
Feasibility Study for Connection of
Severn Tidal Generation
For
Department of Energy and Climate Change
Final Report
Version 1.4

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1 Executive Summary

This feasibility study has considered three main options for connecting tidal generation in the Severn Estuary to the National Grid Transmission System. The options considered are as follows: -

- **8.64GW** of generation located at the site for the Middle Barrage without transmission circuits across the Barrage (Option 1).
- **8.64GW** of generation located at a site for the Middle Barrage with either AC or DC transmission circuits across the Barrage (Option 2 – AC ; Option 2A – DC).
- **1.365GW** of generation located at a site for the Inner Barrage.

Each of the generation options described above has been assessed in detail considering system design issues, including identifying the required reinforcements to maintain the transmission system integrity and compliance. For each of the options; the high level investment costs, construction and consents issues involved in maintaining the integrity and compliance of the transmission system have been considered.

Table 1.1 summarises the indicative latest contractual background cost and indicative proposed connection dates for each option in 2009 prices.

	1 (Middle Barrage - No circuits across barrage)	2 (Middle Barrage - With circuits across barrage)	2A (Middle Barrage – With Circuits across the barrage DC option)	3 (Inner Barrage)
	(£m)	(£m)	(£m)	(£m)
Generation MW	8.64GW	8.64GW	8.64GW	1.365GW
Indicative Connection Dates	2024-2026	2021-2023	2021-2023	2019-2021
TOTAL + Contractual (£m)	£2,349	£2,253	£2,256	£292

Table 1.1 Severn Tidal Generation Options indicative costs and indicative connection dates

Middle Barrage Options (8.64GW)

Option 1 for connecting generation at the Middle Barrage location requires the greatest transmission works, including the requirement to construct a new 125km transmission line between Bridgwater and Nursling. The reinforcements for this option include: -

- 12 new transmission substations.
- 200km of new overhead line routes
- 485km of uprating existing overhead line capabilities

Option 2 for connecting generation at the Middle Barrage location requires AC transmission circuits to be cabled across the barrage structure. This has the advantage of potentially avoiding the need for the 125km transmission line between Bridgwater and Nursling (subject to contracted backgrounds). The reinforcements for this option include: -

- 10 new transmission substations.

-
- 78km of new overhead line routes
 - 220km of upgrading existing overhead line capabilities

Option 2A for connecting generation at the Middle Barrage location requires DC transmission circuits to be cabled across the barrage structure. Otherwise Option 2A is identical to Option 2. Due to increased problems with generator stability for an AC circuit option, the DC option is more desirable from a system point of view as it eliminates some of these problems.

All the options described above have significant technical issues to overcome from an electricity transmission viewpoint. Option 1 (with no circuits across the barrage) has a later anticipated completion date due to the volume of work required. The AC and DC Options 2 and 2A can potentially be delivered earlier as the volume of physical work on the transmission system is less.

DC circuits across the barrage are a desirable option as it limits some of the electrical design issues which are difficult to resolve. However, the technology required is not yet commonly utilised to the capability required for this project and would need very detailed investigation to establish the full feasibility and cost associated with it.

Inner Barrage Option (1.365GW)

Option 3 for connecting generation at the Inner Barrage location requires significantly less transmission works due to the smaller generation size. However, any connection would need to be made to the English side of the Severn Estuary. If a connection were to be made to the Welsh side an approximate **£120m** (in 2009 prices) of additional cost would be incurred due to the need to construct new transmission circuits across the Severn Estuary. The reinforcements for this option include: -

- No new transmission substations (extensions only to the proposed Aust 400kV substation)
- 5km of new overhead line routes
- 51km of upgrading existing overhead line capabilities

Unlike for the Middle Barrage, the studies show that for this smaller generation connection there is no requirement for reinforcement works in South Wales or London.

Changes to the Contracted Background

Since commencing the feasibility study for the inner and middle barrage options National Grid has made generation offers which have been subsequently accepted by generation applicants. National Grid has an application process that is open to any entity seeking to connect generation to the transmission system at any point during the year. This has had the consequence of introducing additional transmission works to each of the options above. This list of additional works is the minimal quantity of works required as a consequence of these connections and would be reviewed in detail as part of any application. The additional works would include: -

- 1 new transmission substation

-
- 41km of new overhead line routes
 - 40km of upgrading existing overhead line capabilities

All Options

The analysis work has shown, that the selection and design of the generator (for all the options) is key to ensuring a viable connection offer can be made. Certain assumptions have had to be made for this feasibility study, but any competent connection application would need to be accompanied by accurate and validated data. To overcome stability issues for all options, serious consideration needs to be given to ensuring any generator selected for the tidal project has an inertia constant in the order of 1.5 MWs/MVA as a minimum.

The contracted background is subject to change at any time, however from the feasibility assessment carried out for tidal generation in the Severn Estuary, National Grid is confident of being able to provide a viable connection solution for all options studied, subject to gaining the required consents.

2 Feasibility Report Terms of Reference

The terms of reference for this feasibility report were originally set out in the feasibility agreement between National Grid and the Department for Energy and Climate Change (DECC). The elements here are a review of these requirements and set out the scope and objectives of this feasibility study.

The report has been undertaken on the basis of two identified connection points set out below:-

Site	Preliminary Connection Point	Configuration	Total Transmission Entry Capacity	Preferred Connection Date
Inner Barrage	South of Second Severn Road Crossing Grid Ref: ST 506854	39 x 35MW Straflo Turbines	1365MW	1 October 2019
Middle Barrage	The mid point between Brean Down and Lavernock Point Grid Ref: ST 226622	216 x 40MW Bulb Turbines	8640MW	1 October 2021

Table 2.1 Connection Options Studied

These options above were chosen for investigation, as for most variants of the tidal schemes identified in the "Severn Tidal Power Phase 1 Consultation" document these options would be representative of the majority of electricity transmission works required.

The works undertaken by National Grid for each connection location has been as follows: -

Electrical Design

- Winter Peak thermal Studies (100% demand levels with winter equipment thermal ratings)
- Maximum summer demand Thermal Studies (70% demand levels with summer equipment thermal ratings).
- Minimum summer demand Thermal Studies. (40% demand levels with summer equipment thermal ratings)
- Voltage Assessment for Winter Peak, Summer Minimum and Maximum.
- Full busbar fault level assessment of South Wales and South West transmission and Grid Supply Points
- Stability Studies, looking at intact Winter Peak conditions; Summer minimum Outage conditions; both options consider pumping as well as generating scenarios.
- Considerations of varying generation on each side of the estuary.
- Single line diagrams of each connection point.
- Single line schematic and geographical representation of wider system works
- Description of all works required to meet the requirements of the National Electricity Transmission System Security and Quality of Supply Standard (NETS SQSS)

Cost and Construction issues

- Indicative Costs of each option, including breakdown of major elements for each option.

-
- Costing implications on replacing Circuit Breakers impacted by higher fault levels.
 - Indication of fault level rises seen at Distribution Network Operator interfaces.
 - Indicative connection date, based on current contracted commitments.
 - High level consenting view on new and existing transmission equipment works.

This report has been compiled on the basis of works listed above looking at the impacts to the England and Wales Transmission Systems. There shall be variations across some transmission boundaries throughout England and Wales, but neither of the connection options should have an impact on the Scottish Transmission System which is very remote from the impacts of these schemes.

Description of Study Work

Analytical Work

The analytical study work has been carried out using the National Grid electrical study backgrounds, with specific models created for each option and each season studied e.g. 100%, 70% and 40% backgrounds for each. The fault level studies are performed against a specific background also with its own data set for each option. The stability studies looked specifically at the 100% and 40% backgrounds only as these represent the extremes of the worst case scenarios.

Thermal and Voltage studies are performed against the requirements of the National Electricity Transmission System Security and Quality of Supply Standard (NETS SQSS). This requires National Grid to consider faults of two transmission circuits occurring within the studied timescales. Under such a scenario, there should not be;

- the loss of any supply (except for the limits loss of infeed for generation connected directly to the faulted circuits);
- any unacceptable overloading of primary transmission equipment;
- Unacceptable Voltage conditions;
- System instability.

Studies looking at the thermal and voltage for each option and each season were performed in line with this requirement. All reinforcements proposed for Thermal and Voltage reasons in this report are required to maintain compliance with the NETS SQSS, as required by National Grid's Transmission Licence.

Fault level studies are carried out in the report based on National Grid's implementation of IEC 60909-0 and ER-G74 methods of calculation. Again this is covered by the NETS SQSS and transmission licence requirements and is performed against a 100% peak background, and any necessary reinforcements are required to maintain compliance.

Stability requirements at peak studies are performed on the same basis as the voltage and thermal studies considering two transmission circuit faults. However the 40% studies will consider the realistic condition of a single transmission circuit maintenance outage (pre-fault outage) and a concurrent double circuit fault. This double circuit must have the circuits on the same transmission tower and stability must be maintained during the worst of these faults.

For all study backgrounds the tidal generation was treated in such a way as to ensure the reactive output met the requirements of section CC.6.3.2 of the Grid Code grid code for a Power Park Module of 0.95 lagging and 0.95 leading at the grid entry point.

The electrical design background alters with each application that is accepted and is constantly evolving. Therefore any requirements highlighted in the report are only valid for the background they are studied against and could alter due to other applicant's requirements.

Costing Work

Costs produced in this report are done on the basis of National Grid's Investment Procedure level 1 (IP1) documents. These IP1 documents are desk top high level costing exercises using the equipment identified during the studies and ascertaining costs based on historical costs. These IP1 models cannot take into account the unique nature of each physical site proposed, and specific costs associated with elements which will only be defined in detailed design.

The IP1 model's forecast costs are in 2009 prices.

3 Introduction and Background

3.1 Existing South Wales and South West Transmission System

Figures 3.1.1 and 3.1.2 below show the schematic and geographical representations of the existing transmission system in South Wales and the South West. These two networks are mostly independent of each other in local electrical terms and converge at Melksham 400kV substation.

South West

The South West Transmission System wholly consists of 400kV transmission equipment and has 4 transmission circuits connecting it into the rest of the main interconnected transmission system (MITS). These circuits join the MITS at Melksham 400kV, Lovedean 400kV and Fawley 400kV.

Current connected generation in the South West Consists of: -

Indian Queens	= 140MW
Langage	= 905MW
Hinkley Point B	= 1261MW
Fawley	= 1036MW
ESSO Fawley (Embedded)	= 158MW
Marchwood	= 900MW
Seabank 1 and 2	= 1234MW
Total	=5634MW

South Wales

The transmission system in South Wales consists of both 400kV and 275kV transmission equipment. The 275kV system in South Wales forms connections to power stations typically on the estuary coast line and is characterised by extensive use of L3 transmission towers. L3 towers are of a smaller and structurally lighter design and can not be re-used to carry 400kV conductors and insulation. The remainder of the system is characterised by a 400kV loop to the north of the 275kV system, providing connections to Pembroke 400kV. Pembroke 400kV was the former site of an oil fired power station, now decommissioned.

The South Wales Transmission System is connected to the rest of the MITS via six circuits. These six circuits, 3 double circuits, each cross natural river constraints which have limited the existing circuit capacity.

- The Northern 400kV circuits to Walham cross the Wye valley via cable circuits at Ross-on-Wye.
- The southern 400kV circuits to Seabank and Melksham cross the River Severn via a cable tunnel.
- The southern 275kV circuits to Iron Acton cross the River Severn by the means of a high level river crossing.

These circuits described above currently represent the limiting factor for power export across the South Wales transmission boundary.

Current Connected Generation in South Wales Consists of: -

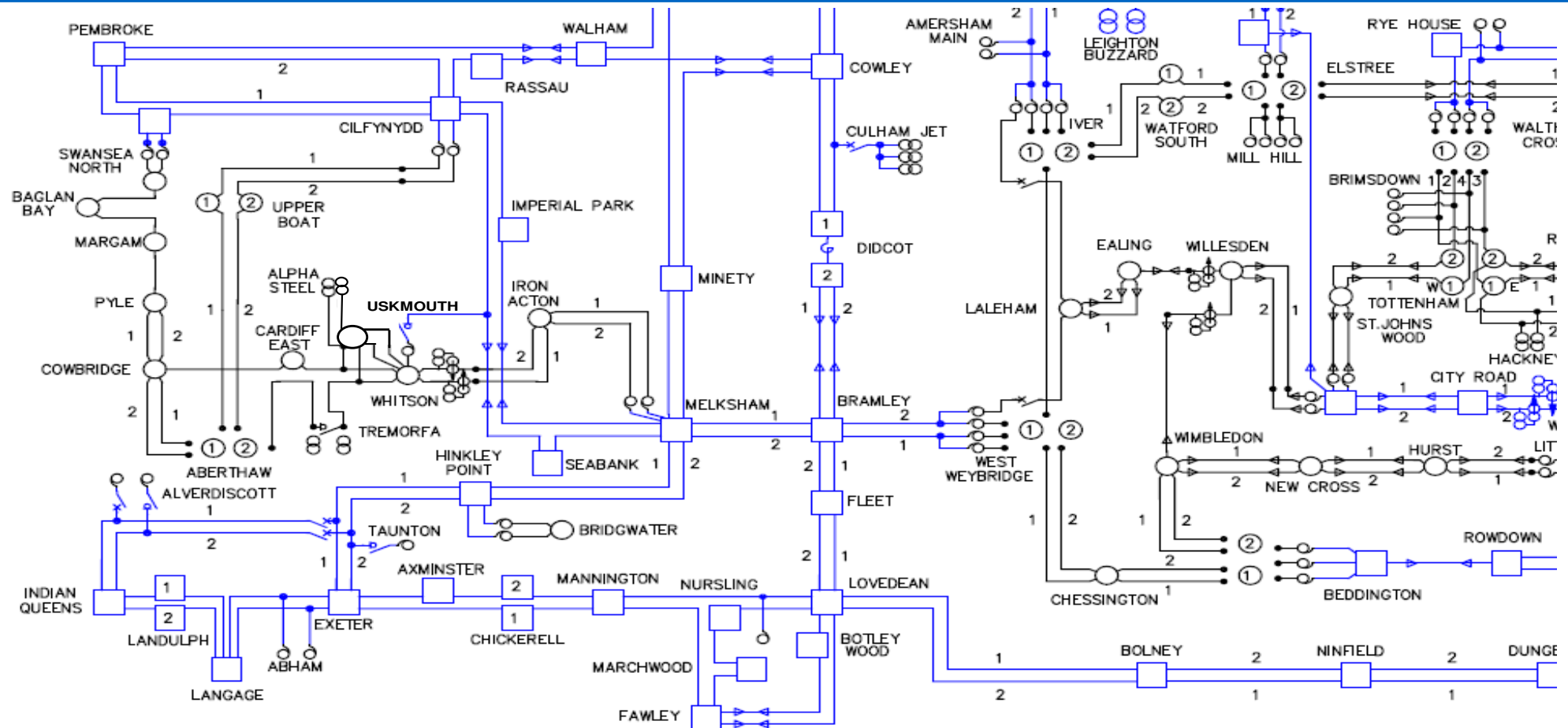
Aberthaw	= 1455MW
Barry (Embedded)	= 245MW
Uskmouth	= 363MW
Severn Power	= 850MW
Baglan Bay	= 552MW
Total	=3465MW

Generation Backgrounds

Generation backgrounds need to be included in the analytical backgrounds to ensure that enough generation is running in the study to meet demand. However if too much plant is available to satisfy this requirement, some is removed from the background. National Grid selects its generation backgrounds to meet demand on the probability of plant running in any season based upon historical operating data.

