benefits or longer term impacts.
- Workstream unlikely to assist Pentland Firth generation or indeed acting as a barrier, perhaps through the blocking of capacity or through the imposition of high charges.

6.2 Transmission Access Review

6.2.1 Introduction

The so-called Transmission Access Review started as an initiative from the UK government‘s Department for Business, Enterprise and Regulatory Reform (BERR)[ii] and the regulator OFGEM to bring together and build upon disparate workstreams on transmission access [46] [47]. It has latterly passed to National Grid to develop detailed changes to the transmission grid access code – the Connection and Use of System Code (CUSC) and associated charging arrangements.

National Grid has formed three Working Groups (WGs) to assess six CUSC Amendment Proposals (CAPs) for new transmission access products. The WGs are also, at the same time, considering consequent changes to charging for transmission access. National Grid‘s proposals are all centred on changes to its existing Investment Cost Related Pricing (ICRP) charging methodology.

The amendments examine the most appropriate form of access required, and whilst proposed by National Grid, essentially represent an attempt to bring together a wide range of views and collectively develop a number of access models from which the regulator can choose.

The focus points are:

- Increasing the utilisation of existing transmission capacity through the creation of short term access products.
- The release of existing access rights back on to the market through reform of the long term access arrangements.
- The concept of —connect and manage” rather than —invest and connect”, i.e. allowing generators to connect ahead of completion of all the reinforcement works required.

All three of these could help free up capacity on the wider transmission system and assist Pentland Firth generation in being realised in the timeframes it requires. They are discussed in the following sections.

[ii] It should be noted that the Energy Group from BERR has been merged with much of the Climate Change Group, previously housed within the Department for Environment, Food and Rural Affairs (DEFRA), under the newly formed Department of Energy and Climate Change (DECC).

6.2.2 Short term access

Increasing existing system utilisation is being progressed through the proposed introduction of new short term access products. These products seek to release “spare” capacity to the market – this can be either capacity that is truly spare, or capacity that existing generators have booked, but are not at one time or another actually using. No one generator uses transmission capacity to its full extent all of the time. Intermittent generators‘ output varies with weather/sea conditions, whilst other generators may vary their output according to market conditions. The aim is to encourage different generators with different generation profiles to complement each other and make better use of the existing assets.

- TAR short term access could be useful to the Pentland Firth generators but would depend on whether other generation in the area could complement the pattern of output from tidal generation. There are deterministic models which could examine the potential for “sharing” of capacity with other intermittent generators. Pending the outcome of TAR, HIE could look into bilateral negotiation of sharing arrangements to secure some capacity.

6.2.3 Long term access

The release of existing rights is concerned with providing better closure signals for existing power stations. The proposals are for a redefinition of long-term access rights through an explicit definition of the time for which access is booked, and, additionally, to allocate all rights via an auction process.

The latter auction proposal is very controversial. OFGEM believes that it could be an efficient means of allocating capacity to those who most value it. However, the electricity industry, including renewables, does not support the proposals because of concerns over the cost and complexity. There is also a question mark over the legality of an auction in its most extreme form, i.e. an auction of all existing rights and future bookings.

- TAR is about clarity on when capacity will be released by existing generators and as such it could help HIE understand whether it needs to wait for system upgrades, or whether earlier connection dates might be possible through freeing up of existing capacity. There are some legal arguments which could delay this aspect of TAR. In the meantime, HIE may wish to use the short term arrangements described above.

6.2.4 Connect and Manage

At the moment, the grid companies generally operate an “invest and connect” regime where generators connect once the grid companies have invested in and provided the system reinforcements required to accommodate them. “Connect and Manage” is a proposed alternative approach where the grid companies would allow generators to connect in advance of system reinforcements and take more system balancing actions to accommodate them. The idea is that a Connect and Manage regime would provide a stronger and more direct onus on the grid companies to build new capacity and better utilise existing assets.

Connect and Manage is popular with renewable generators but many stakeholders are concerned about the consequences (mainly the costs) of an unfettered Connect and Manage policy.

- TAR Connect and Manage could allow Pentland Firth generation onto the transmission system ahead of wider reinforcement works. The commercial form this might take and the costs to the generators are still however in development.

6.3 Other key consultations

6.3.1 GBSQSS Review

The current firm-access-only (long term) regime is defined in technical terms in the GB Security and Quality of Supply Standard (SQSS) [48]. Moving to less-firm transmission access rights will require a major review of the SQSS. National Grid has initiated a ―fundamental" review of the GB SQSS in the light of the work of the TAR WGs [49]. Changes to the SQSS are central to meeting the objectives of the TAR work, and so this review is very important. Existing work on intermittent generation is being rolled into the present review [50].

OFGEM has also stated its willingness to allow interim SQSS derogations to facilitate near-term connections under a ―form of" Connect and Manage. This is very much framed as an interim measure to accommodate existing projects which are in a position to proceed. The preference is to move towards a more long-standing regime rather than rely on derogations, and so this option should be superseded by an altered GB SQSS.

- Changes to the GB SQSS are important to assist Pentland Firth generation as they are required to support TAR and to allow more intermittent generation onto the same amount of grid.

6.3.2 Grid company investment incentives

OFGEM has announced a wholesale review of the financial regulation of the grid companies, and, specifically, of their incentivisation to invest in new capacity [51]. It has mooted the prospect of allowing a rate of return on speculative investments, which would incentivise at least some investment in advance of firm user commitments from generators. The grid companies have been formulating ideas which have been discussed with OFGEM and will shortly be issued for consultation. Proposals may include for instance over-sizing new capacity to accommodate forecast use.

These proposals are an essential element of delivering future network capacity in a timely fashion. At present the grid companies are very risk averse and given the timescales in planning and constructing new lines, this leads to situations where generators are ready but waiting for new strategic upgrade capacity.

Aligned to this is work on strategic planning of reinforcements. OFGEM has sponsored work looking at future network scenarios and an Electricity Network Strategy Group has also been re-formed and tasked to consider strategic planning of the grid for 2020-30 [52]. The Electricity Network Strategy Group‘s plans will be published in January 2009.

These initiatives are extremely important for emerging technologies in offering a route by which grid investment can be undertaken on behalf of generic, rather than specific, projects. It is clearly very important to the Pentland Firth for timely delivery of both local and wider grid works.

- Work on grid company investment incentives is fundamentally important in enabling more timely delivery of grid capacity and over-build for anticipated future use. This impacts on the local works and wider transmission system works.

6.4 The queue of generation

6.4.1 Introduction

As noted earlier, the current regime for connecting generators is based on an ―Invest and Connect" approach. The electricity network is interconnected and is built to collect, transmit, and distribute electricity from generators to demand customers. Generators need to wait for grid assets to be built before they can connect, and because groups of generators tend to be contingent on the same assets for transmission of their power, this leads to generators queuing for wider transmission system reinforcements in what is now referred to as the ―GB queue". The back end of this queue and hence any new applicants are in general currently being given grid connection dates of ―beyond 2018". This applies to all transmission connected generators and large embedded generators (above 10MW in grid network in the north of Scotland) and hence affects most of the commercial scale Pentland Firth generation.

6.4.2 Current queue statistics

The queue is built up of a large number of projects at varying stages and is subject to change. This will be a critical factor in freeing up capacity. Key issues are:

- Terminations of projects in the queue for various reasons including failure to obtain planning permission.
- Reduction in capacity requirements of projects in the queue for various reasons but particularly as a result of developers over-sizing their grid connection applications on the basis that it is easier to relinquish than to obtain later, and as a result of planning restrictions.
- Date slippage of projects in the queue.
- Manipulation of the queue to bring projects forward if they can connect sooner than their scheduled dates.
- Closures of currently connected generators.
- Applications of new competing generators extending the queue.
- Network reinforcement plans falling behind schedule or, possibly, being refused planning consent.
- Network reinforcement plans changing as a result of changes to queued generation.

Much of the above requires a degree of speculation and thus whilst a best view can be taken, it could be subject to considerable error. The following subsections examine these issues at high level to provide a view on how the queue might change in the future.

Analysis of the National Grid Transmission Entry Capacity Register [41] yields the following statistics for the GB queue as of November 2008:

- Contracted and yet to connect in northern Scotland (SHETL) 5,016MW
- Contracted and yet to connect in southern Scotland (Scottish Power) 3,559MW
- Total contracted generation to be connected in Scotland 8,575MW

6.4.3 Capacity reductions (planning and consents)

Capacity reductions are generally due to planning and consenting issues which force projects to reduce capacity or in extremis terminate agreements due to rejection of planning consents. Developers can adopt a strategy of over-sizing their planning and grid applications, fully anticipating that these numbers will be negotiated downwards. This is exacerbated by the need to apply for grid capacity well in advance of a project‘s completion, and the currently relatively low cost of booking more capacity than a project may or may not need. Therefore it is widely accepted that capacity reductions will occur.

It is very difficult to predict what decrease in queue capacity will be seen as a result of terminations and reductions. XE has undertaken a brief historical analysis based on the queue as registered between the end of March 2008 and November 2008 and has found the following:

- Capacity has reduced by 430MW across Scotland.
- Reductions in the north (SHETL) account for 350MW.
- Reductions in the south account for 80MW.
- An additional 137MW has also been released, primarily from Hunterston nuclear power station.

Whilst this limited time window can only provide a very loose indication of queue capacity reduction, it does show capacity reductions are already happening and given the volume of projects still in planning or due to enter planning suggests a lot more is to come.

6.4.4 New generator applications

It is very difficult to predict what increase in queue capacity will be seen as a result of new applicants and XE notes that embedded generation may start to increasingly appear in the queue also as a result of regulatory changes. At present, smaller projects may be proceeding without any participation in the queue. A brief historical analysis based on the queue as registered between the end of March 2008 and November 2008 has found only one new project – a 50MW scheme in the SHETL area.

This suggests new entrants are limited and largely discouraged by the currently poor prospects, i.e. “beyond 2018” dates.

6.4.5 Existing generator closures

The transmission system operator has very little visibility of existing generator closures or reductions in capacity. For closures, only six months notice is currently required and hence there is no incentive on generators to provide any forewarning as economics can change and the ethos is to hold connection capacity if it might be useable. However, two important potential closures are looming. They are:

- Cockenzie coal fired station in 2013 releasing 1,152MW. This closure is the result of the European Union‘s Large Combustion Plant Directive.

- Hunterston nuclear power station in 2016 releasing 1,200MW. This is a scheduled date although Hunterston has already relinquished 121MW of its grid entry capacity.

Clearly these two closures are significant and could free up some 2,352MW across the Central Belt depending on plans for the sites.

6.4.6 CAP 150

OFGEM has recently approved CAP 150 ―Capacity Reduction" [53] which allows the transmission system operator, National Grid, to remove grid entry capacity from projects in the queue where it believes it cannot be utilised – for instance if a project's planning permissions are for less MW than the MW being held in the queue. There is significant scope for interpretation, and developers will be making cases for retaining capacity for instance where planning permissions are being appealed.

That said, the clear intent is to prevent queue blocking with speculative capacity and this is likely to increase the rate at which capacity is released, another positive step for the Pentland Firth.

- Now in force, CAP 150 provides a means for capacity to be released where it is unlikely that a generator will use it. This provides some acceleration of capacity release which Pentland Firth generation will benefit from.

6.4.7 Queue management

Hand in hand with CAP 150, National Grid has published a queue management methodology [54]. This sets out the methodology to ensure that any unused long term access capacity available on the GB transmission system is utilised by the projects that are best able to take advantage of this capacity. This effectively means that if capacity is available in the wider system and Pentland Firth generation is ready to connect then it may come forward in time. This will offer some opportunity for Pentland Firth generators to get connected quicker but such opportunities are likely to be limited.

- GB queue management rules may allow some progress forward in time for Pentland Firth generation that is ready to connect but is likely to be limited in the far north, at least until / if Beauly Denny or an equivalent reinforcement is in place.

6.4.8 Embedded generators (CAP 167)

Generators embedded in the distribution system can, depending on their size, also be contingent on wider transmission assets. The extent to which embedded projects affect the need for transmission reinforcements is currently subject to industry debate. The project size at which an assessment must be undertaken is in consultation processes [55]. Clearly if smaller projects can avoid waiting for wider system reinforcements, that is a significant advantage. Historically, it has not been an issue because the distribution system was seen primarily as a means of distributing power from the transmission system to customers, with embedded generators providing power directly to customers and avoiding the need to transmit it long distances.

However, as embedded generation has grown, the role of the distribution networks has begun to change with some exporting power onto the transmission system rather than off-taking power. This has led to a re-evaluation of whether embedded generators should wait for transmission system reinforcements alongside other transmission-connected generators and whether they should also be charged for use of the transmission system (see Section 6.5.4 for transmission charges for embedded generators).

- Whilst support for small embedded generation to avoid contingency on the wider transmission system would assist Pentland Firth generation, XE suggests this would be an inappropriate action given the issues in the north of Scotland and support for a sensible assessment methodology is more important.

6.4.9 Queue Summary

XE has examined the factors affecting the queue and conducted a brief analysis on seven months of recent available data for Scotland. The analysis shows that capacity reductions are occurring and these are much more significant than additions. The brief analysis combined with industry understanding and commercial experience suggests:

- The queue will reduce of its own accord under pressure from planning and other considerations.

- Given the volume of projects still to complete planning there will continue to be significant reductions.

In addition to the queue reductions XE‘s examination of the issues also shows:

- Existing power station closures in the Central Belt may free up 1,152MW in 2013 and a further 1,200MW by 2016 assisting connections further north.

Extrapolation of the analysis suggests that the queue will reduce to the extent that many generators will be able to connect much earlier. This will be a contributory factor to Pentland Firth generation being able to achieve connection against the set of issues surrounding the wider transmission system. Beatrice Offshore Wind Farm apart, queue reductions will almost certainly allow at least some Pentland Firth generation to utilise reinforcements already planned but currently booked out by competing generation. It is of note that at 1,000MW Beatrice may well be a driver for new DC transmission to the region.

In addition to the above, National Grid, the transmission system operator has put in place two queue management practices which will help accelerate the “natural” queue reduction processes and assist generation that is ready to connect to move forward.

6.5 Grid charging

This section provides a brief overview of charging arrangements for connection to and use of the distribution and transmission systems. An outline of XE‘s approach to costing grid works is contained in Appendix B. XE has provided capital costs for the grid works based on the necessary reinforcements, system extensions and related work for the grid operator/owner to put the works in place. Actual charges passed on to projects are another matter altogether. This sections sets out the structure of charging for reference purposes, noting that it is currently in a state of flux across the board.

Charges for transmission and distribution are split into:

- An up front connection charge
- An annual ―use of system” charge

Details of the existing charging regime, and proposed changes, are provided in the following sections. Distribution charging is dealt with first as it is simpler.

6.5.1 Distribution charging

6.5.1.1 Connection

Distribution connections are currently charged on a semi-shallow basis. This means that the Pentland Firth generation projects will fund works which are dedicated to them but share reinforcement works costs with SHEPD according to their respective usage. The rules for sharing can be difficult to understand and vary between Distribution Network Operator‘s across the country. SHEPD‘s rules are set out in its charging methodology [43] and XE has applied them to the proposed distribution works as far as is reasonably practical to do so. Connection charges start at around £160k for 11kV connections (perhaps less for smaller connections under a single MW) and around £260k for 33kV. Costs increase with reinforcement requirements.

6.5.1.2 Use of system

Once connected, projects pay an annual charge for using the distribution system. The annual charges are set out in SHEPD‘s Use of System charging statement [56] and vary with connection characteristics. At 33kV the charge is currently some £4.92 per kW per annum and at 11kV £5.52 per kW per annum (assuming unity power factor else slightly higher).

It is noteworthy that distribution connection charging is changing and OFGEM is currently consulting on a move to a locational use of system charging system similar in some ways to that applied at transmission. The currently preferred methodology is as developed by Western Power Distribution and set out in its Use of System charging methodology statement [57]. This could, if agreed upon, be implemented by 2010, although further change is quite possible.

- What implication a new distribution charging system will have is at present unclear.

6.5.2 Current transmission charging onshore

Like distribution charging, transmission charging for both connections and use of the system is changing with many changes in consultation. It is also different for offshore connections.

6.5.2.1 Connection

Currently the regime applies a super shallow connection charge which for many cases effectively means the connection charge is zero. In practice however, projects will need to factor in the metering switchgear (probably at 33kV) with costs similar to distribution (i.e. around £260k per connection). Beyond this there are normally no costs. This is on the basis that the transmission infrastructure provided can be used by other projects or users and as such is not classed as connection assets payable by the generator [58]. This is assumed to be the case for the strategic works where new 132/33kV GSP will be shared.

6.5.2.2 Use of system

Once connected the projects then pay an annual use of system charge – Transmission Network Use of System (TNUoS) – which for the far north of mainland Scotland is just over £22 per kW per annum at present [42]. For Orkney connections, costs are likely to be much higher. A wide range of forecast TNUoS costs for the Scottish islands have been tabled over the years. The most recent estimate provided by National Grid is an Orkney TNUoS charge of £61 per kW per annum [59].

6.5.2.3 Small generator discount

Sub-100MW generators connected to the 132kV transmission system currently qualify for a discount on their TNUoS charge. It is designed to level the playing field between equivalent 132kV-connected generators in England and Wales where 132kV assets are classified as distribution and hence these generators are liable for a distribution use of system charge, not TNUoS. The discount for 2008-09 is £4.9 per kW per annum.

The small generator discount is intended as an interim measure until such time as an enduring charging regime is implemented for embedded generators in the context of any impact on the transmission system.

6.5.3 New transmission charging proposals

National Grid has initiated a number of changes to the transmission charging regime based on evolution of the existing TNUoS model. Two key changes are proposed across-the-board onshore and offshore, with some further iterations offshore (discussed in Section 6.5.5 below).

First, there is the concept of separating out "local" and "wider" portions of the locational transmission charge. The local part is charged to reflect the costs of the generator's use of assets up to the Main Interconnected Transmission System. The wider part remains a zonal charge as it is now i.e. all generators in the same zone pay the same charge.

There is also a proposal to change the way in which the so-called "residual" element of TNUoS is charged. The residual serves to collect National Grid's remaining costs not covered by the locational charges paid by northern generators net of payments to southern generators. It is currently charged on a per kW of capacity basis. National Grid is proposing to change this to a per kWh utilisation charge, in line with the TAR proposals and a focus on increasing system utilisation.

6.5.4 Transmission charges for embedded generators

As discussed in Section 6.4.8 above, there is an ongoing debate on the extent to which generators connecting to the distribution system have an impact on the transmission system and the need to reinforce the transmission system. Related to this is whether it is appropriate to charge embedded generators for use of the transmission system.

This has been a very difficult area to resolve, for a number of reasons. Unsurprisingly, embedded projects often object to the notion that a small amount of power put into the distribution system can have a material effect on the transmission system. National Grid‘s approach is to look at the incremental impacts rather than the relative impacts of large or small projects. Furthermore, whilst very small projects could have little to no impact individually, a collection of small projects can have a similar impact as one big one.

For charging purposes, it has been difficult to reach agreement around who should pay, what any payment should reflect, and setting MW thresholds for small projects. The debate has latterly been put aside until the outcome of TAR and should be picked up again early in 2009.

- This area of work will be very important for connecting small amounts of capacity in the Pentland Firth around 2010 and a sensible outcome will be necessary to ensure that even the smallest projects can be connected.

6.5.5 Transmission charging offshore

Charging for offshore transmission is different again. In December 2007, NGET issued a consultation on offshore charging which effectively extended the current system offshore [60]. This has been revised to reflect the developing tender process for offshore transmission owners, issues with single circuit type designs, and the socialisation (or not) of offshore substation costs which are relatively high. Matters were further complicated by other work on charging such as charging of local assets.

The consultation was reissued in October 2008 [61]. The proposals still follow the broad onshore principles but put a number of additional offshore costs into the locational part of the charge. Coupled with the notion of a ―local" charge, which will probably target the majority of offshore related costs separately onto each generator, this makes the resulting offshore use of system charges very high.

Costs for the offshore substations examined herein are likely to give TNUoS charges in the range of £40-50 per kW per annum depending on where the substation circuits are brought from and the final out-turn of the consultation process. This cost is based on the proposals in [61].

Offshore transmission assets are to be tendered for and owned by an Offshore Transmission Owner (OFTO). The connection process and the process of appointing an OFTO will have a significant bearing on the grid works actually built offshore. There is clearly significant merit in a coordinated approach to ensure efficiency in what an OFTO will build out, as indeed there is for onshore grid work.

- Current offshore charging proposals lead to very high offshore costs and this will have a negative impact on the Pentland Firth generation.

6.5.6 Scottish Government transmission charging proposals

The Scottish Government, backed by the Scottish Renewables Forum, ScottishPower and Scottish and Southern Energy, has spearheaded a completely different charging methodology. It proposes to replace the current locational TNUoS charge with a flat utilisation (per kWh) charge averaged across all generation users. It maintains the concept of a generator-specific local charge as developed under the TAR proposals and is currently the subject of a National Grid consultation [62].

Clearly the intent is to reduce the very high charges levied on Scottish generators, the justification for which is largely the pressing need for reinforcements to meet government renewable energy targets which are in turn for the ultimate benefit of GB consumers. This would clearly benefit Pentland Firth generation in reducing its costs and from this perspective is worth supporting.

- The current consultation for a flat rate TNUoS charge would greatly benefit Pentland Firth generation and is thus worthy of support.

6.6 European and National Policy

6.6.1 The Renewable Energy Directives

As noted in the introduction to this report, the Scottish Government has set a target that 50% of Scotland‘s electricity (as a proportion of whole demand) should come from renewable sources by 2020, with an interim target of 31% by 2011.

The European Commission has announced a number of measures aimed at increasing the proportion of energy supplied from renewable sources to 20 % by 2020 [63]. The UK has agreed to this ambition, but there is a great deal of negotiation on the detail, including the allocation of member state targets and whether targets can be met through trade of renewable energy credits.

The outcome of these negotiations is thought to be extremely important in determining, at a UK level, the growth of renewable energy and, crucially, the political will and market mechanisms for UK-wide implementation. The Commission‘s targets and the UK‘s agreement to them, has been pivotal in stimulating a shift in the push from UK government to boosting long-term plans for large volumes of renewable electricity, and for taking steps in planning the network to accommodate this.

A new Renewable Energy Directive is a central plank in the European Commission‘s plans, and will detail member state targets. Of particular note for renewable generators is the provision in the first draft for ―priority access” for renewable plant to the network. Recent press articles have reported the UK government‘s efforts to water down these provisions such that the UK would not have to implement priority access.

The Directive in its final form will have a major influence on transmission access for renewable energy. Specifically, at present, the regulator and the network companies cannot discriminate in favour of renewable projects unless this can be objectively justified. A European Commission Directive which requires priority access would however provide this justification.

- Support for a priority access clause in the new European Commission Directive on renewable energy will assist Pentland Firth generation by helping to remove contingency on wider transmission system issues and is worthy of support, although may be termed such that its impact will be watered down.

- In addition to the above, the European Commission is very proactive for socio-economic development of peripheral areas and has a policy of non-discriminatory charges to renewable energy projects in such areas, both of which are relevant to the Pentland Firth.

6.6.2 Government guidance to OFGEM

BERR is currently consulting on a replacement to OFGEM‘S Environmental and Social Guidance and has published draft guidance [64] which sets out *inter alia* OFGEM‘S remit with respect to the network. It includes provision for improved grid access, work on planning grid upgrades prior to a generator‘s ability to underwrite the works, and “appropriate” measures to enable generators to connect “in timeframes consistent with their development programme.”

The renewables industry wants the guidance to be more pointed, especially with respect to the provision of connection dates. Other environmental organisations would like a change to OFGEM‘S primary duties to include an environmental remit. This is because the guidance is just that, and must be set against other priorities, highest of which is OFGEM‘S primary duties. Others argue that a primary duty would be interpretable, whereas specific guidance, if worded correctly, is unambiguous.

- The guidance to OFGEM is an important part of setting the scene for future regulation of the networks and is worthy of input although will not impact the Pentland Firth generation as directly as other workstreams.

6.7 Section summary

6.7.1 General

Based on the preceding analysis it seems likely that despite current wider transmission system issues, not least of which is that transmission capacity is fully booked for the foreseeable future, Pentland Firth generation projects may nonetheless be able to connect and generate over the coming years. Connection opportunities could be created by a number of factors including:

- Completion of planned reinforcement works and further works, see also Section 5.2.
- A reduction in the queue of generation seeking to utilise the upgraded grid and management of queued projects to improve connection prospects.
- Changes in the regulatory regimes (see below).

The above concerns access to the wider transmission system which means being able to connect and generate. Another important area is charging and how the costs for connection and use of the grid may change in the future.

6.7.2 Queue for connection

XE has examined the queue for connection and suggests it is likely to significantly reduce to the benefit of Pentland Firth generation. This is in part largely due to natural processes driven by planning and other considerations.

In addition, mechanisms put in place by National Grid will help accelerate this process and opportunities for earlier connection of individual projects will arise.

⇒ Analysis suggests that the queue will reduce to such an extent that at least some Pentland Firth generation will be able to connect to and use the existing and planned grid without waiting for as yet unclear future reinforcements potentially —beyond 2018”.

6.7.3 Regulation and access

The regulatory regime is in a state of flux, primarily as a result of the large amount of renewable energy projects (and nuclear power in England and Wales) coming forward and requesting a connection to the grid. There is an opportunity to participate and influence the relevant workstreams. The most important that concern access to the grid for the Pentland Firth marine generation are:

- TAR earlier connection opportunities by virtue of making better use of existing grid assets by way of means such as sharing.
- TAR Connect and Manage which could offer a long-term, bankable route to market ahead of grid reinforcements if the costs of managing the access prove acceptable.
- The GB SQSS review which could improve connection prospects by making better use of existing grid capacity through technical considerations.
- Grid company incentives which may allow upsizing on current (and future) planned grid works although the impact will probably be felt later on (i.e. 2015-2020).

6.7.4 Regulation and charging

At present, charges for use of the distribution system are on a par with other parts of the country. At transmission however the costs for TNUoS once connected are very high. These currently sit at just over £22 per kW per annum in the mainland north, with charges for connections on Orkney recently quoted as up to £61 per kW per annum, and for connections to offshore substations estimated at around £40-50 per kW per annum. The current small generator discount for 132kV connected generation in Scotland is £4.9 per kW per annum but is likely to disappear shortly.

As with access, charging for connection to and use of the grid is also changing and opportunities exist to participate in the relevant workstreams. The most important are:

- The review of the methodology to assess the impact of small distribution connected projects on transmission which is ongoing and the outcome of which could hinder connection of small and early Pentland Firth projects. This is in part a charging issue but also very much an access issue.

- Offshore transmission charging which is in consultation processes and the proposals of which lead to very high charges.

- Proposals have been made for a flat rate transmission charging scheme by a collection of Scottish parties led by The Scottish Government and this could greatly benefit Pentland Firth generation if successful.

6.7.5 Policy developments

There are various political developments that impact on the regulatory developments. The most important are:

- European policy which filters into government policy and OFGEM and which favours priority access to the grid for renewable energy projects.

- The European Commission is very proactive for socio-economic development of peripheral areas and has a policy of non-discriminatory charges to renewable energy projects in such areas, both of which are relevant to the Pentland Firth.

- BERR guidance to OFGEM which is setting the scene for future regulation.

7 Blueprint

7.1 Introduction

This section of the report brings together all the preceding sections to set out a blueprint of how the 1,000MW and 1,700MW scenarios set out in Table 1-1and Table 1-2 can be met in terms of grid connection.

The blueprint is made up of the various options within the preceding sections and as such is not a definitive set of works but a larger set of options which, when at least some are implemented, will facilitate the Pentland Firth marine energy scenario.