Therefore all the generation that is available within an area may not necessarily be expected to run under all of the analytical background scenarios. The treatment of each generator in a specific background is commercially sensitive information to National Grid; however treatment of generation in this feasibility study meets National Grid processes used for the basis of investment in the transmission system.

Existing South Wales/South West Transmission System



KEY

- 275kV
- 400kV
- NEW ASSETS
- CHANGES TO EXISTING ASSETS
- HOTWIRING

Figure 3.1.1 Existing South Wales/South West Transmission System

Geographical Existing South Wales/South West Transmission System

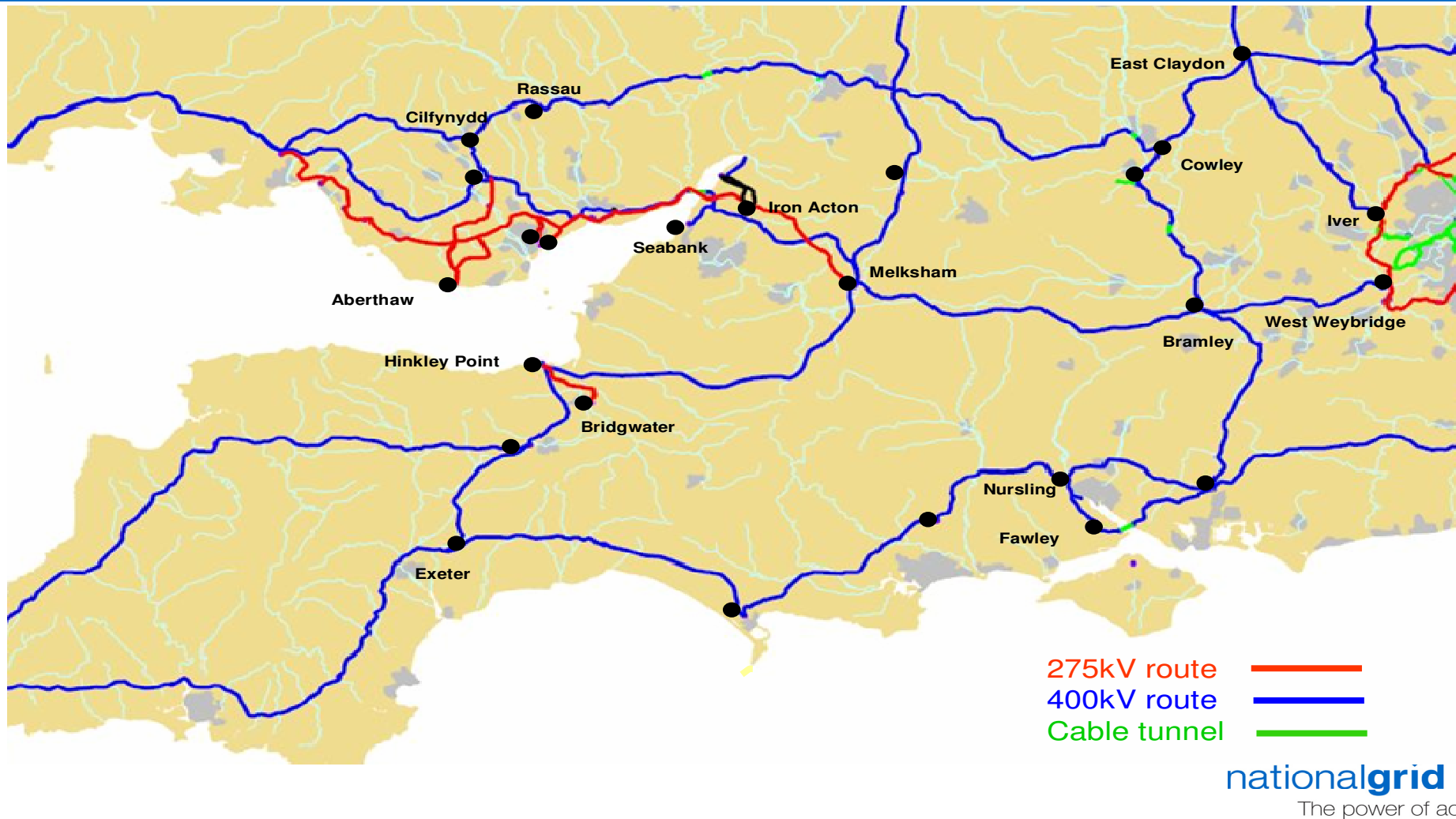


Figure 3.1.2 Geographical Existing South Wales/South West Transmission System

3.2 Contracted Background to 2018

National Grid has an obligation to make firm date connection offers to both demand and generation customers wishing to connect to the transmission system. National Grid has 3 months from the submission of an application to make an offer to the respective party for connection and these applications can be submitted at any point during the year. The applicant has 3 months to accept the connection offer and once accepted it forms the basis of National Grid's contracted background, i.e. there is a bilateral agreement to connect the user to the transmission system by the offered completion date.

At the time of commencing this feasibility study, National Grid had contracted positions with demand and generation customers to 2018. Therefore between 2009 and 2018 a number of projects are due to make connections, which require new infrastructure and changes to existing infrastructure. This work will require access to the transmission system to complete, thus needing a significant number of system outages. National Grid has a contractual obligation to meet the signed connection date of these customers.

At the time of commencing the feasibility study the contracted background included the following signed major connection offers:

Demand

- Swansea North 400kV Grid Supply Point reinforcement (connection 2011)

Generation

- Pembroke Power Station 2000MW CCGT (connection 2011/12)
- Prenergy Power at Margam 350MW Bio Mass (connection 2011)
- Rhigos Windfarm 299MW (connection 2012)
- Abernedd Power Station at Baglan Bay 870MW CCGT (connection 2013/2016)
- Atlantic Array Windfarm at Alverdiscott 1512MW (connection 2014)
- Hinkley Point C Power Station 3300MW nuclear EPR (connection 2017/18)
- **This generation totals 8331MW**

Note: more generation has entered the contracted background and is described in section 7 of this report.

Figures 3.2.1 and 3.2.2 below show the schematic and geographical representations of the transmission works required to complete the contracted connections National Grid has with each of these customers.

Below is a brief summary of major works National Grid will need to undertake out to 2018 to meet its contracted commitments.

- Construct 8 new substations
- Install 2 new 2750MVA 400kV Quad Boosters
- Consent and Construct approximately 60km of new overhead lines
- Re-conductor approximately 240km of existing overhead lines
- Re-conductor the 275kV high level Severn River crossing

-
- Install new 2nd cable per phase on the Ross-on-Wye 400kV cables to enable matching the overhead line rating
 - Install new 2nd cable per phase on the Hinskey 400kV cables (outside Oxford) to enable matching the overhead line rating

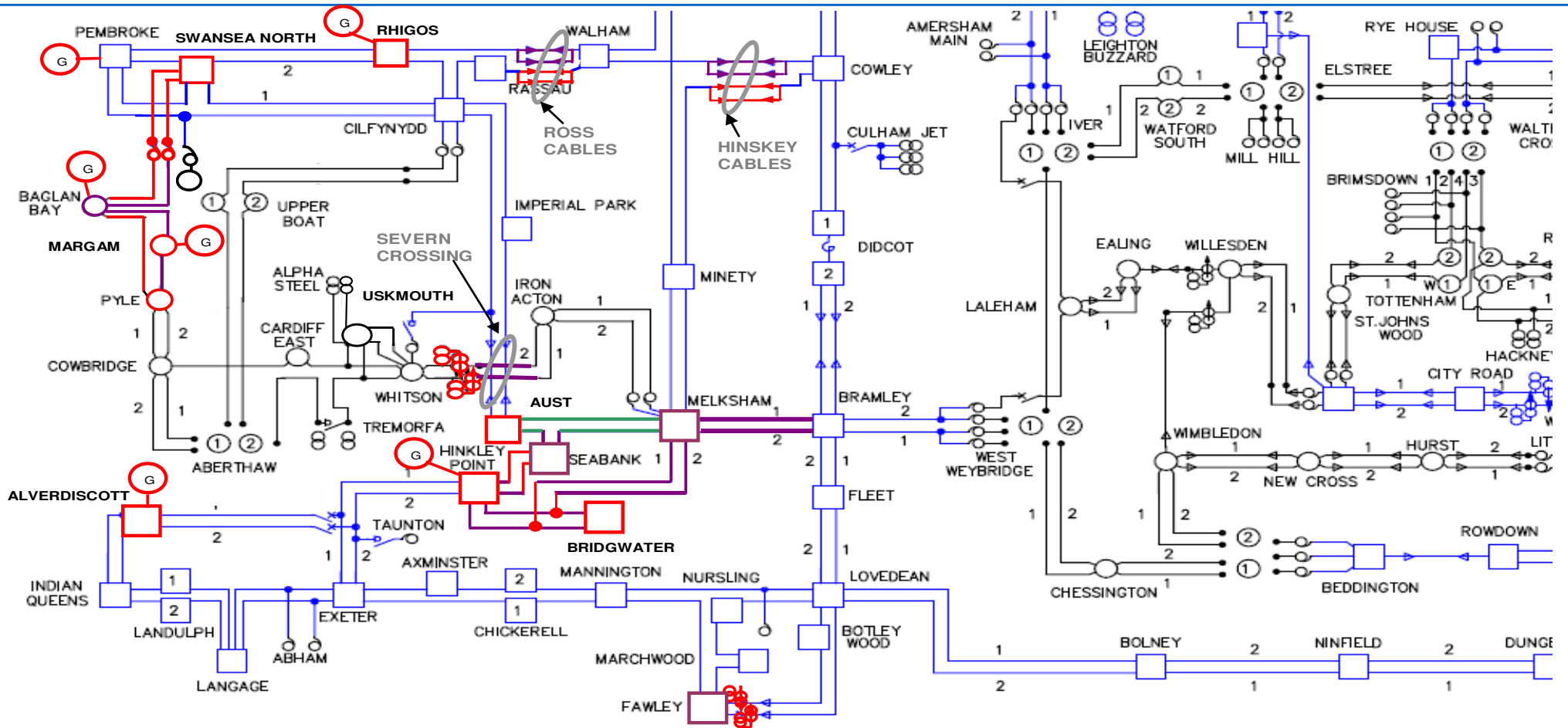
The point of note from the works listed is that two of the restrictions commented upon in section 3.1 above, namely the Ross-on-Wye 400kV cables and the 275kV Severn River crossing are proposed to be reinforced during these works. This will enable both of these double circuit routes to operate to the ratings of the remainder of the overhead line routes improving South Wales export capability.

The final restriction on the South Wales exports shall be the Severn 400kV cable tunnel. This section of circuit is within 50-100MW of requiring replacement and connections in South Wales above 50-100MW will trigger this reinforcement. Options are limited for uprating these cable circuits as the existing tunnel does not have sufficient capacity to accommodate the required additional cable circuits. To increase the rating of these routes would either require establishing an overhead line crossing, which is unlikely, due to suitable crossing points being unavailable, or establishing an additional tunnel. **Any option to resolve this issue will incur significant cost and is to be avoided if more economic solutions can be identified.**

Where reference is made to hotwiring, this is the ability to operate a conductor to a higher temperature. Whether this can be done or not is dependant upon the type of conductor, especially the grease it contains and whether will not melt at higher temperatures. It is also determined by the increased sag of conductors and whether this will infringe electrical clearances to roads and buildings especially. The ability to operate conductors to a higher temperature has a finite thermal limit and can be used where the increases to circuit capacities are minimal.

Current cost estimates of capital expenditure required to complete works for National Grid's contracted position to 2018 in South Wales and the South West is in the order of £1.5bn.