The options blueprint draws on the preceding sections to set out the following:

- Small projects connecting over short timeframes using local existing infrastructure with low risk reinforcements.
- The extension in connectable capacity by use of innovations, again over short time horizons.
- Strategic grid reinforcements and extensions to facilitate medium to longer term objectives for projects of a few tens or hundreds of MW ultimately leading to realisation of the full Pentland Firth potential.
- Summary details of MW, costs, timelines and issues.

In understanding the options it is important to realise that what grid is used and built will be led and dictated by what projects are developed where, in what timeframes and how soon the appropriate signals are provided to SHEPD and SHETL (via National Grid) in the form of connection applications and acceptances.

Even with early and timely signals all works are subject to consenting procedures which could take much longer than expected or indeed not deliver the consents. These two factors alone suggest that slippage is possible if not likely and considering the volume of grid work to be undertaken for the 2020 targets this means that early signals for large volumes of generation are essential.

XE has examined three blueprint scenarios, all with some options:

- 1,000MW by 2020 using the mainland and Orkney.
- 1,000MW by 2020 using the mainland only.
- 1,700MW by 2020 using the mainland and Orkney.

The blueprint scenarios are all the same until around 2013, making as much use of the existing grid as possible prior to larger scale new works being implemented, then they diverge. The short term (to 2013) scenario is presented in the following sub-section followed by each of the three follow on blueprints.

7.2 Short term to 2013 (up to 145MW)

To end 2009/10

Over short time horizons of up to 2 years till the end of 2010 it is expected that single devices and small projects will use the capacity in the existing grid with some easy to obtain upgrade works. Section 3 of this report has shown that around 26MW is possible, built up as follows:

- 5-6MW in the mainland coastal 11kV networks.
- 1.5-2MW from Orkney 11kV networks.
- Around 18-20MW from the 33kV grid near Thurso.

To end 2010/11

Section 4 of the report showed that the above capacity was extendable by innovation by around 8-10MW on the local lines but ultimately up to around 90MW by using generation constraint to access non-firm transformer capacity at Thurso and to a lesser extent Mybster. To achieve this capacity will require one or two 33kV connections direct to Thurso in addition to the local line connections. If access to non-firm transformer capacity cannot be gained through generator constraint then transformer upgrades will be required. SHEPD/SHETL has confirmed these as achievable within these short timeframes.

To extent the above with relatively low impact works and over short timeframes is difficult. There is one key strategic upgrade that will need to happen early on. This will involve 33kV operation of the Hastigrow to Gills line. With upgrades this could release an additional 25MW or so but will require Thurso transformer upgrades (or a switch over to Mybster GSP with non-firm capacity access or transformer upgrade). This puts the total capacity by end of 2011 at a maximum 115MW.

To end 2012/13

A second 33kV circuit can be added from Gills to raise the total capacity connectable to around 145MW by the end of 2013. This is a new line but will strengthen local supplies as well as increasing generation export.

All scenarios considered follow the above pattern to squeeze as much as possible out of the existing local grid. Hastigrow to Gills upgrades are a special case, involving distinct new works, but are of significant benefit to local consumers.

From this point onwards, significant new works are required specifically for the generation and the blueprint options diverge.

7.3 1,000MW by 2020 (mainland only)

From 2013 onwards major new infrastructure is required. Taking new grid infrastructure to Orkney will be expensive and it is just possible to reach 1,000MW by 2020 with mainland based infrastructure and one offshore substation. This requires new infrastructure to be installed at 132kV.

7.3.1 Medium term 2013-2017 (750-900MW)

New lines and substations are required to extend capacity much above 145MW, so, to deliver the much higher capacities sought, significant works must be commenced by end 2010/11, preferably earlier.

To end 2015

To exploit the large resource off Dunnet Head, and undertake works requiring least distance and cost it seems sensible to examine a 132kV extension to create a new GSP at Brough. This allows 150/300MW or a large jump to 445MW total.

At the same time, work could be progressed on a new offshore substation potentially deliverable as early as 2015-17 and aimed at exploiting the area south of Hoy, thereby avoiding a need to take infrastructure to Orkney. An offshore substation would raise off-take to around 745MW and probably be sufficient for the western region.

7.3.2 Longer term to 2020 (1,000MW+)

As yet, no options have addressed the eastern resources off Duncansby Head or South Ronaldsay in any meaningful way. This will require either very significant new build from the east of the region across the mainland or longer term reliance on a new DC interconnector on the east coast.

A 33kV connection could be brought from Wick but would also be accompanied by reinforcement from Wick through to Mybster and to the transmission system. It is relatively far away, expensive and not overly attractive. It would also not deliver enough capacity for the targets.

Eastern-most resource areas are possibly best developed in the longer term from a potential new DC link. New build at 132kV to Duncansby could allow off-take of up to 300MW. If consenting issues were problematical it might be possible to undertake much of route subsea off the east coast although finding a landing point may be difficult.

Completion of this work would probably be close to 2020 due to reliance on the DC link but would deliver the 1,000MW.

Figure 7-1 shows the works, timelines and MW delivery. Timeframes for delivery of grid works are as quoted in preceding sections. The blocks of works are white to show the minimum term with the orange as the typical lag, when for example quoted as X-Y years. The lag is not representative of consenting difficulties however, just typical lag with consents and works.

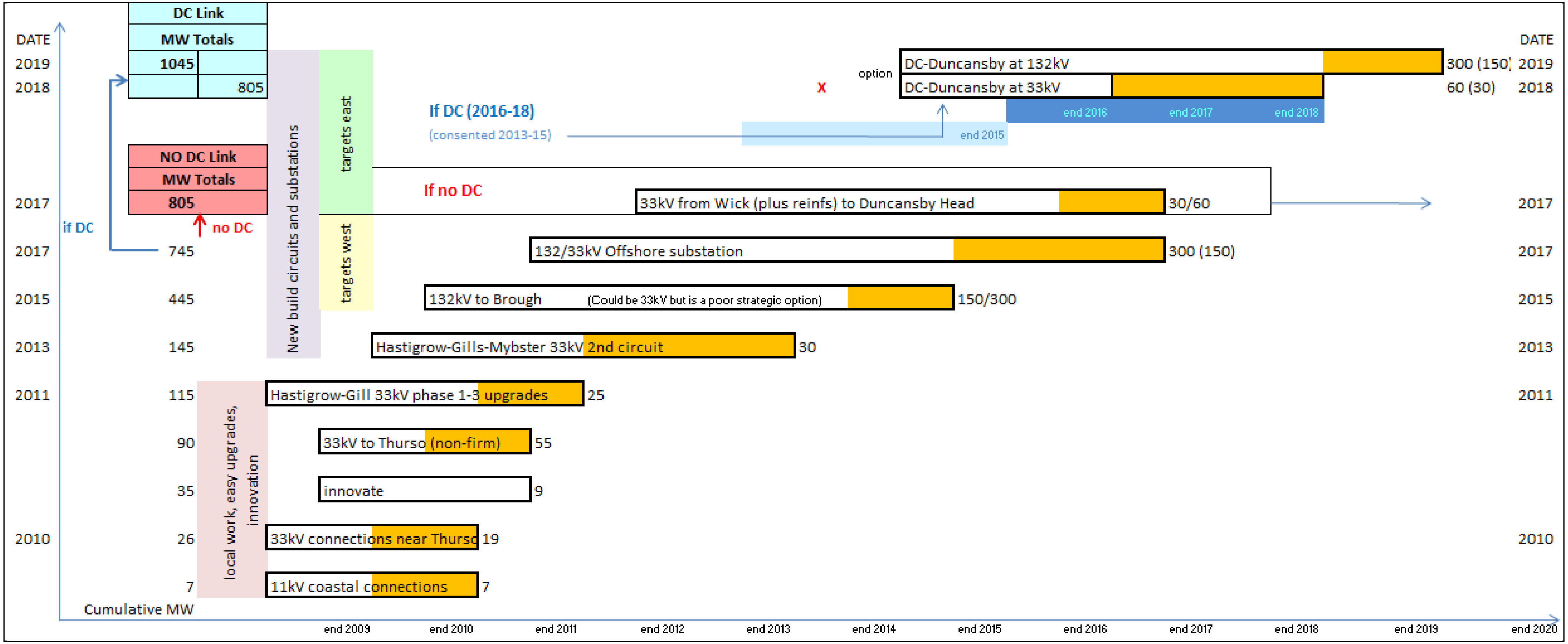

Figure 7-1: Blueprint for 1,000MW by 2020 (no grid to Orkney)

7.4 1,000MW by 2020 (mainland and Orkney)

Taking new grid infrastructure to Orkney will be expensive but provides wider benefits and allows easier off-take of northern Pentland Firth developments. There are also more options and more opportunity to hit the targets earlier, possibly by 2017.

7.4.1 Medium term 2013 to 2017 (potentially 1,000MW)

Unlike mainland only works there are choices between 33kV or 132kV developments to be made. Despite this, new works still need to be commenced by the 2010/11 timeframe or preferably earlier.

A western 132/33kV GSP at Brough is a sensible first step. This allows 150/300MW or a large jump to 445MW total. This could be done at 33kV but this makes little sense other than in reducing consenting issues.

At the same time, work could be progressed on a new offshore substation and/or new subsea links to western Orkney both potentially deliverable in the 2015-2017 timeframe with the offshore substation aimed at exploiting the area between Dunnet Head and Hoy. An offshore substation would raise off-take to around 745MW, with a single circuit to Orkney adding another 150MW at 132kV or 30MW at 33kV, a grand total of 775-895MW, probably sufficient for the 1,000MW target from this western region.

As with the mainland only scenario a 33kV cable could be brought from Wick to develop eastern resources but is not overly attractive if a DC converter station is to go ahead. If the DC station is not to go ahead then double circuit 33kV extensions to Duncansby Head and South Ronaldsay would just be sufficient to meet 2020 targets. These would however need significant new reinforcement works from Wick to the transmission system.

7.4.2 Longer term to 2020 (1,000MW+)

With a possible new DC link, better options exist to build at 33kV or 132kV to Duncansby allowing anything from 30-300MW to be realised.

An eastern subsea cable could also be taken to South Ronaldsay, at 33kV, but possibly more attractive at 132kV giving anything from 30-150MW as a single circuit and up to 300MW as a 132kV double circuit. These developments would also significantly assist off-take from the central Pentland Firth, e.g. north of Stroma and from the area off South Ronaldsay.

The level of build on the eastern side could be selected to match the marine developments, to meet the target of 1,000MW and could be 33kV or 132kV depending on other developments.

Figure 7-2 shows the works, timeframes and MW delivery with the options. Considered in the green MW totals are options which involve only new 33kV cable routes to Orkney, in black 132kV to Orkney.

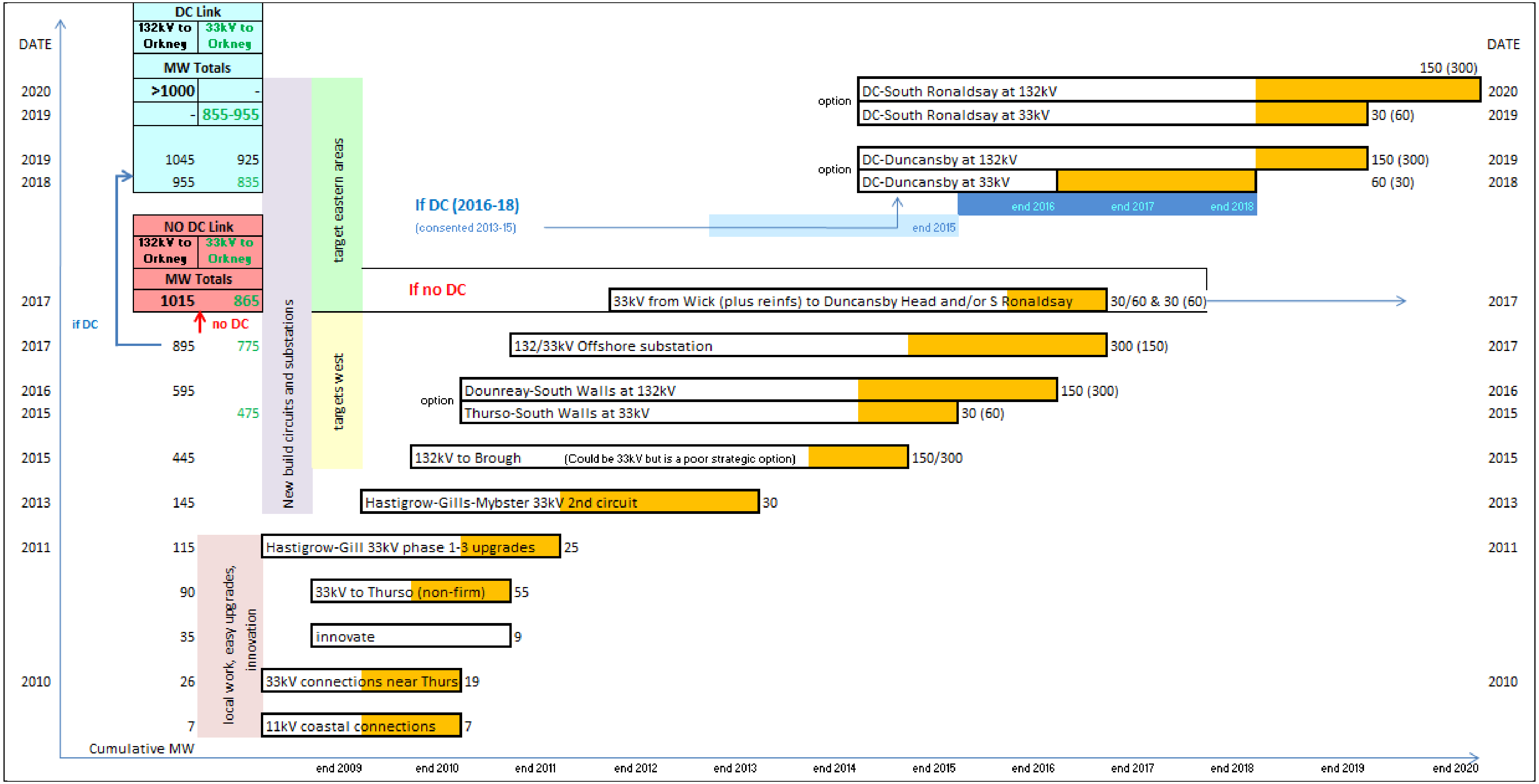

Figure 7-2: Blueprint for 1,000MW by 2020 (includes grid to Orkney)

7.5 1,700MW by 2020 (mainland and Orkney)

The scenario of 1,700MW is bold. Short term developments will be similar to the base case up to around 2013. However, developing 1,700MW requires more major infrastructure and this needs to ramp up significantly from this point. The analysis shows that the delivery of new capacity in the period 2013 to 2017 or so will struggle to meet the targets, but provided it is underway should catch up later in the decade to 2020.

Analysis on the various options tabled shows that 132kV infrastructure to Orkney is unavoidable, even with two 300MW offshore substations, although one Orkney route could be cabled at 33kV. Since the development of a 132kV Orkney ring holds much promise for Orkney and other Orkney generation as well as the Pentland Firth it would seem worth considering over and above 33kV connections to Orkney.

The keys to releasing 1,700MW lie in adding a second offshore substation and building at 132kV to Orkney. Enough non-firm capacity can be created such that one GSP could be reduced to a single circuit 132kV feed, or one subsea route to Orkney could be completed by a single 132kV circuit only, or one single circuit 132kV link could be replaced by two 33kV circuits.

The blueprint is again skewed towards western developments with eastern developments reliant on new major transmission being brought to the north east coast, e.g. a DC link. Without this, the targets are difficult to meet from any balanced off-take from the region and to exploit the east, major new infrastructure across the mainland, and/or to a lesser extent Orkney, would be needed.

As with the base case, eastern works (at 132kV) come later in the 2015-2020 period, potentially as late as 2018-2020, but if double circuit 132kV, could give good access to the central as well as eastern areas potentially allowing up to 300MW from the Duncansby-Gills-Stroma offshore zones and/or up to 300MW from the South Ronaldsay-Stroma area.

7.5.1 Medium term 2013 to 2017 (potentially 1,350MW)

Works and options are similar to the 1,000MW cases with a western 132/33kV GSP at Brough a sensible first step. This allows 150/300MW or a large jump to 445MW total.

At the same time, work on new offshore substations and new subsea links to western Orkney need to be progressed, all potentially deliverable in the 2015-2017 timeframe. Two offshore substations would raise off-take to over 1,000MW, with a 132kV Dounreay to Orkney link adding another 150/300MW as single/double circuit, a total of up to 1,145-1,345MW.

7.5.2 Longer term to 2020 (1,700MW+)

A new DC link (or other similar major transmission link) to the region more or less essential to reach 1,700MW locally but is also essential to get power out of the region. With a possible new DC link, options exist to build at both 33kV or 132kV to Duncansby and subsea to South Ronaldsay to reach 1,700MW but some 132kV is essential.

Figure 7-2 shows the works, timeframes and MW delivery with the options.

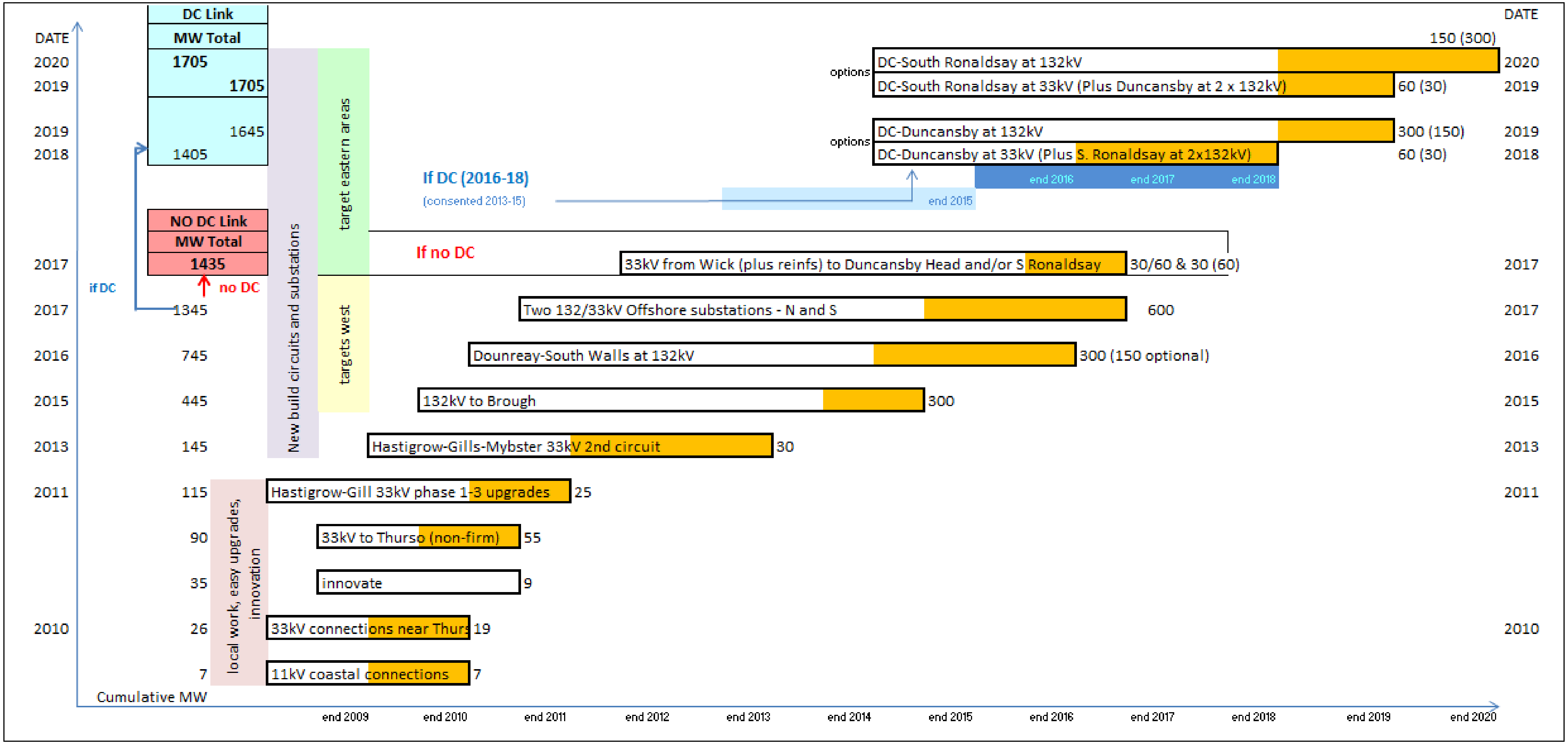

Figure 7-3: Blueprint for 1,700MW by 2020 (mainland and Orkney)

7.6 Section summary

7.6.1 General

This section of the report has drawn together the analysis of preceding sections to scope out blueprint scenarios for 1,000MW or 1,700MW from the Pentland Firth by 2020. Three scenarios have been developed:

- 1,000MW by 2020 using mainland works only (predominantly 132kV) thereby avoiding the high costs to take new subsea cables to Orkney.
- 1,000MW by 2020 using both the mainland and Orkney with 33kV and 132kV options balanced across the Pentland Firth.
- 1,700MW by 2020 using both the mainland and Orkney with a predominance of 132kV work.

7.6.2 Capacity delivery

All scenarios considered make use of the existing grid in early years to allow cost effective and rapid connection of small devices and smaller projects with minimal consents issues for grid works. This involves some targeted grid upgrades and the use of innovative techniques. A maximum of 145MW, virtually all to the mainland, is calculated as achievable by 2013. Most of this may be achievable by 2011. From 2013 onwards major new grid works are required with increased costs, consents risks and timeframes.

Due to the high costs of taking new infrastructure across to Orkney, a scenario of 1,000MW from mainland developments only has been examined. It is possible but requires a predominance of 132kV works and an offshore substation. A mainland only scenario for 1,700MW would seem impractical and 132kV development to Orkney is necessary. The potential to create a 132kV Orkney ring may however be an attractive option allowing wider benefits to Orkney and generation other than that of the Pentland Firth.

To continue to develop the region from 2013 onwards will require much of the major work to be started early, e.g. 2010/11. Any delays in commencing it will lead to delays in providing capacity during the medium and longer term. The 1,000MW blueprint, although ambitious, shows this is possible, and that delivery of grid can lead project development. For the 1,700MW case however this is a particular issue which needs a large volume of major work to be started early, i.e. in the next 2-3 years. This is shown in Figure 7-5 where a rapid build is required to keep pace with targets and the expected rate lags the targets until much later in the next decade. Later commencement of work, or slippage due to issues such as consents, will mean a lag of available grid capacity mid-term, although it will catch up towards 2020.

All scenarios focus on western resources in the medium term from 2013-2017. This is because the existing transmission system is to the west and off-take from the west is easier, cheaper and quicker to achieve.

The development of eastern resource areas is more difficult. Some off-take can be achieved by building out new 33kV grid from Wick (or across from Gills) but this is relatively distant, beset with reinforcement issues, and relatively costly for relatively few MW. A more attractive, but less certain, option is to wait for a possible new DC link (and associated transmission infrastructure) to be established on the east mainland coast and build out at 33kV and/or 132kV from there. This is only likely to realise eastern development in the 2015-2020 timeframe, possibly very close to 2020.

All scenarios are subject to delays in the timelines due to consents and are sensitive to when works are started. This is an issue as at present works will only commence once appropriate signals have been provided to grid through signed agreements for connection meaning that very significant levels of generation will need to have gone through formal grid connection processes within the next few years, unless regulatory changes are made or an alternative mechanism is found to trigger the works.

The delivery of capacity for the 1,000MW scenarios against targets is shown in Figure 7-4 and for the 1,700MW scenario in Figure 7-5.

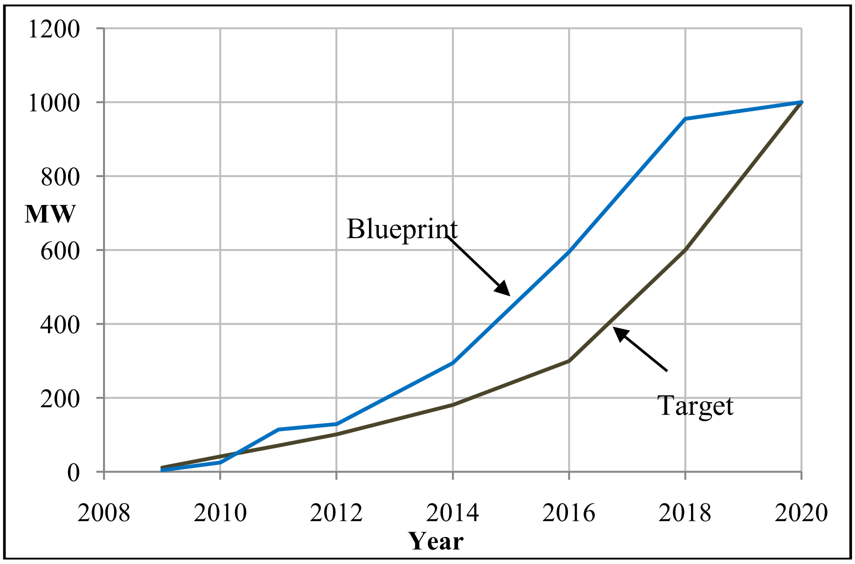

Figure 7-4: 1,000MW blueprint compared to targets

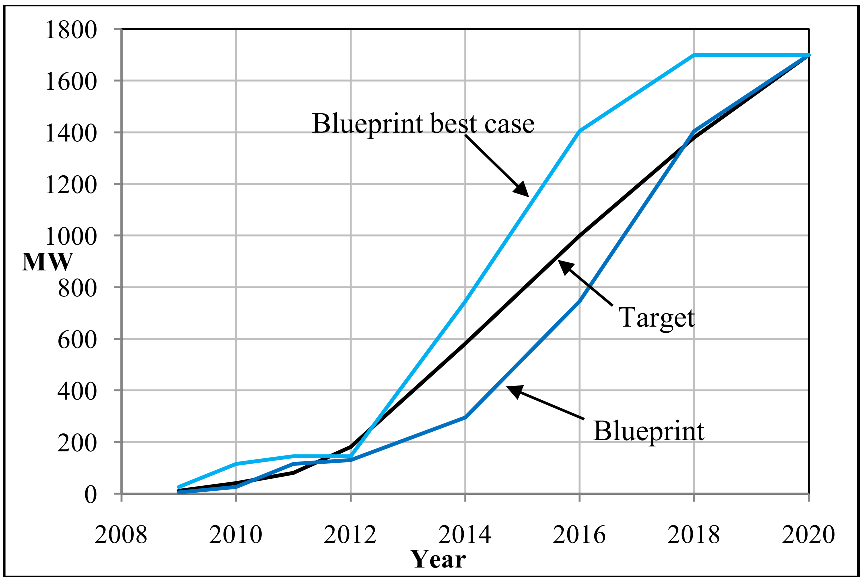

Figure 7-5: 1,700MW blueprint compared to targets

7.6.3 Costs

Total grid related investment is estimated to be from £150 million to £435 million depending on the blueprint scenario and options chosen.

- 1,000MW by 2020 using mainland works only is estimated at some £150-155 million (of which about half is for an offshore substation).
- 1,000MW by 2020 using both the mainland and Orkney is estimated at some £210-250 million.
- 1,700MW by 2020 using both the mainland and Orkney is estimated at some £405-435 million.

The costs are driven up progressively by the need for increasing levels of infrastructure to Orkney and the use of a second offshore substation for the 1,700MW scenario.

No costs are included for wider transmission works outside of the immediate geographic area, any later conversion and/or interconnection of 132kV assets to 275kV, or for a transmission interconnection across the mainland between a DC station and Mybster or thereabouts.