Contracted Background South Wales/South West System to 2018



KEY

- 275kV
- 400kV
- NEW ASSETS
- CHANGES TO EXISTING ASSETS
- HOTWIRING

Figure 3.2.1 Contracted Background South Wales/South West System to 2018

Geographical Contracted Background South Wales/South West System to 2018

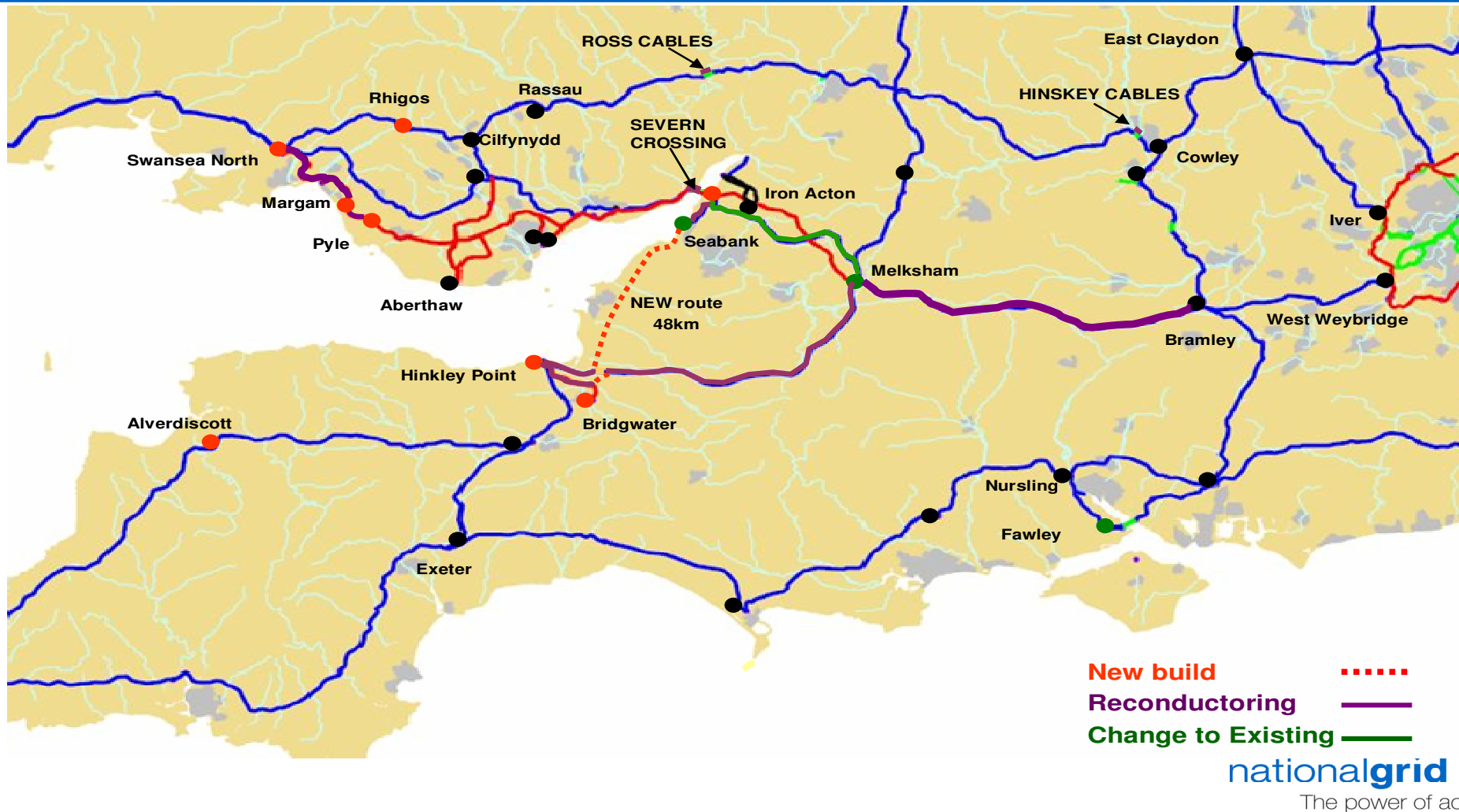


Figure 3.2.2 Geographical Contracted Background South Wales/South West System to 2018

4 Middle Barrage feasibility – Without Transmission Circuits Across the Barrage

4.1 Background

The middle barrage option is a connection between Brean Down to the south of Weston - Super – Mare and Lavernock Point to the south of Penarth. This barrage is expected to generate up to **8.64GW** of energy at peak output.

National Grid does not currently have any connection infrastructure at these connection points with the nearest existing substations being: -

- To Brean Down - Hinkley Point 400kV 20miles (via land) & Seabank 400kV 25miles
- To Lavernock Point – Aberthaw 275kV 10miles.

This option considers generation being cabled from the barrage onshore to National Grid connection points on land. This option also does not make any provision for transmission circuits across the Barrage structure. The option of transmission circuits across the Barrage is considered in section 5.

4.2 Thermal Study Considerations – (including variation of power injection points)

The thermal studies for this option showed major system reinforcement works required in South Wales, the South West and also the outer London 275kV network. Each area is described in turn below for the connection **8.64GW** of tidal generation.

South Wales

The South Wales transmission system currently consists of substantial sections of 400kV and 275kV transmission assets. Due to the location of the proposed barrage connections on the Welsh Severn estuary coastline, the nearest existing National Grid transmission assets are of 275kV construction. To enable the transmission of power from the connection point at Lavernock Point, 400kV assets will need to be constructed to manage such a large power flow.

Figure 4.2.1 below shows the existing network following the completion of the contracted background work by 2018. Figure 4.2.2 shows the thermal works required to make south Wales compliant with the NETS SQSS following the connection of **4.32GW** of the barrage generation to a substation south of Penarth.

The first element of work shows the requirement for the new substation south of Penarth being connected to a new Aberthaw 400kV substation via 4 (2 x Double Circuit) 400kV overhead lines. These circuits are required to meet the infrequent infeed loss risk (currently 1320MW but which could rise to 1800MW).

From Aberthaw onwards, substantial reinforcement of the transmission network is required to provide assets capable of operating at 400kV for the onwards transmission of the large power injection at the connection point. Therefore the existing 275kV network between Aberthaw – Upper Boat – Cilfynydd needs to be updated to 400kV. This will require re-conductoring existing L2 towers with 400kV conductors and insulation and the replacement of existing 275kV Super Grid Transformers (SGT) supplying Western Power Distribution Demand with 400kV SGTs.

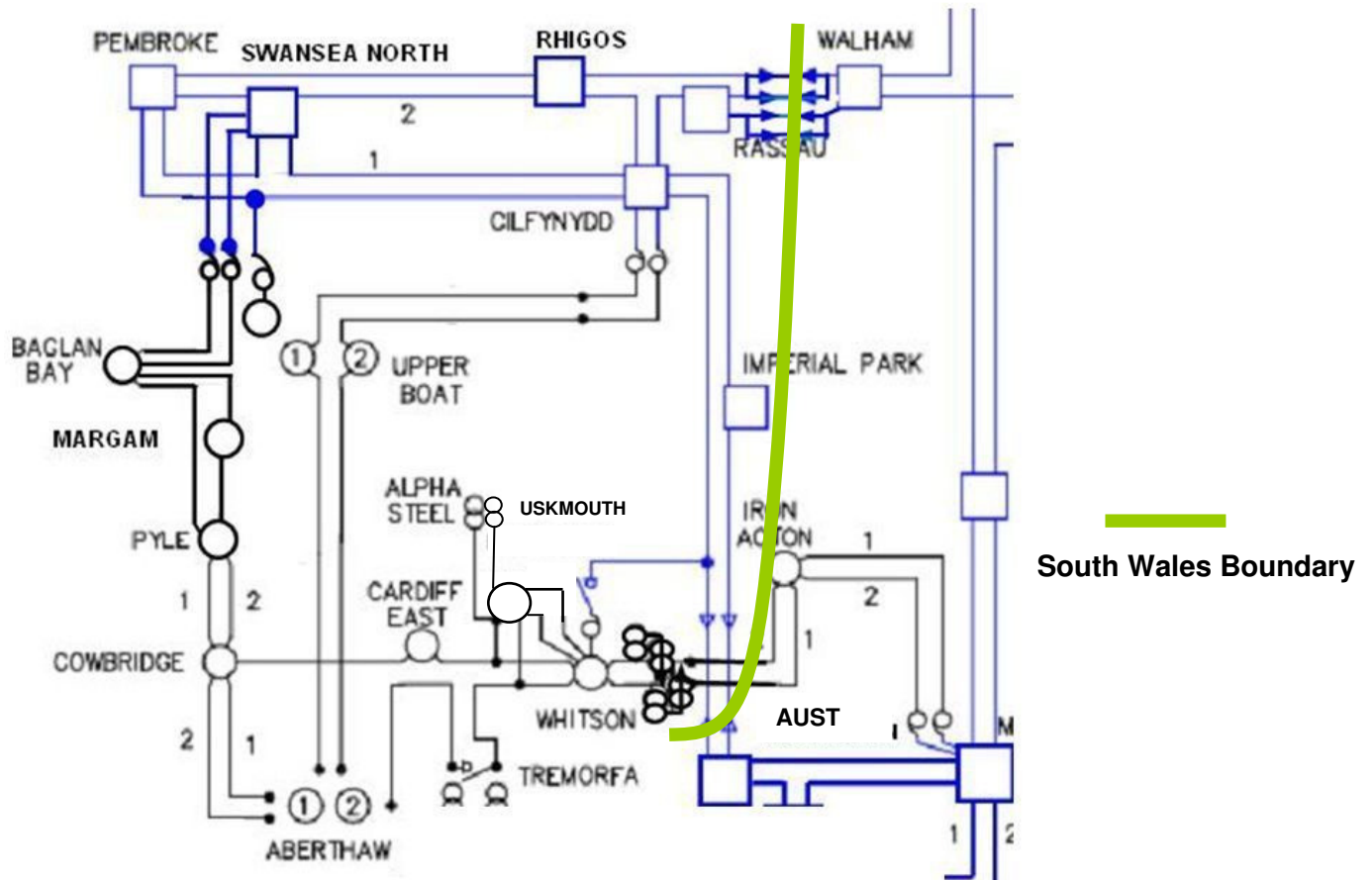


Figure 4.2.1 Existing South Wales Transmission System Post 2018

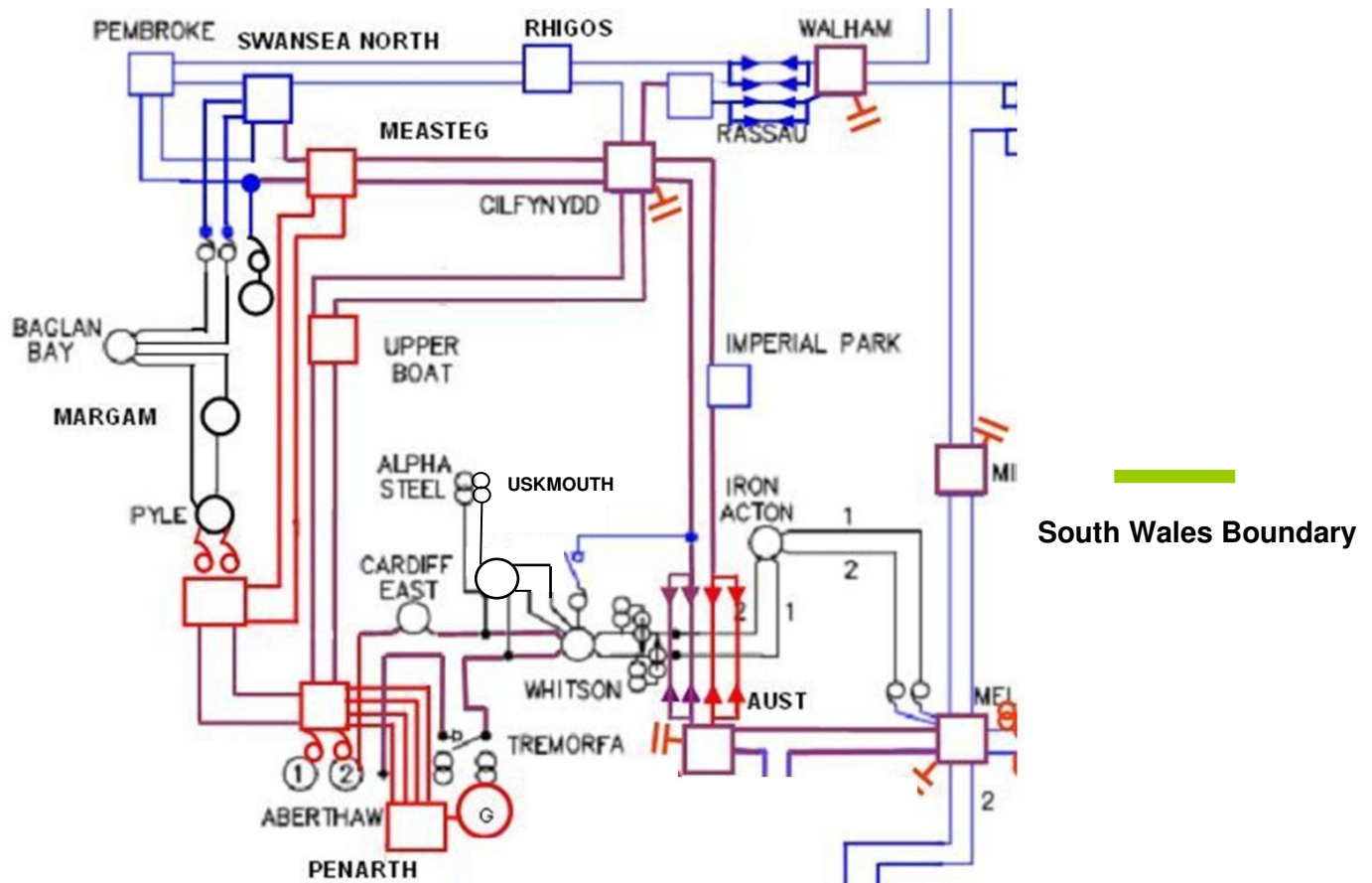


Figure 4.2.2 South Wales Transmission System Post Connection Middle Barrage

If the double circuit between Aberthaw – Upper Boat – Cilfynydd experienced faults during operation of the generation the remaining 275kV network would quickly become substantially overloaded above the thermal rating.

To resolve this issue a parallel 400kV route is required. This is best achieved by up-rating the existing 275kV connection between Aberthaw and Pyle to 400kV. Parts of this route currently utilise L2 transmission towers which can easily carry the required 400kV conductors. However, a short section utilises L3 transmission towers which are of a smaller, structurally lighter design and hence will require replacing to meet the need for 400kV transmission.

To complete the 400kV connections from Aberthaw via Pyle, there is a requirement to build a short section of new 400kV line (approx 10km) between Pyle and the existing 400kV Swansea – Cilfynydd lines to the south of Measteg. A new substation South of Measteg would be required to connect these new Pyle 400kV circuits.

The remaining 275kV network between Aberthaw – Cardiff East – Uskmouth and Aberthaw – Tremorfa – Uskmouth would also require re-conductoring to manage increased power flows.

The final elements of work in South Wales effect the capability of the boundary circuits reflected on Figures 4.2.1 and 4.2.2. These circuits in South Wales are constrained by natural landscape features, namely the Wye valley and River Severn. The 400kV Severn tunnel circuits are the limiting factor for this boundary and to remove this constraint the circuit capability needs to be raised to 3000MVA per circuit. This is most likely to be achieved by an additional cable tunnel as the existing tunnel does not have the capability to carry circuits of a greater capacity than those

currently installed. Table 4.2.1 below shows the South Wales Pre and Post fault boundary capacity for 2018 and required rating following the connection of tidal generation.

South Wales Boundary Circuit	2018 Capability	Required Capability
Walham – Rassau 400kV Walham – Rhigos 400kV	5960MVA	5960MVA
Imperial Park – Aust 400kV Cilfynydd – Whitson – Aust 400kV	3200MVA	5960MVA
Whitson – Iron Acton 1 & 2 275kV	1750MVA	1750MVA
Pre-Fault Boundary Capacity	10910MVA	13670MVA
Post - Fault Boundary Capacity	4950MVA	7710MVA

Table 4.2.1 South Wales Boundary Capacity

The post fault boundary capacity is based on the NETS SQSS requirement to consider two transmission circuit faults on the boundary as described in section 2 of this report. Thermally, year round there should be no loss of supply capacity (demand or generation) for the post fault condition across the boundary.