Included in the blueprint scenarios are transformer upgrades at both Thurso and Mybster, a new 132kV switching station near Thurso and works to develop a new 33kV switching station on Stroma.

Also excluded for the bulk of the capacity is the cost of individual project metering switchgear and associated plant. This is difficult to estimate as the number of projects and the type of connections are uncertain. Based on the scenarios outlined in Table 1-1 and Table 1-2, XE estimates these costs at around an additional £6 million for the 1,000MW scenario, and £9 million for the 1,700MW scenario. These are marine energy project specific costs.

It is noteworthy that the bulk of the capital cost is associated with transmission works and is not payable by the marine energy projects but is assumed by SHETL as the transmission owner. Depending on the scenario, between about 7% and 25% is distribution works associated cost which is chargeable directly to projects. For the 1,000MW scenarios the figures are typically 10-15% although, where distribution works are taken to Orkney, this can rise to over 20%. For the 1,700MW scenario the figures are lower due to the higher degree of transmission works and can be as low as from 7% up to around 15%. In addition, projects will only pay a share of distribution reinforcement works and so further cost savings on these figures will be achieved.

Once connected, all projects pay a Use of System charge. As described elsewhere this is between £4.92 and £5.52 per kW per annum for a distribution connection, some £22.26 per kW per annum for a mainland transmission connection, estimated at £40-50 per kW per annum for a connection to an offshore substation, and in the region of £61 per kW per annum for Orkney. A small generator discount of £4.88 per kW per annum applies to the transmission connections but will soon disappear.

8 Report summary

8.1 General

This report has examined the development of local grid infrastructure in and around the Pentland Firth to facilitate the off-take of marine energy, primarily tidal. An ultimate target of 1,000-1,700MW by 2020 has been aimed for. This report has examined the following in developing a blueprint set of options for grid connection of such capacity.

- Background studies which inform the report on resource location, offshore conditions, routing issues for cables and issues with environmental designations and similar sensitivities. A summary is contained in the following Section 8.2.

- The capability of the existing grid in the region to accept generation from the Pentland Firth region and its potential if upgraded. This is summarised in the following Section 8.3.

- The various innovative practices that can be applied to the marine generation and the grid to obtain further increments in capacity from the existing grid. A summary of innovation is contained in the following Section 8.7.

- An overview of the strategic transmission and distribution system upgrades and extensions that can be undertaken to release large amounts of capacity. These involve longer timeframes, more risk, higher consenting issues and more cost, but are required to significantly develop the resources of the Pentland Firth region. The use of these works to deliver the 2020 targets is summarised in the following Section 8.4.

- A review of the existing regulatory system and the potential future changes that will be an essential part of freeing up and creating capacity for even the smallest projects. This is summarised in the following Section 8.8.

The above have been used to develop three blueprint scenarios, further summarised in Section 8.5, for connection of Pentland Firth marine energy to the grid. The blueprint scenarios all contain various options over which works are progressed but are:

- 1,000MW by 2020 using mainland works only.

- 1,000MW by 2020 using both the mainland and Orkney.

- 1,700MW by 2020 using both the mainland and Orkney.

A fundamental assumption has been that wider grid system issues which currently prevent development will be resolved at least to the extent that Pentland Firth generation can connect to and use the grid. The report is therefore focused on the local region and the local grid works required to connect the generation back to the wider transmission system. Cost estimates for the work are contained in Section 8.6.

The report has found that connection of the Pentland Firth generation is challenging but possible and that the targets are achievable but dependant on many factors, some of which the Pentland Firth Tidal Energy Project can directly control and the rest of which it can influence to a limited degree.

Recommendations on how to optimise the prospects for marine energy in the Pentland Firth in regards grid connection are contained in the following Section 9.

8.2 Background studies

The range of background studies reviewed has indicated that understanding of the Pentland Firth resource needs development. The studies have however been able to provide some guidance on various important aspects such as offshore seabed conditions and environmentally sensitive areas. The following is a summary.

8.2.1 Project/resource locations

The likely resource locations are spread around the Pentland Firth from east to west and from the shores of the mainland to Hoy and South Ronaldsay. No background work appears to be able to definitively set out how much tidal resource can be developed in any one location however and it is clear that much more work is required on what appears to be a complex area. XE has concluded that there are five likely areas that could provide development opportunity for tidal stream devices – between Dunnet Head and Hoy, Gills Bay, north of Stroma, off South Ronaldsay and off Duncansby Head.

8.2.2 Offshore conditions

Much of the seabed through the Pentland Firth is a hard rocky surface with outcrops and strong currents and hence a very hostile environment for subsea cables making burial virtually impossible and protection difficult. Offshore substation installation is similarly problematic. Both will be very difficult and expensive in the main resource area and are best avoided. On the eastern and western edges of the identified tidal resource the seabed surface is more amenable and installation work would be easier in these regions. Hence, XE has examined eastern and western cable routes between Orkney and the mainland and suggested locating offshore substations west of the worst subsea terrain.

8.2.3 Environmental constraints on subsea cable routes and landings

There are numerous environmentally designated areas around the coast making grid work and cable landings potentially difficult. Therefore, these areas have been effectively excluded from consideration for grid work as far as possible.

Subsea cable landing is problematic around the Pentland Firth area presenting difficulties for subsea grid cables and project developers alike. XE has where possible tried to locate grid in areas where landings are possible and run grid cables on what appear to be sensible routes. Appropriate landing sites need to be identified, probably as part of a wider survey of the region.

XE has additionally added in a non-exhaustive set of onshore environmental designations which also act to guide where new grid works can and cannot easily go.

8.2.4 Wider grid issues

All of the background documents reviewed indicated that grid capacity is one of, if not *the*, major hindrance to the exploitation of commercial scale marine energy both in the Pentland Firth region and elsewhere. This concerns both the regulatory regime and the physical capability of the grid itself. These issues are already well understood by XE and commented on in this report.

8.3 Connections to the existing grid

8.3.1 General outline

The region itself is poorly served by grid infrastructure. On the mainland, the current 132kV system approaches no closer than Thurso, the existing 275kV transmission is some distance west at Dounreay, and the local 33kV distribution system does not penetrate the coastal regions in any significant way. This means the region is chiefly served by long 11kV lines with poor connection prospects for prospective projects.

Orkney is even worse. There is no transmission grid to Orkney and the current Orkney distribution system is already operating under an innovative RPZ scheme to allow an additional 15MW to connect under constraint arrangements. In regards the Pentland Firth, the southern end of Hoy is served by a 33kV line but this is already used by significant generation. Some 11kV network is also present. South Ronaldsay is only served by a very long 11kV line with existing voltage issues and a generator operating in voltage control mode.

The report has focused on use of this existing grid first to release small devices and small projects in the short term as described below.

8.3.2 Short term capacity to 2011-2013

Immediately connectable capacity in the existing mainland and Orkney grid is very limited and with achievable local upgrades only reaches some 5-6MW in the coastal networks.

If longer routes are taken from the offshore development areas to the area around Murkle Bay and Thurso, up to 26MW total is available but this requires quite long connections from the offshore area to the grid. Orkney is severely restricted by its over-abundance of generation and the need to bring new subsea cables to the islands.

Thurso GSP‘s firm transformer capacity ultimately limits initial developments to some 26MW total according to SHEPD‘s Long Term Development Statement [21]. This does not allow for prospective Orkney RPZ generation yet to be confirmed or other generation in process with SHEPD the grid operator. Hence capacity at Thurso could be much lower.

The use of innovation can help extend connectable capacity and XE estimates an additional 8-10MW (possibly more) could be released in the coastal networks through generator constraint and improved substation voltage control, bringing the total short term capacity to around 35MW. A summary of innovation is contained in the following Section 8.7.

Employing constraint could also avoid transformer replacement at Thurso upping the available capacity to around 86MW (non-firm). This is the available capacity at Thurso and apart from connecting direct to Thurso is difficult to access. Use of Mybster GSP is also an option and the same practice can be employed there as current capacity is understood to be zero. Alternatively, transformers at both GSP‘s can be replaced within short time horizons. Using the existing network with some reconfiguration via Mybster allows up to 90MW.

A key strategic upgrade that can be achieved relatively quickly is the Hastigrow to Gills line on the mainland. This is built to 33kV specification but currently operated at 11kV. Uprating could progressively allow from 8MW to 25-30MW from Gills with fairly low consents issues.

Beyond the above a second 33kV circuit from Gills could add another 30MW but would constitute a later addition. This would be the first new grid line needed giving a total of around 145MW if all options are well utilised. From this point onwards, new lines and substations are required.

8.4 Connections to new grid works

To extend connectable capacity to anything significant, new grid works are required. This is simply a function of the lack of grid in the Pentland Firth area. XE has split these works out into a medium term bracket (approximately 2013-2017) and longer term bracket (approximately 2015-2020).

8.4.1 Medium term connections (2013 to 2017)

There are various works that can deliver significant capacity from around 2013/14 onwards if started early enough. However, most require new lines and substations with timeframes of 3-5 years at best and probably longer depending on consenting issues. There is therefore a potential gap between very small initial developments and moderate to larger developments which may not be realised until around 2015 or so depending on their commencement dates.

New works will need to choose between 33kV (slightly less local impact, cheaper and faster but less capacity – typically 30/60MW) or 132kV (more local impact, more cost and slightly longer timeframes but more capacity – typically 150/300MW). These works would, particularly at 132kV, start to significantly open up capacity in the region and probably focus on the mainland due to the high costs associated with taking subsea cables to Orkney.

A western 132/33kV GSP at Brough is a sensible first step. This allows 150/300MW or a large jump to 445MW total. This could be done at 33kV but this makes little sense other than to reduce consenting issues.

At the same time, work could be progressed on a new offshore substation(s) and/or new subsea links to western Orkney both potentially deliverable in the 2015-2017 timeframe and both aimed at exploiting the area between Dunnet Head and Hoy.

An offshore substation could raise off-take to around 745MW, with a single 132kV circuit to Orkney adding another 150MW at 132kV or 30MW at 33kV, a grand total of 775-895MW, and probably sufficient for the 1,000MW scenario from this western region. For the 1,700MW scenario, a double circuit to Orkney and a second offshore substation are worthy of consideration (total around 1,350MW).

Offshore substations are expensive but allow access to the middle area of resource without an overabundance of onshore infrastructure, offshore to shore cabling, or consenting issues. They can also be used to avoid taking infrastructure to Orkney for the 1,000MW scenario.

Eastern development is more problematical and in the medium term could be achieved by 33kV infrastructure from Wick to Duncansby Head and/or South Ronaldsay. This is not overly attractive as it involves distance, expense, releases relatively few MW and involves reinforcement issues from Wick back through distribution to the transmission system at Mybster. Other options are to bring new transmission infrastructure across the region which is also undesirable from a consents viewpoint, or press for development of a potential east coast DC link with a focus on Pentland Firth generation.

Either way, development of eastern resources is more problematic, primarily due to its remoteness from any substantial grid infrastructure.

8.4.2 Longer term connections (2015 to 2020)

Wider transmission system developments, apart from being required to take power away from the region, will also effect development. A potential east coast DC link from Morayshire may offer opportunities to significantly develop the area around Duncansby Head and develop eastern subsea cable routes to South Ronaldsay. This would also provide a possible opportunity to create a mainland-Orkney ring system between Dounreay, Orkney and east mainland. A substantial development on the eastern mainland side would also allow better off-take from the central Pentland Firth north of Stroma, probably by way of a dedicated 33kV link to the island.

With a possible new DC link establishing a new substation on the east coast, better options exist to build at 33kV or 132kV to Duncansby Head allowing anything from 30-300MW to be realised.

An eastern subsea cable could also be taken to South Ronaldsay at 33kV, but possibly more attractive at 132kV giving anything from 30-150MW as a single circuit and up to 300MW as a 132kV double circuit.

These eastern developments are only likely to be realised in the 2015-2020 timeframe and effectively provide the last jigsaw piece for Pentland Firth generation, particularly for the larger capacity target and eastern resources, notwithstanding wider transmission issues.

8.5 Blueprint scenarios

Three blueprint scenarios have been developed using the short, medium and long term connection options as summarised in Sections 8.3 and 8.4.

- 1,000MW by 2020 using mainland works only (predominantly 132kV) thereby avoiding the high costs to take new subsea cables to Orkney.

- 1,000MW by 2020 using both the mainland and Orkney with 33kV and 132kV options balanced across the Pentland Firth.

- 1,700MW by 2020 using both the mainland and Orkney with a predominance of 132kV work.

All blueprint scenarios have been shown to be achievable but four issues are apparent.

1. A potential time lag between small projects using the existing grid and larger capacities being delivered by new grid works – capacity delivery against time.

2. The achievement of a cost efficient build of new grid.

3. High costs of taking grid infrastructure to Orkney or developing offshore substations.

4. Difficulties in developing the eastern resource areas.

8.5.1 Capacity delivery against time

All scenarios considered make the same use of the existing grid in early years (to around 2013) to allow cost effective and rapid connection of small devices and smaller projects with minimal consents issues for grid works. From 2013 onwards, the blueprint scenarios start to diverge and various options exist as was broadly set out in the preceding sections.

To continue to develop the region from 2013 onwards will require much of the major work to be started early, e.g. 2010/11. Any delays in commencing it will lead to delays in providing capacity during the medium and longer term and a potential lag of grid capacity behind project requirements. This is a particular issue for the 1,700MW case which needs a large volume of major work to be started early, i.e. in the next 2-3 years.

Any issues with consents would delay works further and this is a critical issue also.

⇒ A key question here is how the required grid work will be identified and initiated early enough for projects which may not be well developed and in a position to make financial commitments until much later.

8.5.2 Cost efficient build

To some extent this issue is related to the delivery of capacity and how requirements for it are signalled early enough. As Pentland Firth developments will be commercial projects and grid processes work on a first come first served basis, it is likely that grid works will be uncoordinated against the 2020 scenarios with ad hoc developments planned and progressed on demand. This will not lead to a coordinated and cost efficient build of new grid works and will not in general terms serve to minimise consenting issues. Nor will it facilitate timely delivery.