Due to the boundary capacity out of South Wales being maximised following the completion of the 400kV Severn Crossing, additional capacity out of South Wales could only be achieved by the connection of additional circuits. The circuits, if it is not possible to build them across the estuary, would need to be of substantial length and would be required if more that **4.32GW** of tidal generation were to be connected to the Welsh side of the estuary.

South West

The South West network consists solely of 400kV assets. Figure 4.2.3 showing the contracted background post 2018 and Figure 4.2.4 showing thermal works required to make the South West compliant with the NETS SQSS following the connection of **4.32GW** of the barrage generation to a substation south of Weston-Super-Mare.

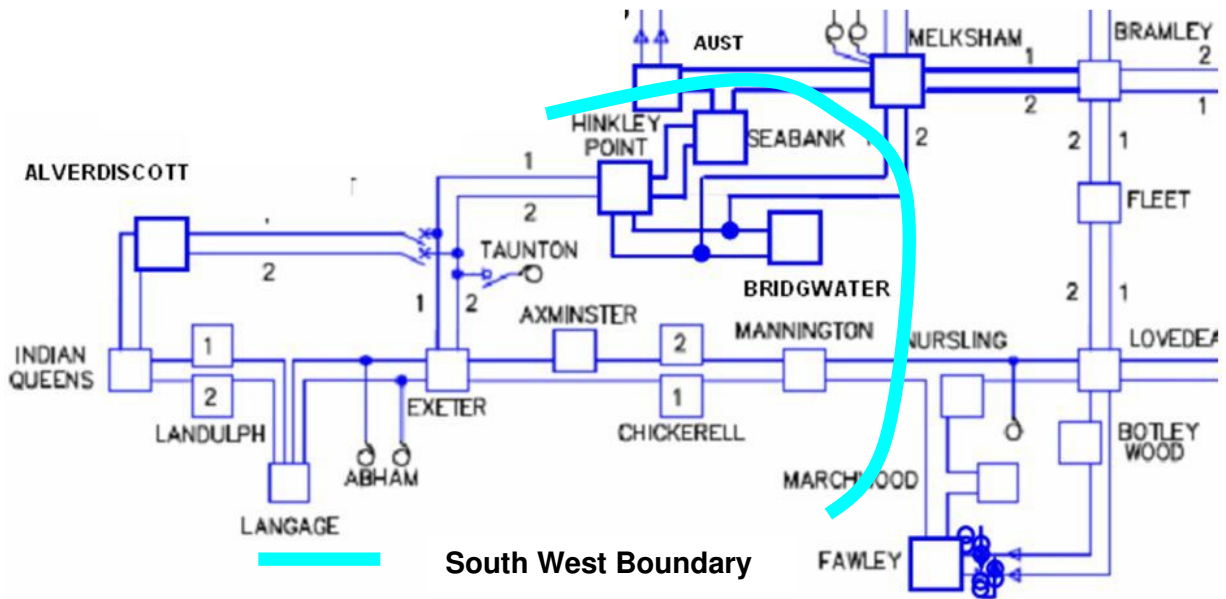


Figure 4.2.3 Existing South West Transmission System Post 2018

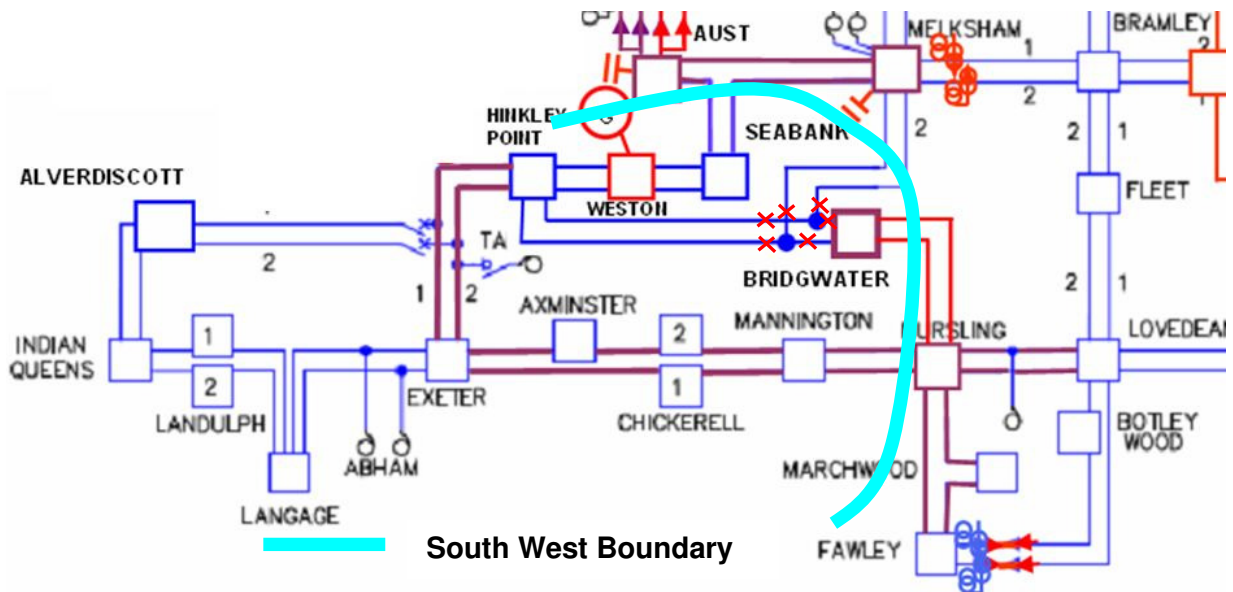


Figure 4.2.4 South West Transmission System Post Connection Middle Barrage

The first element of work shows the requirement for the new substation south of Weston-Super-Mare being connected to 4 (2 x Double Circuit) 400kV overhead lines turning in the Hinkley Point – Seabank 400kV overhead lines. These circuits are required to meet the infrequent infeed loss risk (currently 1320MW but which could rise to 1800MW).

The main areas requiring wider reinforcement are the south coast circuits between Hinkley Point – Exeter and the all the way to Nursing 400kV. Due to constraints on the South West boundary

circuits an additional circuit shall be required to be constructed between Bridgwater and Nursling, as well as line circuit breakers being installed at Puriton tee. The Bridgwater - Nursling circuit is some 125km in length and would also require the construction of bussing point connections at the existing Nursling 400kV and Bridgwater 400kV substations.

In addition to these works the Aust – Melksham and Aust – Seabank – Melksham circuits would need to be reconducted to take account of the increased power loadings seen at this point on the system.

To manage power flows through the Melksham – Bramley circuits there is also a requirement to install Quadrature Boosters (QBs). These assets can be used to decrease the power flowing through these circuits during worst case outage scenarios to prevent thermal overloading of these circuits.

South West Boundary Circuit	2018 Capability	Required Capability
Seabank – Aust 400kV Seabank – Melksham 400kV	5640MVA	5960MVA
Hinkley Point – Bridgwater - Melksham 1 & 2 400kV	5960MVA	5960MVA
Mannington – Nursling 400kV Mannington – Fawley 400kV (Nursling Following Connection)	3500MVA	5960MVA
Bridgwater – Nursling 1 & 2 400kV	N/A	5960MVA
Pre-Fault Boundary Capacity	15100MVA	23840MVA
Post - Fault Boundary Capacity	9140MVA	17880MVA

Table 4.2.2 South West Boundary Capacity

Table 4.2.2 above shows how the capacity of the South West boundary is increased following the construction of this new Nursling line. The post fault boundary capacity is based on the NETS SQSS requirement to consider two transmission circuit faults on the boundary as described in section 2 of this report. Thermally, year round there should be no loss of supply capacity (demand or generation) for the post fault condition across the boundary.

It would be possible to connect more than **4.23GW** of power to the South West England side of the estuary however this does start to significantly impact south coast flows beyond Lovedean 400kV. Therefore the infrastructure impacts start to spread further than the option considered and consequently the costs associated with more generation would increase.

West London

The West London network is characterised by a 275kV link between Iver in the West and Beddington / Rowdown to the south. Figure 4.2.5 showing the contracted background post 2018 and Figure 4.2.6 showing thermal works required to make West London compliant with the NETS SQSS following the connection of **8.64GW** of the barrage generation to the substation south of Weston-Super-Mare and south of Penarth.

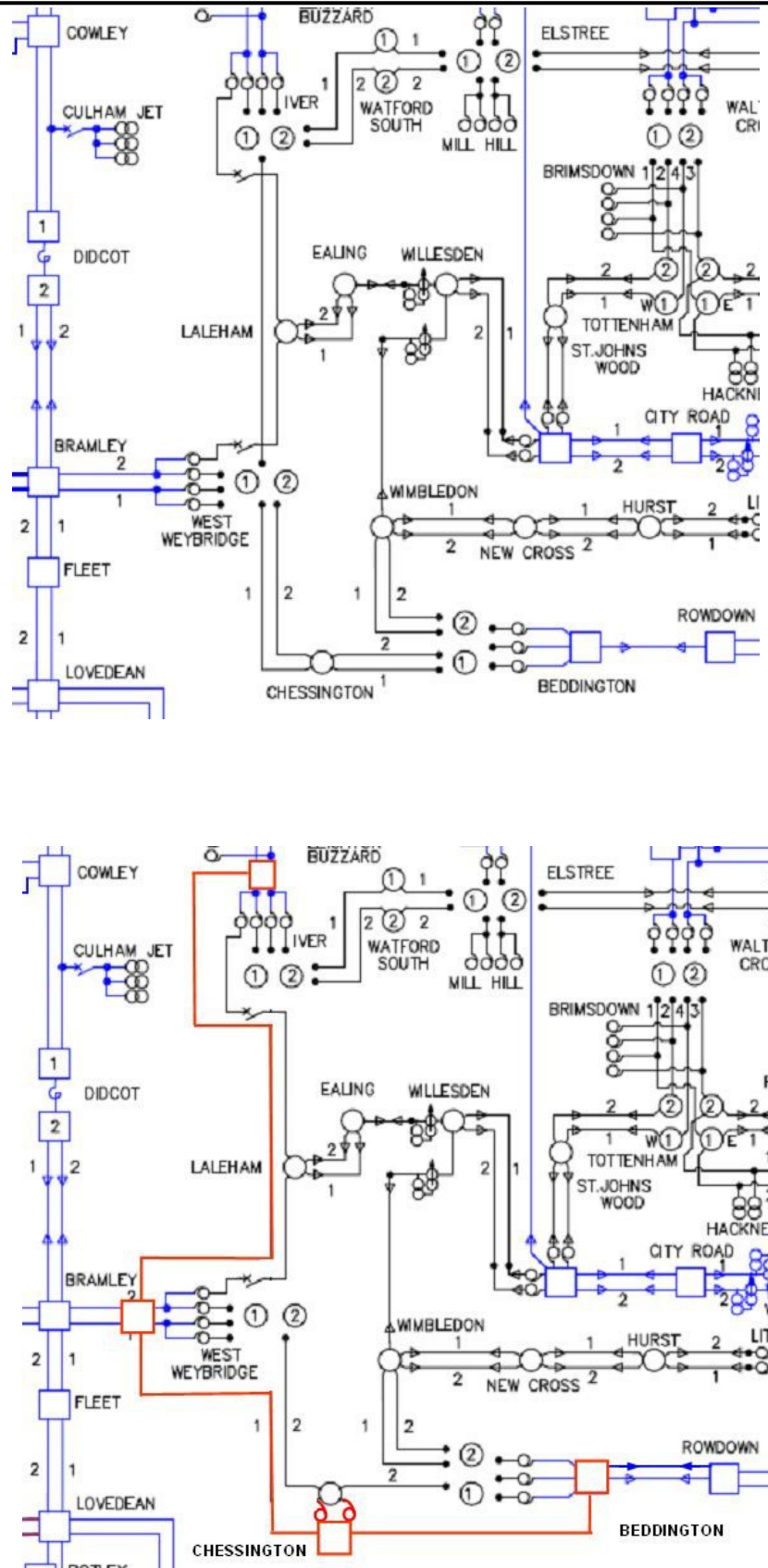


Figure 4.2.6 West London Transmission System Post Connection Middle Barrage

The West London network becomes overloaded following the connection of the tidal generation. To solve this problem one side of the existing 275kV link between Iver and Beddington, via West Weybridge and Chessington needs to be updated to 400kV. This then provides a strong 400kV path from West Weybridge both north and south into the London load centre. Only upgrading one side of this route is the most economic and efficient solution as it does not require the replacement of grid supply points at Laleham or Chessington.

4.3 Voltage Study Considerations

Table 4.3.2 below shows the 10 sites with the worst case voltages seen following transmission system faults. The NETS SQSS requires steady state voltages to remain within the planning limits set out in Table 4.3.1 below;-

Nominal Voltage	Minimum	Maximum
400kV	380kV (0.950 per unit)	410kV (1.025 per unit)
275kV	248kV (0.900 per unit)	289kV (1.050 per unit)

Table 4.3.1 Steady State Voltage limits in planning timescales

400kV Node	Before connecting MSCDN/SVC	After connecting MSCDN/SVC
	per unit voltage	per unit voltage
Walham 400kV	0.878	0.956
Bolney 400kV	0.901	0.977
Rassau 400kV	0.903	0.983
Ninfield 400kV	0.904	0.975
Dungeness 400kV	0.910	0.982
Sellinge 400kV	0.916	0.986
Minety 400kV	0.928	1.011
Beddington 400kV	0.938	0.987
Rhigos 400kV	0.941	0.985
Melksham 400kV	0.942	1.010

Table 4.3.2 List of Worst Case Post Fault Voltages

To resolve the non-compliance of voltages at the sites listed above in table 4.3.2, additional reactive compensation needs to be installed. The voltage problems experienced on the transmission system following the connection of the tidal generation tend to be post fault low voltage issues. These problems are generated by extremely high power flows on remaining circuits leading to a large increase in reactive losses. This can be overcome in the main by the installation of Mechanically Switched Capacitors with Damping Networks (MSCDNs) and Static VAR Compensators (SVCs). Table 4.3.3 shows the compensation required to restore system compliance.

Compensation location	MSCDNs	SVCs
Aust 400kV	2 x 225MVar (450MVar)	
Cilfynydd 400kV	2 x 225MVar (450MVar)	
Walham 400kV	2 x 225MVar (450MVar)	
Minety 400kV	2 x 225MVar (450MVar)	
Melksham 400kV	4 x 225MVar (450MVar)	
Nursling 400kV		2 x -75/150 MVar (-150/300MVar)

TOTAL MVAr	2700MVar	-150/300MVar
-------------------	-----------------	---------------------

7 **Table 4.3.3 Compensation Requirements**

itory supply limits and also prevent voltage collapse, which can lead to a partial or, in extreme cases, total loss of the transmission system.