⇒ The key question is how the correct signals will be provided to enable the grid work to be coordinated and planned to cover a large number of projects that will eventually use it thereby avoiding cost inefficient ad hoc developments.

8.5.3 Orkney and offshore substation costs

A key rationale of taking new grid works to Orkney is to allow a balanced and more practical off-take of generation from the Pentland Firth, making development of northern resource achievable, whilst avoiding an overabundance of grid on the mainland and the costs and difficulties in routing very many project cables to the mainland shores.

The key downside is cost. The capital investment required is high and under the current charging regimes for grid much of this is passed through to projects using the infrastructure. At prospective TNUoS costs of £61 per kW per annum (last quoted by BERR in June 2008 [59]) for transmission connections on Orkney this makes project economics questionable. Similar issues arise for offshore substations where an abundance of the cost is passed to the projects using the offshore works (estimated at £40-50 per kW per annum herein).

⇒ The key questions are whether costs should be charged differently - a regulatory charging issue, and whether wider benefits to Orkney should be accounted for.

8.5.4 Eastern resources

All scenarios focus on western resources in the medium term from 2013-2017. This is because the existing transmission system is to the west and off-take from the west is easier, cheaper and quicker to achieve.

The development of eastern resource areas is more difficult. Whilst some off-take can be achieved by building out new 33kV grid from Wick (or across from Gills) this is relatively unattractive. Similarly, new transmission infrastructure across the region would be undesirable and difficult to consent.

A more attractive option is to wait for a possible new DC link (and associated transmission infrastructure) to be established on the east mainland coast and build out at 33kV and/or 132kV from there. This is not in any formal process at time of writing so remains a risky proposition.

⇒ A key question is how to provide a sufficient driver for development of wider transmission infrastructure to the east coast (DC link) and focus its development on the Pentland Firth eastern resource exploitation.

8.6 Costs

Total grid related capital investment is estimated to be from £150 million to £435 million depending on the blueprint scenario and options chosen.

- 1,000MW by 2020 using mainland works only is estimated at some £150-155 million (of which about half is for an offshore substation).

- 1,000MW by 2020 using both the mainland and Orkney is estimated at some £210-250 million.

- 1,700MW by 2020 using both the mainland and Orkney is estimated at some £405-435 million.

The cost are driven up progressively by the need for increasing levels of infrastructure to Orkney and the use of a second offshore substation for the 1,700MW scenario.

No costs are included for wider transmission works as this is beyond the scope of this report. Also excluded for the bulk of the capacity is the cost of individual project's grid related connection plant. This is difficult to estimate as the number of projects and the type of connections are uncertain but based on the scenarios outlined in Table 1-1 and Table 1-2, XE estimates these costs at around an additional £6 million for the 1,000MW scenario, and £9 million for the 1,700MW scenario. These are marine energy project specific costs.

It is noteworthy that the bulk of the capital cost is associated with transmission works and is not payable by the marine energy projects but is assumed by SHETL as the transmission owner. Depending on the scenario, between about 7% and 25% is distribution works associated cost which is chargeable directly to projects. For the 1,000MW scenarios the figures are typically 10-15% although where distribution works are taken to Orkney can rise to over 20%. For the 1,700MW scenario the figures are lower due to the higher degree of transmission works and can be as low as 7% or up to around 15%. In addition, projects will only pay a share of distribution reinforcement works and so further cost savings on these figures will be achieved.

Once connected, all projects pay a use of system charge. As described elsewhere this is between £4.92 and £5.52 per kW per annum for a distribution connection, some £22.2 per kW per annum for a mainland transmission connection, estimated at £40-50 per kW per annum for a connection to an offshore substation, and in the region of £61 per kW per annum for Orkney. A small generator discount of £4.9 per kW per annum applies to the transmission connections but will soon disappear.

8.7 Innovation

Innovative techniques and equipment do have the potential to increase grid connectable capacity for Pentland Firth marine generation. This is important for initial developments which are severely limited by the capability of the existing grid, even when upgraded.

Whilst it is difficult to quantify, XE has estimated hat an additional 8-10MW, possibly more, could be released from the initial developments. Many of the innovations are very cost effective to implement although require some periodic loss of export.

Innovations alleviating voltage rise issues are particularly relevant to 11kV connections for small projects and single generators and include:

- Voltage dependant generator constraint
- Inline voltage regulators
- Generator dependant substation voltage control

Those innovations alleviating thermal (capacity) issues are particularly relevant to 33kV and above and include:

- Thermal loading dependant generator constraint
- Dynamic line rating and new higher rating line conductors

Dynamic line rating and use of new conductors are likely to be useable within the next few years, adding additional capacity by extending line ratings by 10-20% although are to some extent more useful on new build lines.

Generator constraint is already in practice although considered a little –novel" in some quarters. This allows more generation on a line provided it is constrained according to its balance against demand loading, voltage and thermal line ratings. Loads on the grid systems examined in Section 3 are low and thus this will generally allow only a few extra MW. Generator dependant substation voltage control can be used to further stretch connectable capacity.

Perhaps more interesting is the use of generator constraint to access non-firm capacity at substations. This could be used to avoid, or at least defer, transformer upgrades at Thurso and Mybster GSPs. This could create an additional 60MW of non-firm capacity at both and save around £6M in upgrades. XE has assumed this innovation is adoptable in the strategic work of Section 5 where new build is for the most part used only by Pentland Firth generation (it is worth noting that most renewable generation accepts non-firm connections as standard in any case).

As connectable capacity in the Pentland Firth is severely limited by the existing grid, innovation is important in allowing even just a few more MW in short timeframes. For this reason it needs to be further discussed with SHETL and SHEPD and detailed studies undertaken immediately to pave the way for its implementation whilst more significant grid developments are awaited.

Longer term innovation is probably of less value to the Pentland Firth Tidal Energy Project but is worth keeping a watching brief on and may merit some further investigation.

8.8 Regulatory issues

Changes to the regulatory environment are a fundamental requirement for Pentland Firth generation to get grid connected. Without change, it is likely that virtually no Pentland Firth generation will be allowed onto the grid in the foreseeable future. The regulatory environment is already in a state of flux and it is clear that participation to influence the changes is critical.

Regulatory change cuts across a number of issues but in addition, there are two other very important factors.

- The continuation and delivery of currently planned transmission reinforcements, examined in Section 5.2.

- The change (reduction) in the queue of generation waiting to connect.

From regulation itself there are issues of access (availability and use of grid capacity) and the charges levied for access.

8.8.1 Queue for connection

Analysis suggests that the queue will reduce to such an extent that at least some Pentland Firth generation will be able to connect to and use the existing and planned grid without waiting for as yet unclear future reinforcements potentially ―beyond 2018". This is in part due to natural processes driven by planning and other considerations but also due to mechanisms put in place by National Grid to accelerate this process and provide opportunities for earlier connection of individual projects – queue management.

8.8.2 Regulation and access

The most important regulatory workstreams that concern access to the grid for the Pentland Firth marine generation and are worthy of support are:

- TAR earlier connection opportunities by virtue of making better use of existing grid assets by way of means such as sharing of capacity.

- TAR Connect and Manage which could offer a long-term, bankable route to market ahead of grid reinforcements if the costs of managing the access prove acceptable.

- The GB SQSS review which could improve connection prospects by making better use of existing grid capacity through technical considerations.

- Grid company incentives which may allow upsizing on current (and future) planned grid works although the impact will probably be felt later on (i.e. 2015-2020).

8.8.3 Regulation and charging

At present, charges for use of the distribution system are on a par with other parts of the country. At transmission however the TNUoS charges once connected are very high. Actual charges for both are summarised in Section 8.6. The most important regulatory workstreams are:

- The review of the methodology to assess the impact of small distribution connected projects on transmission, the outcome of which could hinder connection of small and early Pentland Firth projects. This is also very much an access issue.

- Offshore transmission charging which is in consultation processes and the proposals of which lead to very high charges acting against offshore substation connections.

- Proposals made for a flat rate transmission charging scheme by a collection of Scottish parties. This could greatly benefit Pentland Firth generation if successful.

8.8.4 Policy developments

There are various political developments that impact on the regulatory developments. The most important worthy of participation are:

- European policy which filters into government policy and OFGEM and which favours priority access to the grid for renewable energy projects, socio-economic development of peripheral areas and non-discriminatory grid charges for renewables in peripheral areas.

- BERR guidance to OFGEM which is setting the scene for future regulation.

8.9 Concluding remarks

Whilst this report has examined the local grid works required to deliver 1,000MW and 1,700MW by 2020 from Pentland Firth generation, it is clear that there are many issues to be resolved both locally and more widely in respect of grid.

One very clear issue is that a small amount of capacity is deliverable quite quickly using the existing grid with a combination of easy upgrades and innovation, but it is another matter altogether as to how the larger works required for the targets will be coordinated and delivered in a timely and cost efficient manner to realise the targets following this.

Key points for the development of the grid in the local Pentland Firth area include:

⇒ How the required grid work will be identified and initiated early enough for projects which may not be well developed and in a position to make financial commitments until much later.

⇒ How the correct signals will be provided to enable the grid work to be coordinated and planned to cover a large number of projects that will eventually use it thereby avoiding cost inefficient ad hoc developments.

⇒ Whether costs for offshore substations and infrastructure to Orkney are justified and whether they should be charged differently - a regulatory charging issue. There are also wider benefits for Orkney to be considered.

⇒ How to provide a sufficient driver for development of wider transmission infrastructure to the east coast (DC link) and focus its development on the Pentland Firth eastern resource exploitation.

The answers to the above are not entirely clear. It is likely however that the answers can at least in part be found in the regulatory sphere and through the processes of development that the Pentland Firth generation projects will need to go through.

The Crown Estate‘s leasing for the area could be critical in ensuring a timely and efficient grid build. XE suggests that The Crown Estate and related stakeholders need to carefully consider the above issues in the leasing processes and should consult on this with the grid companies and project developers. There may be some parallels to be drawn with the offshore wind regulatory regime processes where offshore transmission is to be tendered on annual windows and projects are required to make significant commitments to deter speculators.

Coordination through leasing could be coupled with regulatory changes that may allow the grid to be built with a speculative view for anticipated need rather than financially committed projects alone. This could also provide some basis to assist the direction for a new east coast mainland DC link. Either way, front end design and consenting work is relatively low cost and could be progressed while projects are still making commitments to new grid works.

In regards the high costs, these are a product of the existing system which is in part changing. Further change is required to bring costs down and this may ultimately need to be a more politically driven process where higher costs for developing offshore renewables are accepted as the norm rather than an undesirable price to be put back on the project developers. There are various regulatory processes that will allow the cost issues to be examined. These processes are also already tackling the access issues which are fundamental to the Pentland Firth generation and it is clear that participation of all stakeholders is essential to achieve results.

9 Recommendations

The following subsections set out recommendations for further work aimed at facilitating the timely delivery of grid connections for Pentland Firth generation.

9.1 Blueprints

In terms of the blueprint scenarios, the recommendations in following sections are aimed at facilitating them. The most useful action in regards the blueprint scenarios from here is to monitor progress against them, modify them as necessary and use them to direct what is required in terms of next steps.

9.2 Background study work

Even with the existing reports and assessments that are currently in the public domain, it appears there is still a considerable amount of detailed analysis work that is required to ensure that stakeholders in the Pentland Firth region can move forward confidently in developing the region for marine renewables. A list of recommendations for further work that is required to help develop marine renewables (and offshore grid reinforcements) in the Pentland Firth region is included below.

- Detailed bathymetry report of the Pentland Firth region.
- Detailed investigation of tidal resource.
- Detailed geological assessment of the coastline and seabed along the Pentland Firth.
- Survey of suitable cable landing routes – north coast of the mainland and southern coast of Orkney Islands.
- Comprehensive shipping/navigation risk assessment.

⇒ XE recommends the above list is developed and scoped out in conjunction with developers and other stakeholders who will be better placed than XE to address the issues in these areas.

⇒ XE further suggests a funding mechanism for the work be found that allows sharing of the information and results for best use.

⇒ Onshore environmental issues and consenting risks need to be better understood and a study on this would offer better insight as to what may and may not be acceptable. This would act to further guide grid works and the blueprint.

9.3 Grid work

There are a number of fundamental issues with the grid works to be addressed, and in particular further investigation is required on how to best coordinate individual commercial developments within the Pentland Firth to ensure an efficient grid build to provide shared connections which keep overall costs, consenting issues and delays down. The process of seabed leasing may provide some degree of coordination but it is not clear how this might work at present.

- XE recommends the Pentland Firth Tidal Energy Project considers how grid work might be coordinated and suggests discussions between stakeholders and SHETL/SHEPD be held to try to identify a form of process.

- As part of the above SHETL/SHEPD need some form of incentive to build grid with an over capacity for projects still in development. Costs and risk apportionment need careful consideration and should at least in part be tackled through the regulatory incentives workstream.

- As part of the above the mechanisms that trigger grid work need further consideration. At present works are only triggered after connection agreements are signed and finance is committed.

- The above need bringing together to develop a process which identifies generation requirements across the Pentland Firth region at an early stage and provides the correct signals, incentives and commitments to SHETL/SHEPD to commence work on shared grid early.

- The Pentland Firth Tidal Energy Project should consider mechanisms to provide up front funding of low cost (but often long lead time) grid work such as front end design work, surveys, and consenting ahead of formal project commitment to ensure grid works are delivered in a timely manner.

- The above gives consideration to projects signing up to connection via an intermediate beneficiary, potentially at a point before significant finance is required for equipment and contractor orders by which time delivery timeframes should be relatively certain.

- The Hastigrow to Gills upgrade offers wider benefit to electricity customers in the region and this is merit worthy giving regional benefits beyond the connection of generation. This type of local system improvement should be further considered as part of the works.

- Interconnection of new Pentland Firth grid works to the existing and future main transmission system are unclear. This needs further consideration and warrants an additional study to examine the options for National Grid and SHETL to upgrade and interconnect with Pentland Firth developments to optimise benefit.

- Eastern Pentland Firth generation appears largely dependant on new transmission infrastructure to the east of the region. This could be via a new DC link. This needs active support from the Pentland Firth Tidal Energy project an stakeholders.

- The DC converter station location and interconnection to the rest of the main transmission system needs further consideration as it involves crossing the region which is not without consenting issues.

9.4 Innovation

Innovation needs support as a means to increase the connectable capacity over the short term in particular. XE recommends the following:

- Innovative techniques and technologies are discussed with SHETL and SHEPD to agree the preferred solutions.

- Detailed studies are conducted to quantify the benefits (additional capacity) that innovation will bring and to pave the way for its implementation quickly.

- Support needs to be given to innovative techniques, perhaps by way of research and development funding and active promotion for the projects.

9.5 Regulation

Change in the regulatory environment is fundamental to facilitating targets for Pentland Firth marine energy developments. XE recommends the following:

- Continued support for grid upgrade work and lobbying to bring any subsea DC link to the region forward.

- Continued involvement in regulatory workstreams so as to influence developments.

- Continued lobbying to reduce high northern transmission charges which make northern mainland and particularly Orkney transmission connections very expensive. This should focus on reduction of locational charging elements, greater socialisation and support for fixed rate charging arrangements as currently proposed by Scottish parties and led by The Scottish Government.

- Lobbying to better bring consideration of socio-economic development into consideration of new grid developments – a key factor for the region.

- Lobbying against the high charges proposed for generators using offshore transmission.

- Continued lobbying for transmission access improvements, primarily through the Transmission Access Review.

- Support for changes to the GB SQSS to allow more renewable capacity onto the grid.

- Support for changes such as the queue management methodology that will allow projects to move forward in the queue and CAP 150, both of which will give Pentland Firth generation a better chance.

- A more detailed review of wider transmission grid issues, the queue of generation for grid connection as affects the northern area, the progress with reinforcements and progress in changing the regulatory regime should be considered.

- Lobbying for a sensible and pragmatic approach to assessing the impact of small distribution connected projects on transmission rather than a blanket –everything affects the transmission system" approach.

- Support for European policy which filters into government policy and OFGEM and which favours priority access to the grid for renewable energy projects.

- Lobbying against European policy which looks strongly to socio-economic development of peripheral areas and non-discriminatory grid charging of renewables in peripheral areas.

- Involvement in BERR guidance to OFGEM which is setting the scene for future regulation.

10 Appendix A – Additional background studies

10.1 Introduction

Other studies reviewed as part of the background report review are briefly summarised in this appendix.

10.2 FREDS Marine Energy Group Report (2004)

Forum for Renewable Energy Development in Scotland (FREDS), Marine Energy Group (MEG) Report 2004, Harnessing Scotland's Marine Energy Potential. July 2004 [65].

The FREDS Marine Energy Group report 2004 outlined the major issues hindering the development of the marine energy sector as well as defining the target potential for marine renewables in Scotland. The Marine Energy Group believes that by 2020:

- 10% of Scotland's electricity production can come from marine resources.
- 1,300MW of marine energy capacity can be installed in Scottish waters.
- 7,000 direct jobs could be created.
- Scotland can become a world leader in the research, development and certification of marine energy devices.

The Marine Energy Group also believes that the Pentland Firth can contribute up to 1,837MW of rated marine capacity, slightly more than the 1,700MW target given to XE by HIE.

Much of the output from this report consists of high level policy advice, and includes a task list which identifies the areas of concern (including grid) that must be addressed to secure the successful deployment of the marine energy sector in Scotland.

10.3 BWEA, The Path to Power (2006)

British Wind Energy Association (BWEA), The Path to Power: Delivering Confidence in Britain's wave and tidal stream industry, June 2006 [66].

The reason this report was compiled was to respond to *'the growing need for Government to commit its support to the UK's wave and tidal stream industry'*. The document provides a holistic view of the marine energy industry and discusses the various issues surrounding the sector, concluding with a timeline of recommendations for each of the major issues.

According to BWEA, one of the three identified hurdles to the development of the marine energy sector is *'Grid Evolution Scenarios and GB Network Access'*. Essentially, this concerns the disparity between the overall marine resource in the UK (mostly along north and west coast of Scotland) and the availability of grid capacity (not in the north and west). BWEA realises the importance of transmission access and charging regimes, which can be construed as penalising generators in the north of the country to such an extent that the economics of power generation along the northern coast of the Scottish mainland are questionable. Therefore the report suggests that marine energy industry stakeholders participate in regulatory review and consultation that is carried out by BERR and OFGEM [67] [68] [69] [70].

XE notes that regulatory issues have been discussed in Section 6 of this report and are as BWEA suggests of paramount importance.

10.4 SDC, Turning the Tide (2007)

Sustainable Development Commission (SDC), Turning the Tide, Tidal Power in the UK, October 2007 [71].

The SDC commissioned a report to assess the potential for exploitation of the tidal resource available in the UK. The report looked into both tidal stream and tidal range technologies. According to the report, 5% of the UK electricity requirement can be supplied by tidal stream energy and it outlines that Scotland has the greatest potential to capitalise on this technology.

SDC conducted a review of all of the tidal stream resource available around the UK and identified that six out of the top ten most powerful tidal stream sites were located in the Pentland Firth. The report claimed that 12.7TWh/year is available from the region. However, this figure did not take into consideration technological limitations of the tidal stream devices, or the physical constraints that exist in the region (e.g. shipping lanes).

This report, similar to the other documentation reviewed herein, cites the transmission grid as a serious barrier for the industry - specifically the transmission grid in northern England and Scotland, with particular concern being expressed about the ‗GB Queue'.

XE has examined and commented on issues of queuing for grid connection and transmission access in Section 6 of the main body of this report.

10.5 HIE, Assessment of Grid Connection Options for the Scottish Islands (2007)

TNEI, Assessment of Grid Connection Options for the Scottish Islands, prepared for Highlands and Island Enterprise, March 2007 [72].

This report looked at the options available to connect the large wind generating capacity available in the Scottish Islands to the mainland grid. The study was based on a scenario consisting of significant generation to be installed on the Western Isles, Shetland, Orkney and Beatrice offshore wind farm as was the case at time of writing (but is now slightly different, particularly for Orkney).

The report identified a number of key restrictions that will impact on the design and installation of offshore interconnectors between the Scottish mainland and islands. Some of the most pertinent issues raised by the report include discussions surrounding cable laying through rocky seabed and foreshore as well as sensitive sites onshore that require mitigation/avoidance.

The key relevant points from this report include a review of potential landing sites for an interconnector between Skaill Bay on Orkney and Murkle Bay on the mainland. The study concluded that there are a number of positions for cable landing south of Dunnet Head. However, it is likely that most of these sites would have issues with regards to radioactive disturbance as a result of proximity to Dounreay power station. The report points out that Hoy is a protected Special Area of Conservation (SAC) and Special Protection Area (SPA) and would therefore be a difficult landing site from a consents viewpoint. There are however existing 33kV cables landing at Rackwick on Hoy which may present an option new cables.

Rackwick is a little north from the area of interest in the Pentland Firth but is probably the most southerly landing point on the western side of Orkney. XE notes that other documents such as the Marine SEA (see Section 2.3) also cover the above.

11 Appendix B – grid assessment methodology

11.1 Introduction

This appendix to the report provides an outline of the methodology used to assess the grid connection options and the capacity available. The methodology has been discussed and agreed with SHETL and SHEPD and is therefore robust against headline issues. Detailed study has not been undertaken however and issues such as consenting are only examined at the highest level. In addition, secondary technical issues such as power quality and stability have not been examined.

11.2 General assessment

The following list provides the basic technical issues addressed in the analysis.

- Thermal capacity.
- Voltage rise.
- Fault levels and switchgear rating issues where accessible.
- Reverse power issues at substations.
- Issues of protection, circuit complexity and other issues where particularly relevant.

The above technical issues are examined to assess grid connections and obtain:

- A connectable minimum MW figure with lowest cost.
- A connectable maximum MW figure considering basic and achievable reinforcement works and/or standard operational procedures.
- Connectable MW through new build works.

Application of innovation is considered also with estimates of its impact made.

Further assessment criteria include:

- Capital costs of the grid works.
- Timeframes for the grid works.

Additionally, and where possible, XE makes some comment on consenting and environmental issues, generally on the basis of the volume of grid works required and for the strategic works (see below) the extent of new lines or substations required.

11.3 Technical methodology

To estimate connectable MW of generation XE has used an analysis based on three key criteria – thermal limits, voltage limits, and, to a lesser extent fault level limits. Other criteria (e.g. power quality) have not been considered for a study at this level. The analysis methodology has been agreed with SHEPD and SHETL.

A. 11kV and 33kV lines

1. Thermal criteria are based on summer line ratings and minimum loads. In some cases 11kV minimum loads are very low and can effectively be neglected as insignificant.
2. Voltage rise is estimated based on circuit impedances and considering generation export real and reactive power and minimum loads. As above, at 11kV, minimum loads can be so low that assuming they are zero gives a reasonable worst case. XE notes that statutory voltage limits applied at Low Voltage are particularly limiting at 11kV due to directly connected consumers.
3. Fault levels and switchgear ratings of main switchgear as identified from [21].

B. 132kV, 275kV and 400kV lines

As for A except voltage rise limits are in general not an issue.

C. Substation transformers

1. Thermal limits are assessed based on:
    a. Maximum generation and minimum demand to give a worst case.
    b. Single transformer outages for a double transformer substation to give a firm capacity estimate, full rating for single transformer substations.
    c. A non-firm estimate is based on no outages.
    d. Reverse power issues are generally assumed acceptable with minor protection and control changes as advised by SHEPD/SHETL. Significant issues requiring tap changer and transformer replacements are not expected.
    e. Use of transformer ONAN ratings only.
2. Voltage issues are assumed satisfactory unless reverse power is an issue and/or the tapping range cannot accommodate the voltage change due to backflow.
3. Fault levels and switchgear ratings of main switchgear as identified in [21].

D. Security

Where appropriate, security of demand and generation is assessed against n-1 outages. In moving to generator only connections and strategic or innovative solutions for connection this requirement may be waived although is notable and requires an inter-trip constraint scheme. Situations where non-firm capacity is accessed are taken up to the non-firm limit (e.g. full rating of a two transformer substation).

E. Protection and control

Issues with protection and control are generally assumed to be corrected through protection setting adjustments and minor relay changes. It is beyond the scope of this report to look at major protection issues although XE notes that these are unlikely given SHEPD‘s (and to a lesser extent) SHETL‘s standard protection arrangements.

11.4 Costs

All costs are assessed using site specifics but with generic and standard equipment and works costs. For this reason some costs are identical. It should be noted that costs are given for guidance and can only be taken as approximations of likely costs for the SHEPD, SHETL, or OFTO grid related works. All costs are quoted as capital costs for the grid works and have been discussed with SHETL and SHEPD and extracted from [42] and [43] as well as from XE‘s experience of similar projects.

In all cases it is assumed that the connection charging boundary is at the connection point and it is the project developer‘s responsibility to reach the connection. This means that for connections far inland or far from the site of interest the additional costs to reach the connection may be significant and are not included.

XE has assumed the project developer will provide housing for the any SHEPD metering switchgear, SCADA, and associated protection and control as is the normal practice at distribution and that at transmission connections are super-shallow, generally with a 33kV interface at a GSP both onshore and offshore. Costs given for single 11kV and 33kV connections in Section 3 allow for a metering circuit breaker and associated plant.

For larger strategic grid works, e.g. GSP, it is not possible to anticipate exactly what works will be required to connect individual projects and how many projects may wish to connect. Quoted costs are therefore for the plain grid infrastructure. The projects will need to find extra costs in these cases. For guidance XE suggests an allowance of £150-250k for 11kV and 33kV metering switchgear and associated protection and control per connecting project. As with all other connections it is the project‘s cost to reach the connection point.

Cable routes, where considered, are assumed to follow public rights of way where practical and installation costs are assumed to be 50% green field and 50% minor roads as befits the region. In general however costs are based on overhead line routes as a preferred option. Subsea cable installation costs are based on common costs extracted from offshore wind farms.

Once connected, projects must pay a use of system charge. For 11kV and 33kV connections this set out in [56]. For transmission connected projects this is set out in [42]. For connection to Orkney and to offshore substations XE has made an estimate based on the current mainland onshore charge and methodology and the proposals for charging offshore [61].

11.5 Consents

It is worth noting that XE has examined overhead routes for low cost and with wood pole lines to keep consenting issues down. At 33kV and 11kV new lines will invariably be wood pole but at 132kV and above this is not necessarily the case. Consents issues are not examined within this report and are largely outside the scope. XE has paid attention to environmentally designated areas however.

Consents issues are judged in the report using a colour code according to the level of new infrastructure required. The coding is a relative system rather than absolute and is as follows:

- Low/minimal consents issues. No new lines or substations.
- Moderate consents issues. New lines or substations not exceeding 33kV and therefore of moderate physical and visual impact.
- High consents issues. New lines or substations with 132kV or greater infrastructure and therefore of greater physical size and visual impact.

In colour ranking, some attention has been paid to proximity of known sensitive areas although this is very site specific and warrants a detailed investigation in its own right.

11.6 Timeframes

Timeframes are indicated based on typical periods for design, survey, consenting, equipment lead times and construction timeframes. Equipment lead times can be very significant for major equipment such as high voltage cables and transformers (2-3 years).

Consenting timeframes are set to a default period of 6-18 months depending on the infrastructure and issues anticipated. It is beyond the scope of this report to examine consenting issues in any detail and slippage due to consenting issues is always a real possibility if not likely. There is also no guarantee that consents will be obtained. XE has provided typical achievable timeframes to build local infrastructure if consenting is not a major problem and as such quoted timeframes represent the best achievable.