4.4 Fault Level Considerations

With 216 turbines and associated network there is significant fault infeed to both the substations at South of Weston-Super-Mare and South of Penarth. These high fault infeeds lead to a requirement to operate a significant number of substations electrically split. However even with substations operating in split configurations there is still a requirement to replace switchgear at some existing sites.

Table 4.4.1 on the next page shows the switchgear which is worst affected by the connection of the tidal generation scheme. The table shows the Route Mean Square (RMS) fault level at the 2018 contracted background level and fault levels following the tidal generation connection. The study is carried out on peak system demand background and is at a busbar level only. The fault levels following the connection of the tidal generation connection has included all the possible operational split substation arrangements being in service.

The columns in table 4.4.1 show;

- The first section of busbar which is affected and the type of fault causing the rating issue, single or three phase fault.
- The green column shows the RMS rating of the breaker given by the manufacturer;
- The purple column shows the de-rated capability based on the DC time constant seen on the transmission system versus that at which the circuit breaker was tested.
- The yellow column is the RMS duty of the breaker seen during the analytical study, which the breaker would see during operation.
- The blue column shows how the output of the study, yellow column, compares with the derated RMS figure, purple column.

When the percentage is greater than 100% this is flagged in red and indicates the rating has been infringed. Due to the increased fault levels, circuit breakers and affected equipment at the locations indicated in table 4.4.1 will need to be re-rated (if possible) or replaced if no breaker enhancement is possible. Due to further investigation being required to establish if re-rating is possible or not, costs for breaker replacement works have not been included in this feasibility.

		Contracted				Middle Barrage without Transmission circuits				
Fault Node	Fault Type	Breaker Rating RMS (kA)	DC time Derating RMS (kA)	Fault Duty RMS (kA)	% of derated rating	Breaker Rating RMS (kA)	DC time Derating RMS (kA)	Fault Duty RMS (kA)	% of derated rating	% Increase on contracted
BEDD11	ONE	15	14	14	98.65%	15	12	13	115.73%	17.08%
CARE10	ONE	25	25	25	99.32%	25	22	25	111.81%	12.49%
MANN10	ONE	32	29	28	99.10%	32	25	28	110.36%	11.26%
BEDD12	ONE	15	14	13	93.75%	15	12	13	110.11%	16.36%
ABTH21	ONE	32	31	30	98.57%	32	25	26	104.02%	5.46%
CARE10	THREE	20	20	20	96.82%	20	18	19	103.21%	6.39%
CILF40	THREE	51	45	36	80.12%	51	49	50	100.45%	20.33%
LALE20	ONE	32	29	27	92.35%	32	28	28	100.43%	8.08%
MAGA20	THREE	32	28	28	97.95%	32	28	29	100.19%	2.24%
HINP44	ONE	63	49	43	88.40%	63	49	49	99.57%	11.17%
HINP43	ONE	63	49	43	88.41%	63	50	49	99.20%	10.79%
HINP41	ONE	63	49	43	87.70%	63	50	49	98.64%	10.94%
PYLE20	THREE	40	37	30	80.73%	40	31	30	98.54%	17.81%
PEMB10	ONE	18	14	14	98.19%	18	14	14	98.41%	0.22%
HINP42	ONE	63	49	43	87.71%	63	50	49	98.26%	10.54%

Table 4.4.1 Table of worst fault Level affected substation switchgear

4.5 Stability Study Considerations

During the stability considerations it became very clear that the low inertia constant of the proposed generation units has a significant affect on the transmission system. The worst case contingency was that of the double circuit from Rassau – Cilfynydd and Walham – Rhigos which was found to be unstable just by switching these circuits out of service. To overcome this, 35% series compensation (SC) has to be included in Nursling – Bridgwater, Minety – Cowley/Feckenham, and Melksham – Bramley circuits.

Table 4.5.1 below shows a list of the critical fault clearance times required for the following double circuit faults to prevent instability.

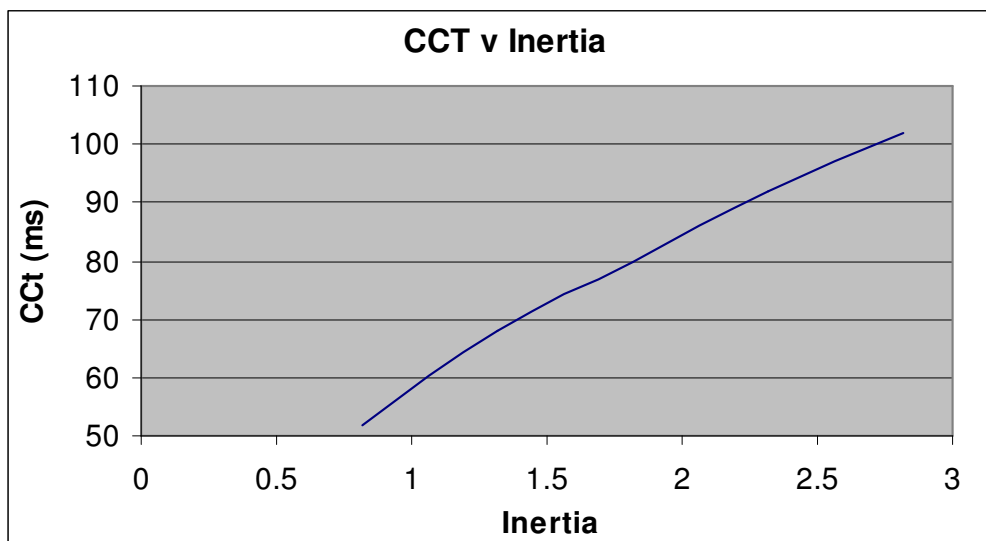
Double Circuit Combination	Critical Fault Clearance Time
Aberthaw – Upperboat 400kV 1 & 2	52ms
Weston – Hinkley Point 400kV 1 & 2	56ms
Penarth – Aberthaw 400kV 1 & 2	62ms
Weston – Seabank 400kV 1 & 2	66ms
Hinkley Point – Bridgwater – Melksham 1 & 2	74ms
Melksham – Minety 400kV 1 & 2	87ms
Rassau – Cilfynydd, Walham – Rhigos 400kV	98ms

Table 4.5.1 Table of Critical Fault Clearance times

The normal fastest fault clearance times considered by National Grid is no quicker than 80ms, although 140ms is considered worst case viable fault duration. Therefore, to maintain a stable system, consideration needs to be given to improving these clearance times.

Improving Inertia Constant

For the worst case fault clearance time for the Aberthaw – Upperboat 400kV double circuit the graph 4.5.1 below, shows how an increase of the generator inertia constant can provide improved fault clearance times. Therefore an inertia constant of 1.8 MWs/MVA would achieve the minimum

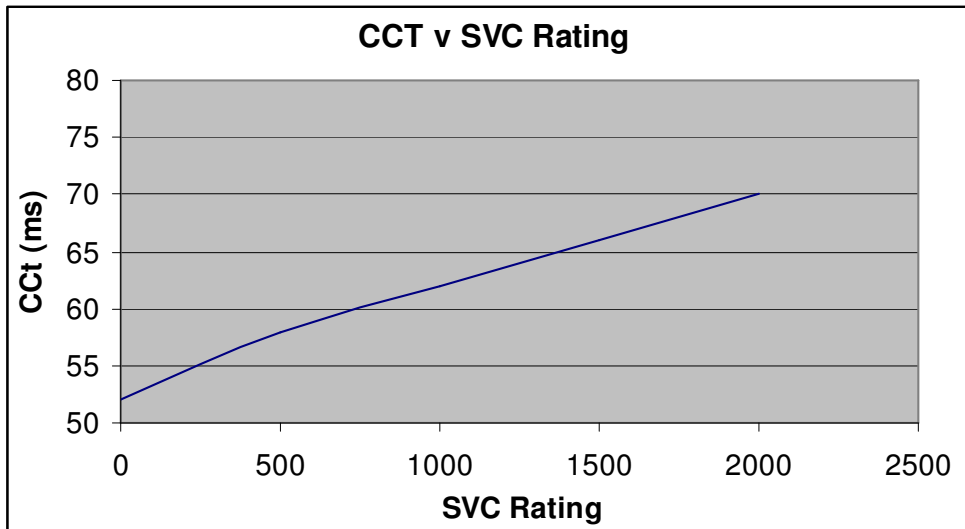


clearance time with the fast protections available. However (MWs/MVA) known if it is possible to source generators of the type required with inertia constants of this value

Graph 4.5.1 Improvement of Critical Fault Clearance Time by increased Inertia

Use of SVCs at Generator Connection Point

It is also possible to improve the critical fault clearance time by installing SVC's at the connection

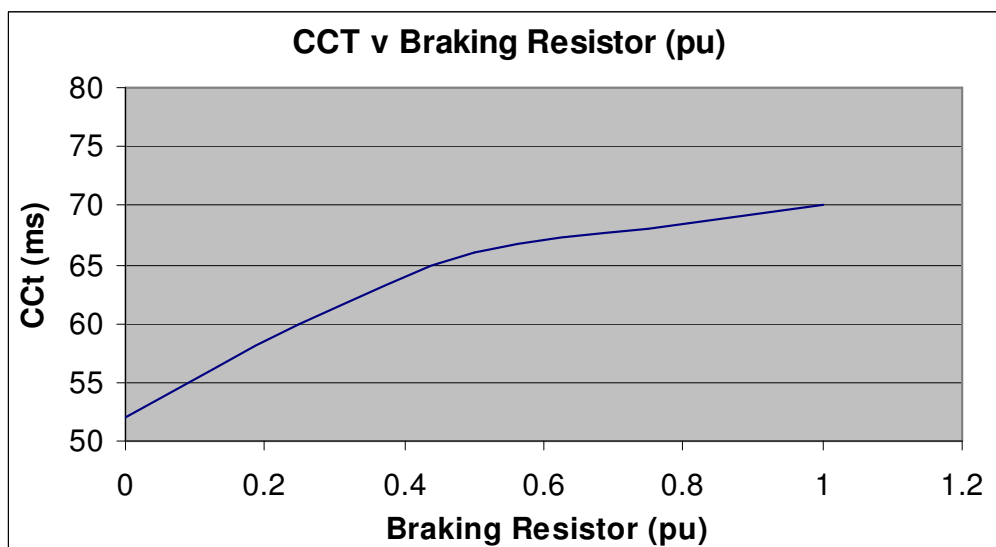


point. Graph 4.5.2 below shows the SVC capacity that would need to be installed at both Penarth and Weston substations, again to improve the critical clearance time for the Aberthaw – Upperboat double circuit fault. It is clear from this graph that a significant amount of SVC capacity needs to be installed to achieve clearance times close to 80ms.

Graph 4.5.2 Improvement of Critical Fault Clearance Time by SVC installation

Use of Braking Resistors at Generator Connection Point

It is also possible to improve the critical fault clearance time by installing Braking Resistors at the



connection point. Graph 4.5.3 below shows the braking resistor per unit size that would need to be installed at both Penarth and Weston substations, again to improve the critical clearance time for the

Aberthaw – Upperboat double circuit fault. It is clear that the breaking resistors are less effective than the other methods proposed and do have other associated issues.

Stability Conclusions

It is clear from this option that work would need to be undertaken to improve system stability to make the connection compliant. However, a combination of the options listed above, i.e. generator inertia constant, SVCs or breaking resistors could be used to provide system compliance, as well as other alternatives yet to be identified.

Pumping operation was also considered as part of this study, however this function is very sensitive to the levels of pumping capacity. If pumping is to match the generation output level then the issues are very similar to those for generating and additional measures would need to be undertaken to improve stability of the system.

4.6 Generation Connection Substations

Graph 4.5.3 Improvement of Critical Fault Clearance Time by Braking Resistor installation Id construct and commission two new substations. One substation shall be constructed on the English side to the south of Weston-Super-Mare as shown in Figure 4.6.1. The other shall be constructed on the Welsh side to the south of Penarth as shown in Figure 4.6.2.

The layout of the substation is determined by the infrequent infeed loss risk currently 1320MW. However for the purposes of this report it assumed that the current proposal to raise this to 1800MW will have been achieved by the connection date. If this was not achieved an additional generator bay would be required, along with further section breakers.

The infrequent infeed loss risk also determines the number of circuit connections required into the connection substation. To reduce the number of circuits below three the generation at any individual connection point would have to be reduced below 1800MW (or 1320MW if the infrequent infeed loss risk is not increased).

It is also worth noting as discussed in the Stability section above there may be a requirement for additional bays and space for either SVCs or breaking resistors at each substation. Though the space and bay requirements can not be determined until the actual proposed machine parameters are available and all alternative stability options have been identified.

Both of these substations are likely to be of indoor Gas insulated Substation (GIS) construction, this is because of their proximity to the saline estuary, and National Grid's pollution policy determines that indoor equipment is to be specified where this is within 5km of a saline environment. Saline pollution creates substantial flash-over risks and premature aging of asset due corrosion and failure if located outdoors.

Middle Barrage No Transmission Circuits Across Barrage (WESTON SUPER-MARE Substation Connections)

WESTON SUPER-MARE SUBSTATION 400kV (no circuits over the Barrage)
New GIS 400kV, 4000A, 63kA switchgear

Key

-  Existing Asset
-  New Generation Connection Asset
-  New Asset

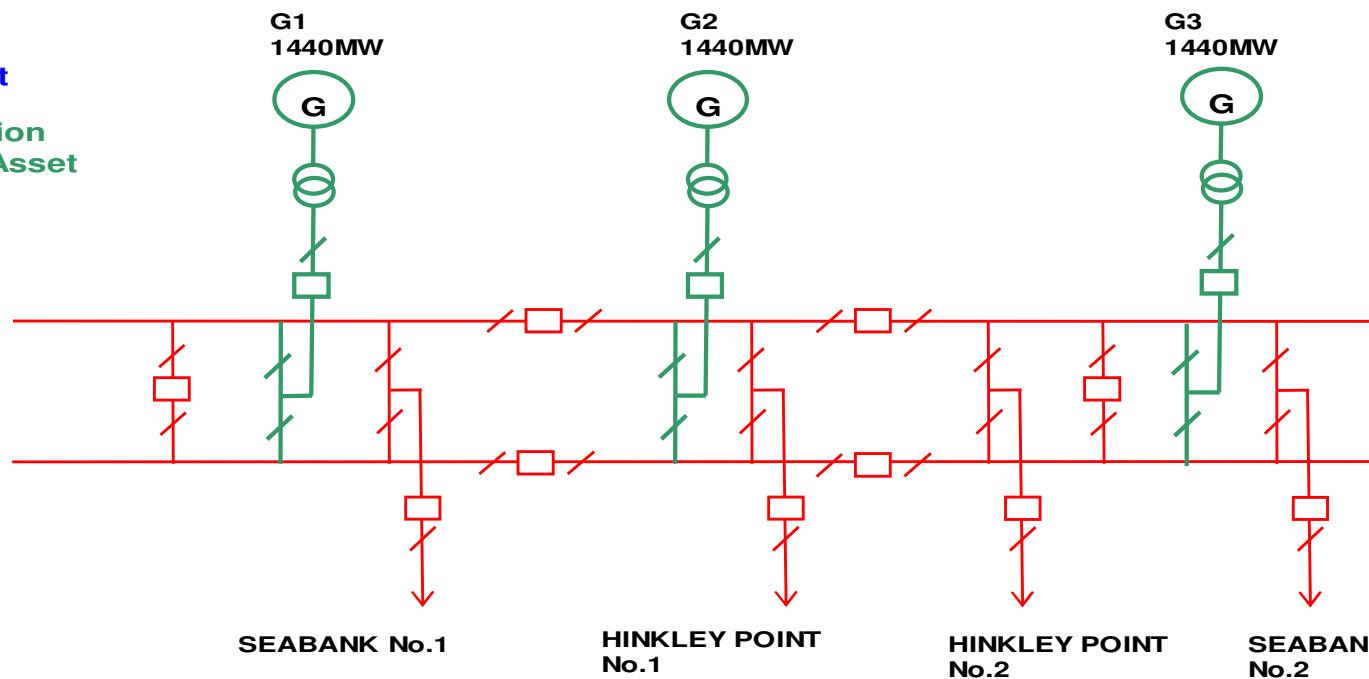


Figure 4.6.1 Generation Connection Substation at Weston Super Mare for Middle Barrage with no transmission circuits across the barrage.

Middle Barrage No Transmission Circuits Across Barrage (PENARTH Substation Connections)

**PENARTH SUBSTATION 400kV (no circuits
the Barrage)**
New GIS 400kV, 4000A, 63kA switchgear

Key

-  Existing Asset
-  New Generation Connection Asset
-  New Asset

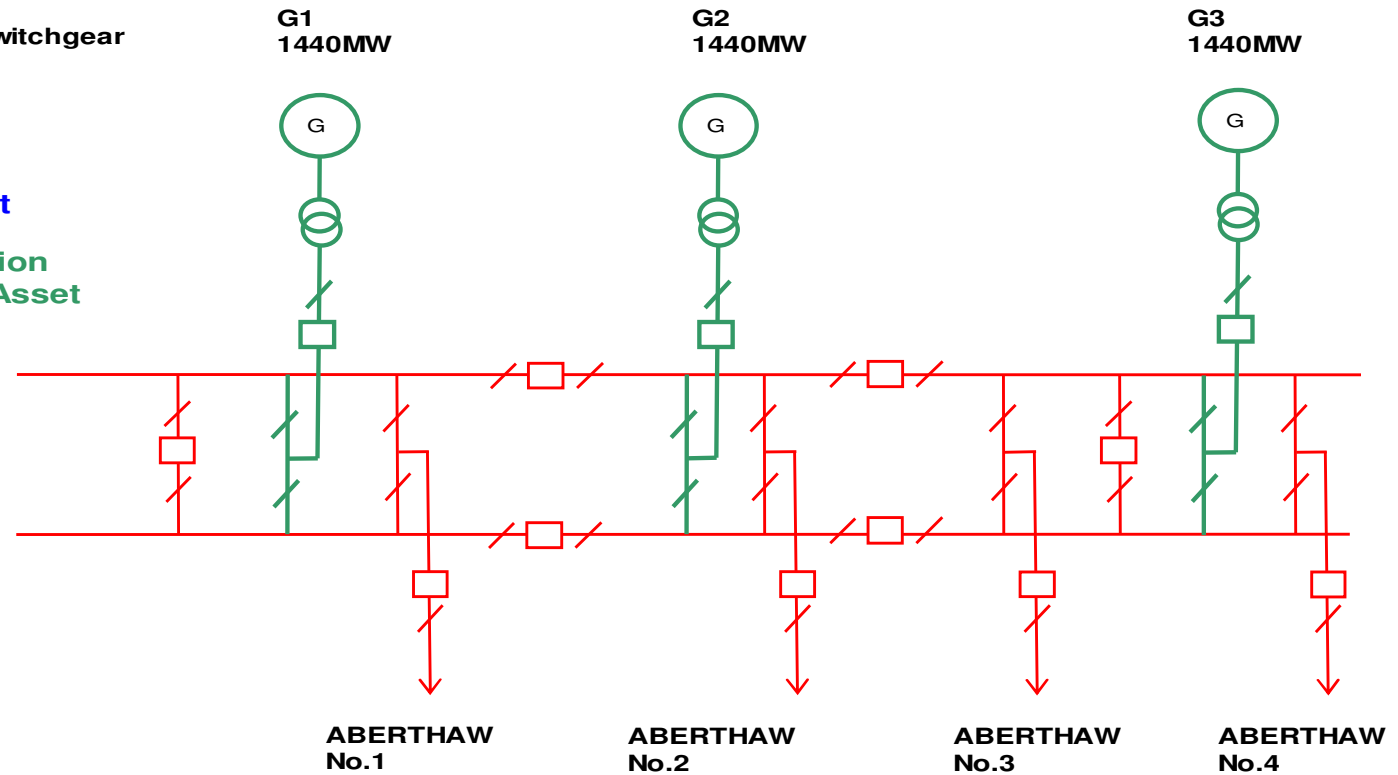


Figure 4.6.2 Generation Connection Substation at Penarth for Middle Barrage with no transmission circuits across the barrage.

4.7 Full Description of Local and Wider Transmission reinforcement

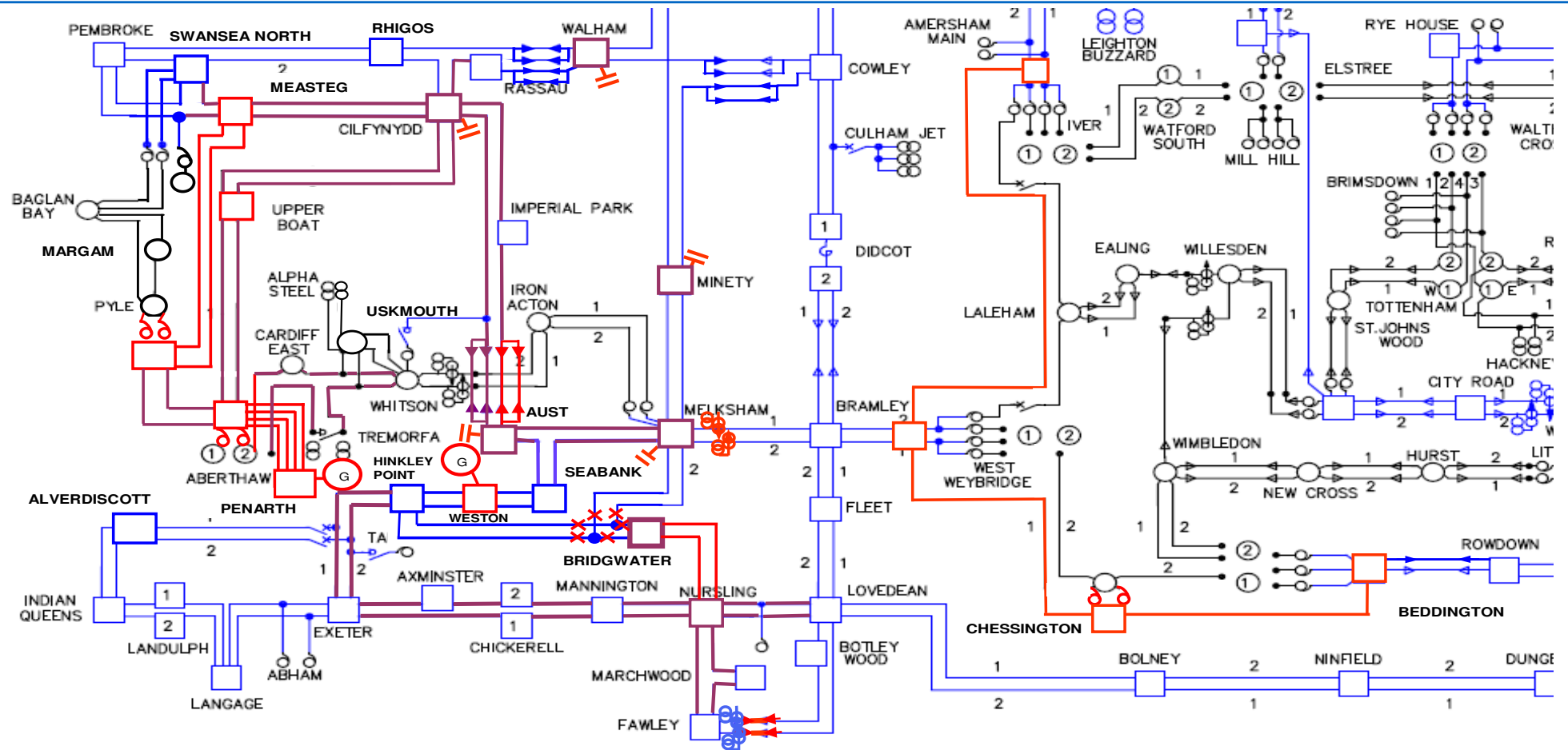
Figures 4.7.1 and 4.7.2 show a schematic and geographical representation of the total transmission works required to allow the connection of a middle barrage to the transmission system. These representations include all of the works identified from the studies described in the previous parts of section 4 of this report.

Table 4.7.1 has a summarised description of the work required to make the connection to the middle barrage with no circuits across the barrage. **Appendix 1** has a full description of works required. However as a high level summary the full local and wider transmission reinforcement works consist of: -

- ◆ **Substations and Equipment**
 - ◆ 12 New substations required.
 - ◆ 2700MVar of Mechanically Switched Capacitors (MSC) capacity required at 5 substation locations.
 - ◆ 2 x -75/150MVar Static Var Compensators (SVC) required at Nursling.
 - ◆ 2 x 2750MVA Quad Boosters (QB) required at Melksham.
 - ◆ 35% Series Compensation at Bridgwater, Mintey and Melksham for the following circuits.
 - ◆ Nursling – Bridgwater
 - ◆ Minety – Cowley/Feckenham
 - ◆ Melksham – Bramley

- ◆ **OHL and Cables**
 - ◆ Approximately 200km route kms of new overhead line routes
 - ◆ Approximately 485km route kms of existing overhead line reconductoring
 - ◆ Doubling of cables within an existing tunnel (Chilling)
 - ◆ Construction of a new cable tunnel (Severn)

Middle Barrage – No Circuits Across Barrage



KEY

- 275kV
- 400kV
- NEW ASSETS
- CHANGES TO EXISTING ASSETS
- HOTWIRING
- ⊙ BARRAGE GENERATION

Figure 4.7.1 Total Transmission Works Middle Barrage – No Circuits Across Barrage

Geographical Middle Barrage – No Circuits Across Barrage

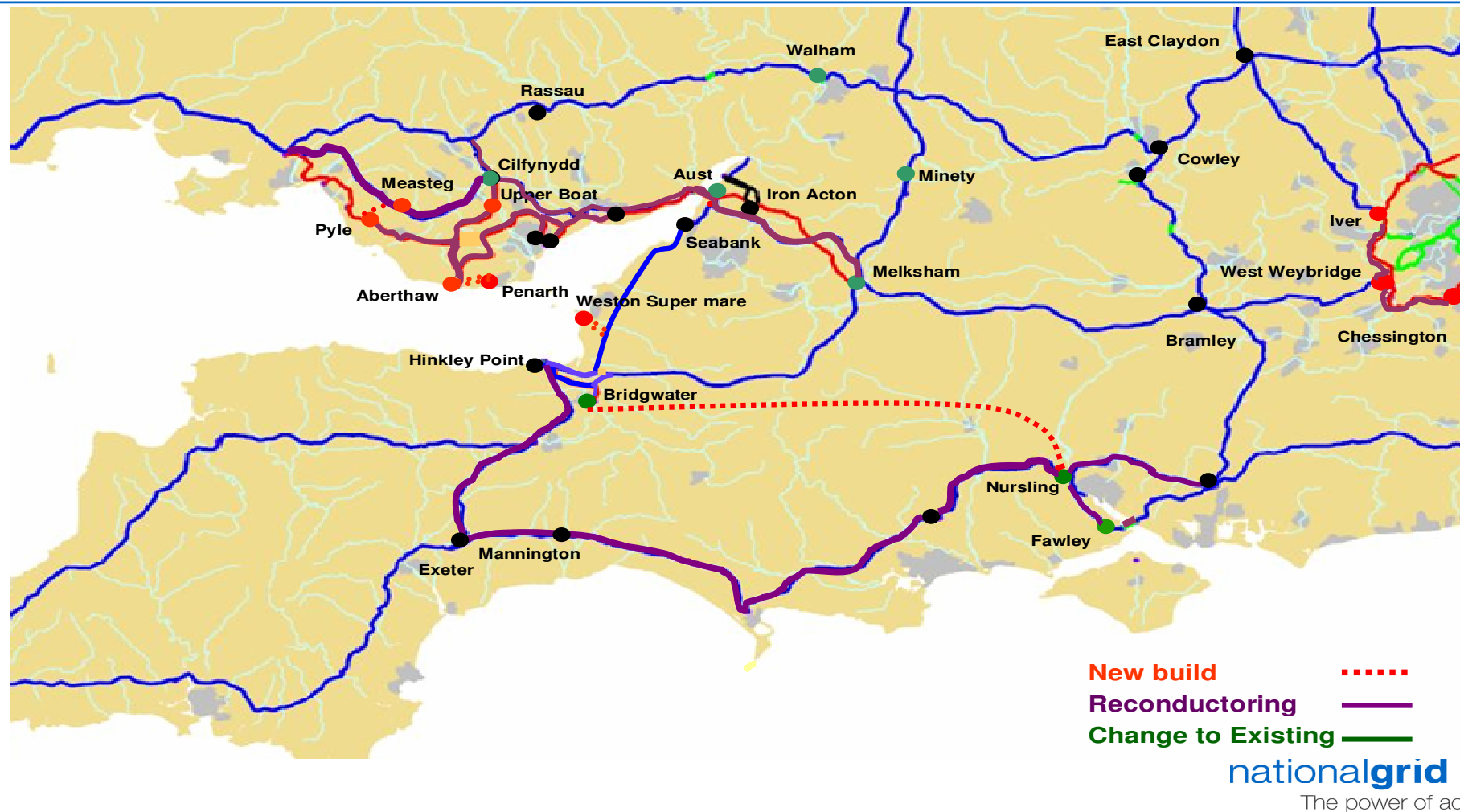


Figure 4.7.2 Geographical Total Transmission Works Middle Barrage – No Circuits Across Barrage