All timeframes have been discussed with SHEPD and SHETL and agreed on as typical provided major issues are not encountered. Consents issues are largely beyond the scope of this work and very difficult to predict in many cases anyway.

As noted elsewhere, this report focuses on the local grid infrastructure only and it is a fundamental assumption that a combination of regulatory regime change, grid reinforcement, and reduction in the level of generation seeking connection allows power export to the wider transmission system from the local works. No contingency on wider transmission work is therefore factored in.

12 Appendix C – Distribution system diagrams

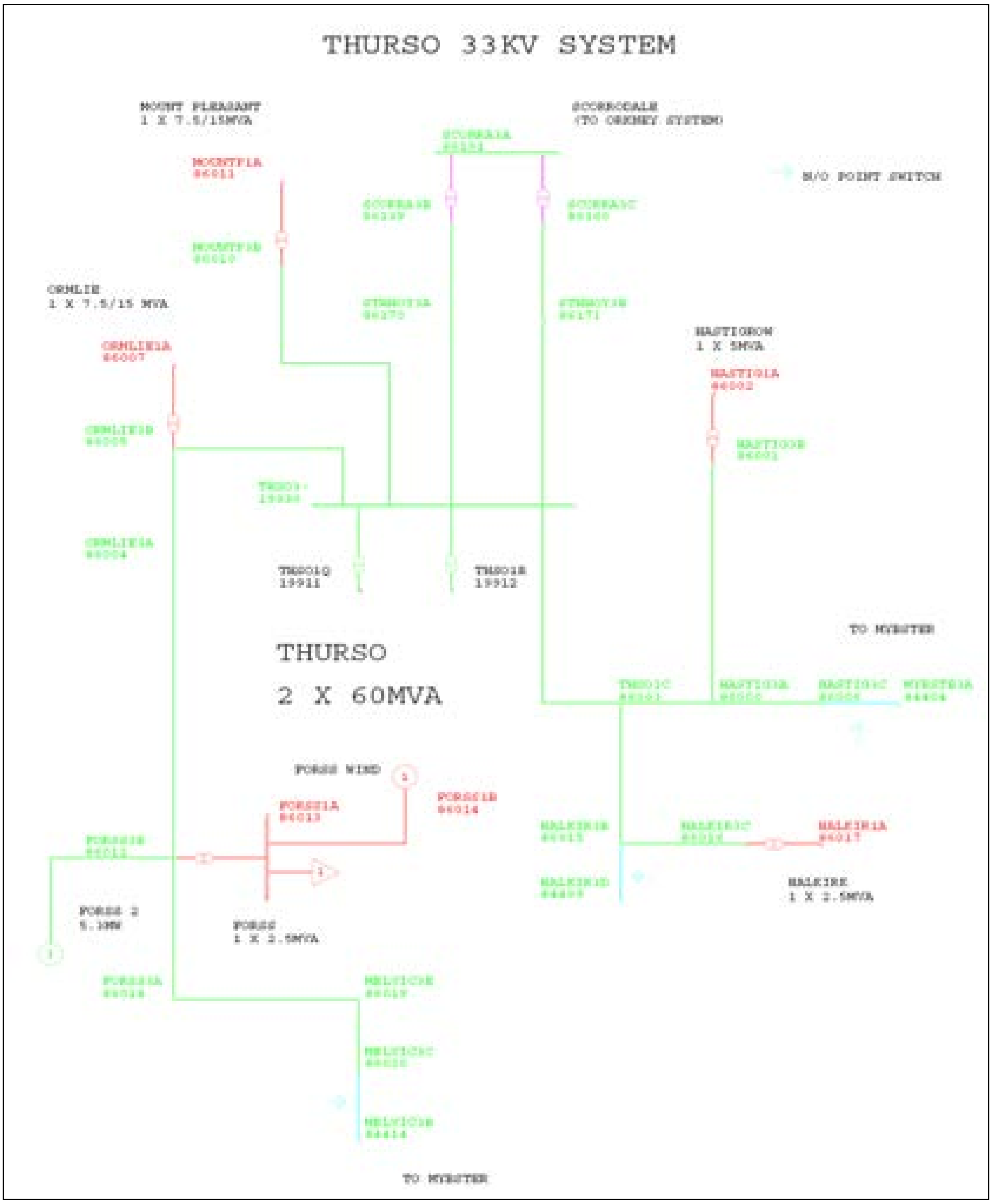

Figure 12-1: Thurso 33kV system [21]

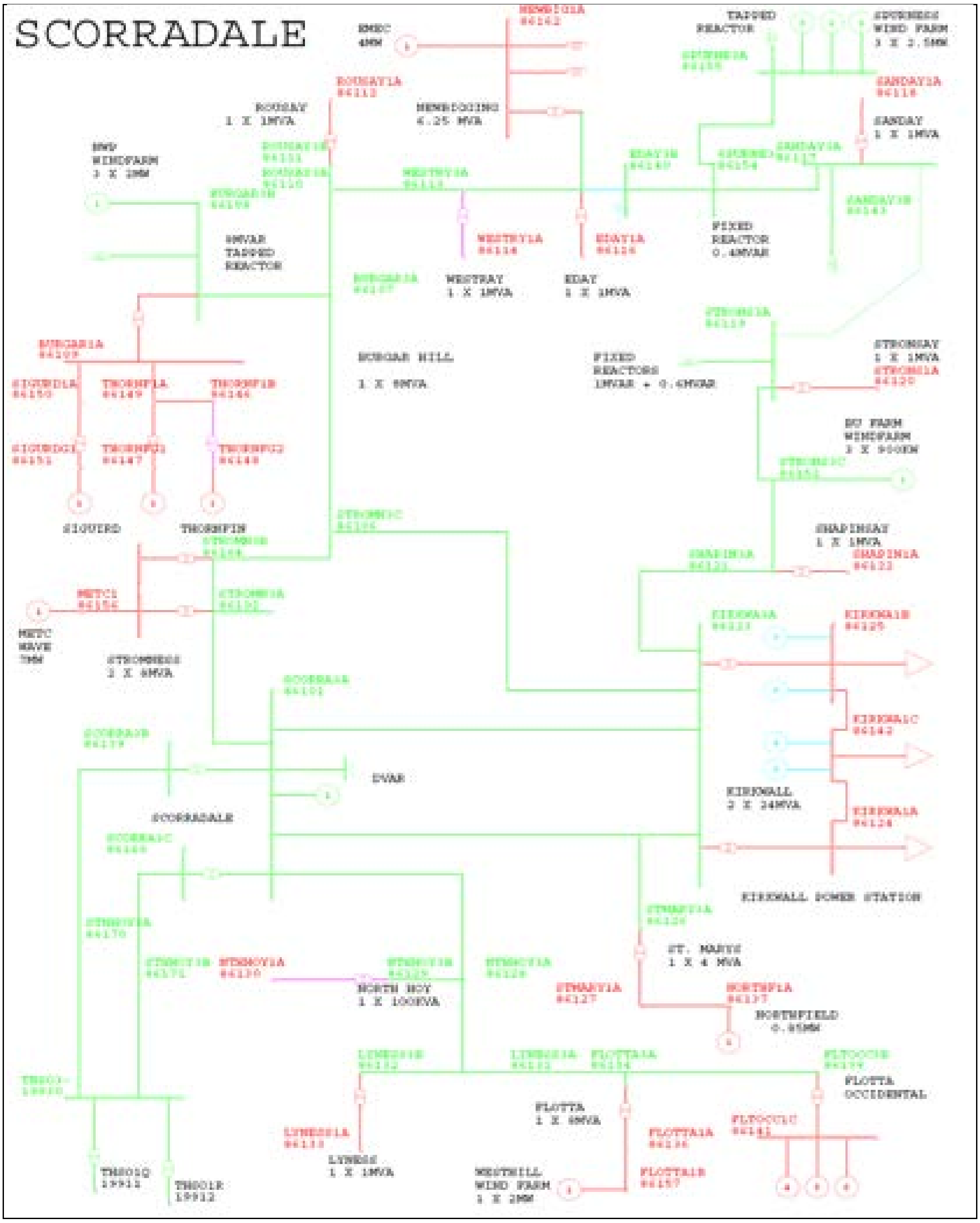

Figure 12-2: Orkney 33kV system [21]

13 Appendix D – Storage and hydrogen

13.1 Introduction

This appendix examines innovative technologies that are unlikely to be of significant use in the timeframes of the Pentland Firth project.

13.2 Storage

Storage technologies have for a long time been considered the missing link for intermittent renewable generators. This section discusses various storage technologies (at different stages of development), all with the potential to allow much larger renewables projects to be developed without the need for the traditionally associated grid system upgrades. Storage technologies are a key to creating ‗dispatchable' renewable energy, resulting in more consistent and dependable power. Increasing the reliability of renewable energy and reducing the requirement for grid reinforcements has an obvious impact on the economic viability of renewable energy projects as well as potentially reducing lead times. However, all of these technologies are expensive (compared to traditional system reinforcements) and there are therefore few examples of implementation.

13.2.1 Pumped hydro storage

Conventional pumped hydro storage is one of the most mature energy storage technologies, with a number of installations throughout Scotland, England and Wales. Recently the Scottish Government commissioned a report that revealed there is an extra 657MW of viable pumped hydro storage potential in Scotland [73]. However, this technology is expensive ($1,300/kW and $80/kWh [74]) and the study suggested that there is only 0.2MW of commercially viable hydropower capacity within proximity of the Pentland Firth. This level of capacity cannot make any significant impact towards alleviating grid issues in the northern mainland. Combined with the fact that it would not be commercially viable (or even possible under current market regimes) to use any hydropower scheme to solely service the renewables industry, this technology is not considered a feasible option for the Pentland Firth.

13.2.2 Batteries

Batteries for large scale energy storage come in a number of forms, including Lead acid, Nickel Cadmium, high temperature batteries and flow batteries amongst others. Not all of these technologies are reviewed in this section, only the ones that are technically most mature and have been commercially deployed on a large scale (several MWs).

Lead Acid

Due to the ongoing development of this very mature electrochemical technology, modern lead acid batteries are both reliable and low cost. However due to the limited energy density of these batteries, they can be heavy and have large storage requirements. This technology also performs poorly in low temperature conditions and would therefore require a thermal management system [75]. The largest system in the world is a 40MWh (10MW) system in Chino, California [76] that was built in 1995. The technology is currently estimated to cost $300/kW and $400/kWh [74].

Nickel Cadmium (NiCd)

The NiCd battery is also a very mature technology and provides a number of advantages over lead acid batteries, including increased reliability and low maintenance requirements. A very large NiCd battery was installed in Alaska in 2003 by Golden Valley Electric Association. The battery provides spinning reserve for an electrical island and is designed to complete 100 full discharges and 500 partial discharges throughout its lifetime. The installation cost $35 million and can provide up to 46MW of power, being able to discharge 27MW of power for 15 minutes or 40MW for 7 minutes [75].

Sodium Sulphur (NaS)

Sodium Sulphur batteries are slightly less well developed than lead acid or NiCd. However, there are examples of very large installations around the world, most notably in Japan. NGK insulators Ltd have recently installed a 34MW, 220MWh NaS battery in Japan. Currently the price for this technology is around $250/kWh, but this price is expected to decrease as production increases [75].

Flow Batteries

Flow battery technology is slightly different from conventional batteries in that flow batteries store two liquid electrolyte solutions in separate tanks and produce electricity by bringing them together on either side of a membrane. Because flow cell batteries store energy in the electrolytes, they display a number of very attractive characteristics. Flow batteries can decouple the power and energy delivery characteristics and are only restricted in storage capacity by the volume of stored electrolyte. Costs are very high for installing batteries, around $300/kW (and between $250 - $400/kWh).

13.2.3 Kinetic energy storage systems (Flywheels)

Conventional steel rotor flywheel technology is mature, while more advanced (composite) technology is less well developed but commercially available. The main focus of flywheel technology is on short duration (10-100 seconds) discharges. Flywheels have a number of advantages in that they have low operation and maintenance requirements, can easily withstand deep cyclic loading and display good reliability. Due to the generally short discharge periods, relatively small scale and high cost ($300/kW and $600/kWh) of the technology it is unlikely that this technology will be overly useful for deployment alongside marine energy developments in the Pentland Firth.

13.2.4 Compressed Air Energy Storage (CAES)

CAES plants use off-peak electricity to compress and store air in large underground caverns, at pressures of around 75 bar until such times that demand for the energy increases. To produce electricity the compressed air is released, heated and expanded through a combustion turbine. Ratings for CAES systems range from around 50MW to 300MW; with potentially very long storage periods due to low storage loss. The cost of implementing CAES is estimated at around $500-$660 per kW [77]. There are three types of underground storage categories that are currently used for CAES: rock caverns, salt caverns and porous media reservoirs. Obviously, one of the main drawbacks of implementing this technology is access to appropriate geological structures. At this time there are only two examples of CAES in the world, Huntorf Plant and McIntosh Plant. Smaller scale, above ground, compressed air storage is currently being developed but there aren't any commercial examples yet of the technology. This storage option has the potential to deliver large volumes of storage capacity. However, whether or not there will be appropriate geological sites for utilising this technology is another matter.

13.3 Hydrogen

Even though hydrogen storage is a long way from being commercially deployed on a large scale, it has the potential to play a significant role in the future deployment of renewable technology. The use of hydrogen as an energy storage medium has a number of benefits including: high energy density, wide range of system sizes (kW-multiple MW), system charge rate, discharge rate and storage capacity are independent variables, the systems can be assembled in stages or in modules and hydrogen does not present an environmental risk if it escapes. The main disadvantages of hydrogen storage are that it has low cycle efficiency (around 50%) especially if used in gas engines rather than in fuel cells and it is very difficult to store and is highly flammable.

13.4 Section conclusions

All of the storage technologies discussed in this report are very expensive (when compared to simply upgrading the existing grid or building new grid) and are generally uneconomic even with RPZ type incentives. Therefore XE does not suggest that energy storage or hydrogen is pursued with priority in regards development of the Pentland Firth energy resource.

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