Description of Works Middle Barrage – No Circuits Across Barrage

◆ Generators

- Middle Barrage
8.6GW
- Penarth Side 4.3GW
- Weston Side 4.3GW

◆ New Works

◆ New Substations

- Pyle 400kV (4F, 2SGT, 2BC, BS)
- Measteg 400kV (6F, 2BC, BS)
- Aberthaw 400kV (8F, 2SGT, 2BC, 4BS)
- Upperboat 400kV (4F, 3SGT, BC, BS)
- Bridgwater 400kV (4F, 2SGT (bay only), BC BS)
- West Weybridge 400kV (4F, 2SGT (bay only), 2BC, BS)
- Iver 400kV (3F, 2SGT (bay only), 2BC, BS)
- Beddington 400kV (3F, 3SGT (bay only), 2BC, BS)
- Chessington 400kV (1MESHCB, 2SGT)
- Penarth 400kV (4F, 3GEN (skel), 2BC, 4BS)
- Weston 400kV (4F, 3GEN (skel), 2BC, 4BS)
- Puriton tee 400kV line breakers (6F)

◆ New Equipment

- 2 x 225Mvar MSCs Aust
- 2 x 225Mvar MSCs Cilfynydd
- 2 x 225Mvar MSCs Walham
- 2 x 225Mvar MSCs Minety
- 4 x 225Mvar MSCs Melksham
- 2 x -75/150 MVar SVC's at Nursling
- Quad boosters at Melksham 400kV (2750MVA PFC)
- 35% series compensation at Bridgewater, Minety and Melksham

◆ New Lines

- Pyle – Measteg 9km 400kV (2820MVA summer, PFC)
- Bridgwater – Nursling 125km (2820MVA summer PFC)
- 2 x Double Circuits Penarth – Aberthaw 18km each (2820MVA summer PFC)
- Aberthaw – Cardiff East 19km (1010MVA winter PFC)
- 2 x Double Circuits Weston Spur (Hinkley Point – Seabank) 9km each (2820 summer PFC)

◆ New Cable Routes

- 2nd Severn Cable tunnel and Circuit (IMPP-AUST, CILF-WHSO-AUST 3000MVA cyclic year round rating)
- Double cables in chilling tunnel (FAWL-BOTW, FAWL-LOVE 3000MVA cyclic year round rating)

◆ Changes to Existing

– Substations

- Nursling 400kV (8F, 3SGT(bay only) 2BC, 1BS)

– Reconductoring

- Measteg – Cilfynydd 400kV 1 & 2 (2980MVA summer, PFC)
- Aust - Whitson – Cilfynydd & Aust – Imperial Park, Imperial Park – Cilfynydd 400kV (2980MVA summer, PFC)
- Aust – Melksham & Aust – Seabank, Seabank Melksham L6 sections 1(2980MVA summer, PFC)
- Aberthaw – Pyle 400kV 1 & 2 (re-rating from 275kV (2820MVA summer,PFC)
- Aberthaw – Upper Boat 400kV 1 & 2 (re-rating from 275kV) (2820MVA summer,PFC)
- Cilfynydd – Upper Boat 400kV 1 & 2 (re-rating from 275kV) (2820MVA summer,PFC)
- Mannington – Nursling 400kV 1 & 2 (2980MVA summer, PFC)
- Nursling – Fawley & Fawley – Marchwood, Marchwood - Nursling 400kV 1 & 2 (2980MVA summer, PFC)
- Lovedean – Nursling 400kV 1 & 2 (2980MVA summer, PFC)
- Chessington – Beddington 400kV single cct (up-rate from 275kV) (2980MVA summer, PFC)
- Chessington – West Weybridge 400kV single cct (up-rate from 275kV) (2980MVA summer, PFC)
- West Weybridge – Iver 400kV single cct (up-rate from 275kV) (2980MVA summer, PFC)
- Cilfyndd to Rassau (2960MVA summer PFC)
- Hinkley Point – Taunton – Exeter 1 & 2 (2960MVA summer PFC)
- Exeter – Axminster – Chickerell 1 & 2 (2960MVA summer PFC)
- Chickerell – Mannington 1 & 2 (2960MVA summer PFC)
- Aberthaw – Cardiff East – Uskmouth – Whitson & Aberthaw – Tremorfa – Uskmouth – Whitson (including USK crossing) 275kV (1010MVA winter PFC)

– Hotwire

- None Currently Identified

Key

F = Feeder

GEN = Generator skeletal bay

BC = Bus Coupler

BS = Bus Section

SR = Shunt Reactor Bay

SGT = Super Grid Transformer & Bay

PFC = Post Fault Continuous

Table 4.7.1 Description of Total Transmission Works Middle Barrage – No Circuits Across Barrage

4.8 Design Options Considered

During the consideration of the middle barrage with no transmission circuits across the barrage, multiple options have been considered including varying the generation on each side of the estuary. Of the **8.64GW** of generation the optimum solution was to consider **4.32GW** flowing into both Penarth and Weston.

When **6.48GW** was injected into South Wales and only **2.16GW** being injected into the South West, there was insufficient transmission capacity out of South Wales. To be able to feed this amount of power into South Wales additional circuit capacity would need to be provided out of South Wales via the means of additional transmission circuits. This would involve a substantial new transmission circuit of substantial length and with unknown stability effects this option is considered neither economic nor efficient.

When **6.48GW** was injected into the South West and only **2.16GW** was injected into South Wales, additional power could be accommodated thermally in the South West. The post fault voltages, stability and fault levels, especially on the south coast, were significantly affected by this configuration. Reinforcements required to overcome these issues are likely to be significantly in excess of the current option and is therefore conceived to be neither economic nor efficient.

Consideration should also be made as to whether the new 125km overhead line between Bridgwater and Nursling is the only solution to relieving transmission issues in the south west. Alternative options would also be considered as part of any connection scheme to ensure the optimum solution is proposed for construction.

Connection of the generation via DC connections may provide an alternative to relieve some of the significant stability and fault level issues associated with a project of this magnitude. With such a low generator inertia constant, seriously affecting system stability, such solutions should be seriously considered if no other measures are forthcoming.

4.9 Conclusions

The transmission reinforcement necessary to accommodate this scheme represents a significant amount of system access and resource to complete. The initial cost estimate of this work is **£2.349bn** in 2009 prices and a high level breakdown of the costs is provided in section 11.

It is possible to connect this scheme; however stability and fault level issues represent significant system challenges to be overcome. With the current committed background and significant amounts of generation in South Wales and the South West, further technical detail and additional studies would be required to take all the transmission issues into account.

5 Middle Barrage feasibility – With Transmission Circuits Across the Barrage

5.1 Background

The middle barrage option is a connection between Brean Down to the south of Weston-Super-Mare and Lavernock Point to the south of Penarth. This barrage is expected to generate up to **8.64GW** of energy at peak output.

National Grid does not currently have any connection infrastructure at these connection points with the nearest existing substations being: -

- To Brean Down - Hinkley Point 400kV 20miles (via land) & Seabank 400kV 25miles
- To Lavernock Point – Aberthaw 275kV 10miles.

This option considers generation being cabled from the barrage onshore to National Grid connection points on land. This option does make provision for transmission circuits across the barrage structure and this is the major difference from the option described in section 4 above.

5.2 Thermal Study Considerations – (including variation of power injection points)

The thermal studies for this option like section 4 showed major system reinforcement works required in South Wales, the South West and also the outer London 275kV network. However now that there is transmission capacity across the barrage South Wales and the South West transmission groups become connected. This effectively means they become part of the same transmission boundary. Each area is described in turn below for the connection of **8.64GW** of tidal generation

South Wales and South West

The South Wales transmission system currently consists of substantial sections of 400kV and 275kV transmission assets, whilst the South West transmission system consists solely of 400kV assets. As in section 4, the location of the proposed barrage connections on the Welsh Severn estuary coastline require 400kV assets to be constructed, to allow the connections from the landing point at Lavernock Point. The South West connections will need to be made from the barrage landing point at Brean Down into the Hinkley Point – Seabank line, which is proposed as part of the 2018 contracted background.

Figure 5.2.1 shows the contracted background post 2018 and Figure 5.2.2 showing thermal works required to make the South Wales and the South West compliant with the NETS SQSS following the connection of **4.32GW** of the barrage generation to a substation south of Weston-Super-Mare and **4.32GW** of the barrage generation to a substation south of Penarth.

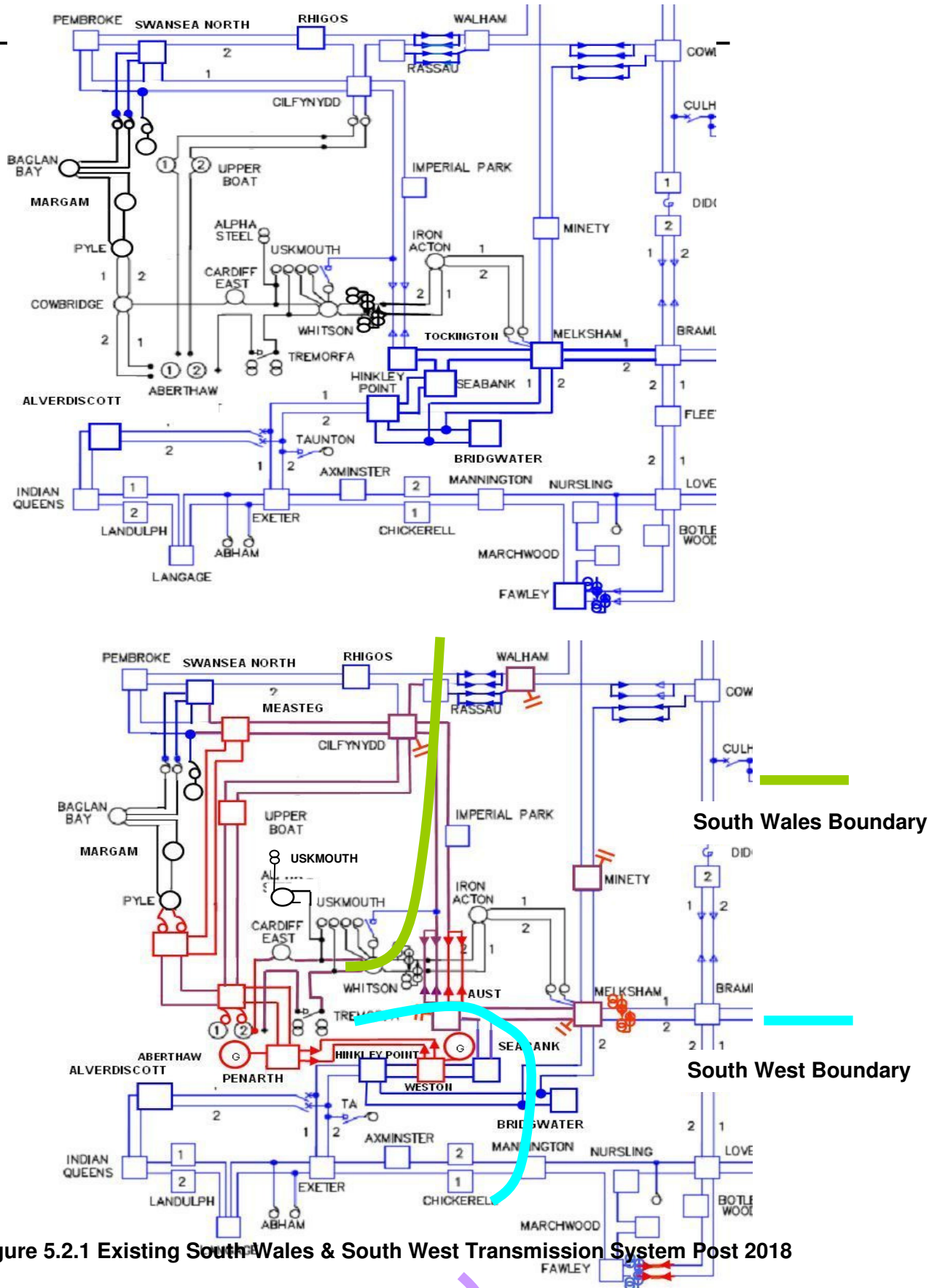


Figure 5.2.1 Existing South Wales & South West Transmission System Post 2018

The two connection point substations in the South West and South Wales remain the same, to the south of Weston-Super-Mare and South of Penarth respectively.

However with circuits over the barrage, only two circuits are required to connect between Penarth and Aberthaw on the Welsh side with the barrage circuits using the previous transmission bays in the substation. The substation south of Penarth shall consist of 4 (2 x Double Circuit) 400kV circuits, two overhead line circuits to Aberthaw and two barrage circuits. These circuits are required to meet the infrequent infeed loss risk (currently 1320MW but which could rise to 1800MW).

On the Weston side, however, additional substation bays will be required to make the connections to the barrage circuits. The substation south of Weston Super-Mare shall consist of 6 (3 x Double Circuit) 400kV overhead lines turning in the Hinkley Point – Seabank 400kV overhead lines and the barrage circuits. These circuits are required to meet the infrequent infeed loss risk (currently 1320MW but which could rise to 1800MW)

The remainder of the Wales Works remains unchanged from those for the previous option with no transmission circuits across the barrage, and are replicated below in *italics for clarity*.

From Aberthaw onwards, substantial reinforcement of the transmission network is required to provide assets capable of operating at 400kV for the onwards transmission of the large power injection at the connection point. Therefore the existing 275kV network between Aberthaw – Upper Boat – Cilfynydd needs to be uprated to 400kV. This will require re-conductoring existing L2 towers with 400kV conductors and insulation and the replacement of existing 275kV Super Grid Transformers (SGT) supplying Western Power Distribution Demand with 400kV SGTs

If the double circuit between Aberthaw – Upper Boat – Cilfynydd experienced faults during operation of the generation the remaining 275kV network would quickly become substantially overloaded in excess of capacity.

To resolve this issue a parallel 400kV route is required. This is best achieved by up-rating the existing 275kV connection between Aberthaw and Pyle to 400kV. Parts of this route currently utilise L2 transmission towers which can easily carry the required 400kV conductors. However, a short section utilises L3 transmission towers which are of a smaller, structurally lighter design and hence will require replacing to meet the need for 400kV transmission.

To complete the 400kV connections from Aberthaw via Pyle, there is a requirement to build a short section of new 400kV line (approx 10km) between Pyle and the existing 400kV Swansea – Cilfynydd lines to the south of Measteg. A new substation South of Measteg would be required to connect these new Pyle 400kV circuits.

The remaining 275kV network between Aberthaw – Cardiff East – Uskmouth and Aberthaw – Tremorfa – Uskmouth would require re-conductoring to manage increased power flows also.

The South West works are completely different from the previous option and as seen in Figure 5.2.2 the majority of the South West works fall away. In particular with the studied contracted background the requirement for the Bridgwater – Nursling line falls away. However it must be stressed that any change in the contracted background could mean the requirement for extra transmission reinforcement in the South West could occur.

Table 5.2.1 below shows how the addition of transmission circuits across the barrage means that the South West and South Wales transmission groups can be considered as one. This means that

the effective boundary capacity is substantially increased as the figures show. However it should be remembered that the amount of generation behind this boundary is much greater, as it now includes all generation in South Wales and the South West.

The post fault boundary capacity is based on the NETS SQSS requirement to consider two transmission circuit faults on the boundary as described in section 2 of this report. Thermally, year round there should be no loss of supply capacity (demand or generation) for the post fault condition across the boundary. Therefore, it should be noted that as only a two circuit transmission fault is considered at peak the effective interconnection provides additional capacity as the boundary is now considered as a whole for South Wales and the South West.

With this option it would be possible to consider additional generation in excess of **4.32GW** on the Welsh side from a thermal point of view. However if this were to be implemented, it is likely the additional circuits to Aberthaw would be required due to the increased flows. From a fault level and stability point of view this option may not be possible or, at the very least, challenging to achieve.

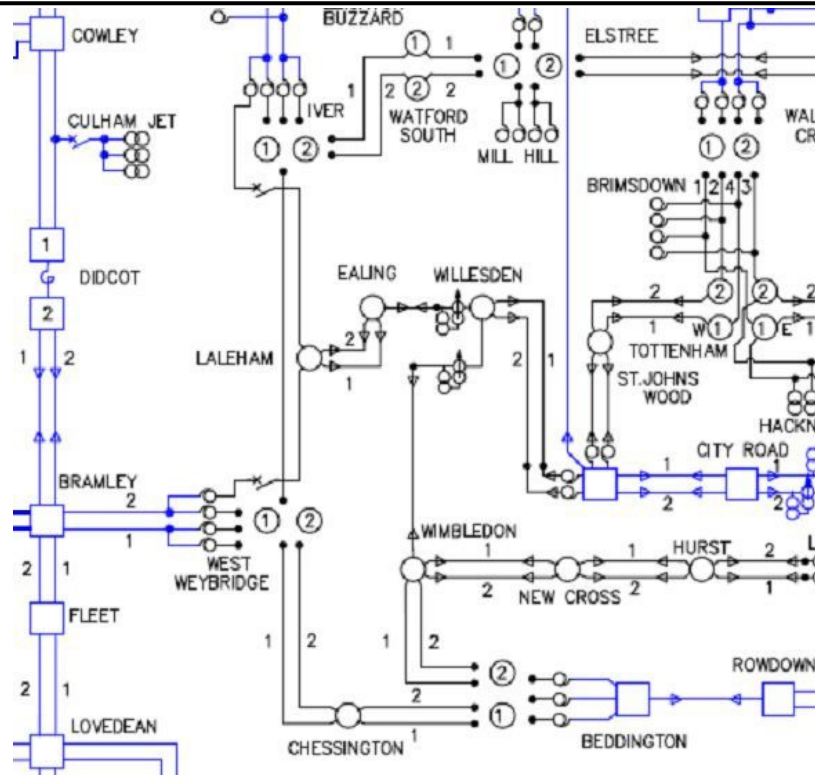
Combined South Wales and South West Boundary Circuit	2018 Capability	Required Capability
Walham – Rassau 400kV Walham – Rhigos 400kV	5960MVA	5960MVA
Imperial Park – Aust 400kV Cilfynydd – Whitson – Aust 400kV	3200MVA	5960MVA
Iron Acton – Whitson 1 & 2 275kV	1750MVA	1750MVA
South Wales Pre-Fault Boundary Capacity	10910MVA	N/A
South Wales Post - Fault Boundary Capacity	4950MVA	N/A
Seabank – Aust 400kV Seabank – Melksham 400kV	5640MVA	5960MVA
Hinkley Point – Bridgwater - Melksham 1 & 2 400kV	5960MVA	5960MVA
Mannington – Nursling 400kV Mannington – Fawley 400kV	3500MVA	5960MVA
South West Pre-Fault Boundary Capacity	15100MVA	N/A
South West Post - Fault Boundary Capacity	9140MVA	N/A
Combined Pre-Fault Boundary Capacity	N/A	31550MVA
Combined Post - Fault Boundary Capacity	N/A	25590MVA

Table 5.2.1 Combined South Wales and South West Boundary Capacity

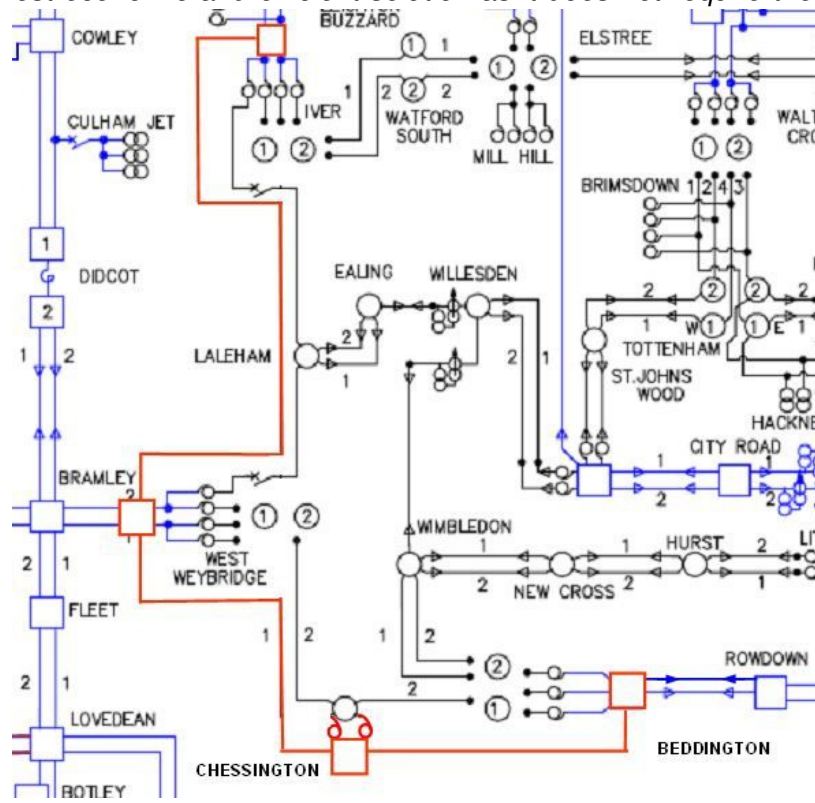
West London (same as section 4 repeated in italics for clarity)

*The West London network is characterised by a 275kV link between Iver in the West and Beddington / Rowdown to the south. Figure 5.2.5 showing the contracted background post 2018 and Figure 5.2.6 showing thermal works required to make West London compliant with the NETS SQSS following the connection of **8.64GW** of the barrage generation to the substation south of Weston-Super-Mare and south of Penarth.*

The West London network becomes overloaded following the connection of tidal generation. To solve this problem one side of the existing 275kV link between Iver and Beddington, via West



Weybridge and Chessington needs to be updated to 400kV. This then provides a strong 400kV path from West Weybridge both north and south into the London load centre. Only uprating one side of this route is the most economic and efficient solution as it does not require the replacement of grid



supply points at Laleham or Chessington.

5.3 Voltage Study Considerations

The option of installing circuits across the barrage to possibly avoid building the Bridgwater – Nursling 400kV overhead line does have adverse affect on Voltages in the South West. Table 5.3.2 below shows the 10 sites with the worst case voltages seen following transmission system faults. The NETS SQSS requires steady state voltages to remain within the planning limits set out in Table 5.3.1 below;-

Nominal Voltage	Minimum	Maximum
400kV	380kV (0.950 per unit)	410kV (1.025 per unit)
275kV	248kV (0.900 per unit)	289kV (1.050 per unit)

Table 5.3.1 Steady State Voltage limits in planning timescales

400kV Node	Before connecting MSCDN/SVC	After connecting MSCDN/SVC
	per unit voltage	per unit voltage
Minety 400kV	0.843	0.954
Melksham 400kV	0.845	0.960
Walham 400kV	0.848	1.017
Iron Acton 275kV	0.871	0.984
Rassau 400kV	0.874	0.991
Aust 400kV	0.893	1.000
Seabank 400kV	0.900	0.995
Bolney 400kV	0.902	0.984
Ninfield 400kV	0.905	0.980
Imperial Park 400kV	0.906	1.008

Table 5.3.2 List of Worst Case Post Fault Voltages

To resolve the non compliance of voltages at the sites listed above in table 5.3.2 additional reactive compensation needs to be installed and a greater amount than the previous option with no transmission circuits across the barrage. The problems experienced on the transmission system following the connection of the tidal generation tend to be post fault low voltage issues. These problems are generated by extremely high power flows on remaining circuits leading to a large increase in reactive losses. This can be overcome in the main by the installation of Mechanically Switched Capacitors with Damping Networks (MSCDNs) and Static VAr Compensators (SVCs). Table 4.3.3 shows the compensation required to restore system compliance

Compensation location	MSCDNs	SVCs
Aust 400kV	2 x 225MVar (450MVar)	
Cilfynydd 400kV	2 x 225MVar (450MVar)	
Walham 400kV	2 x 225MVar (450MVar)	
Minety 400kV	4 x 225MVar (450MVar)	
Melksham 400kV	6 x 225MVar (450MVar)	
Nursling 400kV		2 x -75/150 MVar (-150/300MVar)

TOTAL MVARs	3600MVAr	-150/300MVAr
--------------------	-----------------	---------------------

Table 5.3.3 Compensation Requirements

The compensation is required to keep voltages within statutory supply limits and also prevent voltage collapse, which can lead to a partial or in extreme cases total loss of the transmission system.

5.4 Fault Level Considerations

With 216 turbines and associated network there is significant fault infeed to both the substations at South of Weston-Super-Mare and South of Penarth. These high fault infeeds lead to a requirement to operate a significant number of substations electrically split. However even with substations operating in split configurations there is still a requirement to replace switchgear at some existing sites.

Table 5.4.1 on the next page shows the switchgear which is worst affected by the connection of the tidal generation scheme. The table shows the Route Mean Square (RMS) fault level at the 2018 contracted background level and fault levels following the tidal generation connection. The study is carried out on peak system demand background and is at a busbar level only. The fault levels following the connection of the tidal generation connection include all the possible operational split substation arrangements being in service.

The columns in table 5.4.1 show;

- The first section of busbar which is affected and the type of fault causing the rating issue, single or three phase fault.
- The green column shows the RMS rating of the breaker given by the manufacturer;
- The purple column shows the de-rated capability of the manufacturers rating based on the DC time constant seen on the transmission system verses that at which the circuit breaker was tested.
- The yellow column is the RMS duty of the breaker seen during the analytical study, which the breaker would see during operation.
- The blue column shows how the output of the study, yellow column, compares with the derated RMS figure, purple column.

When the percentage is greater than 100% this is flagged in red and indicates the rating has been infringed. Due to the increased fault levels, circuit breakers and affected equipment at the locations indicated in table 5.4.1 will need to be re-rated (if possible) or replaced if no breaker enhancement is possible. Due to further investigation being required to establish if re-rating is possible or not, costs for breaker replacement works have not been included in this feasibility.

For this scheme with circuits across the barrage the new substations at Penarth and Weston are flagged as exceeding breaker ratings. This is due to the distribution of generation when the substation is running split, as the option to minimise generator bays means it is not possible to balance the infeed across the split. This is because with only 3 generator bays at Penarth and Weston 400kV substations one side of each split has to have two generator bays connected to it. To better balance infeed from the generator and associated network 4 generator bays at each connection should be considered, if this design were selected.

		Contracted				Middle Barrage with Transmission circuits				
Fault Node	Fault Type	Breaker Rating RMS (kA)	DC time Derating RMS (kA)	Fault Duty RMS (kA)	% of derated rating	Breaker Rating RMS (kA)	DC time Derating RMS (kA)	Fault Duty RMS (kA)	% of derated rating	% Increase on contracted
WESM41	ONE	n/a	n/a	n/a	0.00%	63	50	66	131.59%	131.59%
PENA41	ONE	n/a	n/a	n/a	0.00%	63	50	64	127.58%	127.58%
WESM42	ONE	n/a	n/a	n/a	0.00%	63	53	62	117.80%	117.80%
BEDD11	ONE	15	14	14	98.65%	15	12	13	115.65%	17.00%
PENA42	ONE	n/a	n/a	n/a	0.00%	63	53	61	114.19%	114.19%
CARE10	ONE	25	25	25	99.32%	25	22	25	112.28%	12.97%
BEDD12	ONE	15	14	13	93.75%	15	12	13	110.03%	16.28%
MANN10	ONE	32	29	28	99.10%	32	26	28	107.93%	8.82%
CARE10	THREE	20	20	20	96.82%	20	18	19	103.73%	6.91%
HINP44	ONE	63	49	43	88.40%	63	51	51	101.31%	12.91%
HINP43	ONE	63	49	43	88.41%	63	51	51	101.25%	12.84%
PYLE20	THREE	40	37	30	80.73%	40	31	31	101.07%	20.34%
HINP41	ONE	63	49	43	87.70%	63	51	51	100.41%	12.71%
HINP42	ONE	63	49	43	87.71%	63	51	51	100.35%	12.64%
LALE20	ONE	32	29	27	92.35%	32	28	28	100.34%	7.99%
MAGA20	THREE	32	28	28	97.95%	32	28	28	99.97%	2.02%
CILF40	THREE	51	45	36	80.12%	51	49	49	99.11%	18.99%
PEMB10	ONE	18	14	14	98.19%	18	14	14	98.55%	0.36%

Table 5.4.1 Table of worst fault Level affected substation switchgear

5.5 Stability Study Considerations

During the stability considerations it became very clear that the low inertia constant of the proposed generation units has a significant affect on the transmission system. The worst case contingency was that of the double circuit from Rassau – Cilfynydd and Walham – Rhigos which was found to be unstable just by switching these circuits out of service. To overcome this, 35% series compensation (SC) has to be included in Minety – Cowley/Feckenham, and Melksham – Bramley circuits.

Table 5.5.1 below shows a list of the critical fault clearance times required for the following double circuit faults to prevent instability.

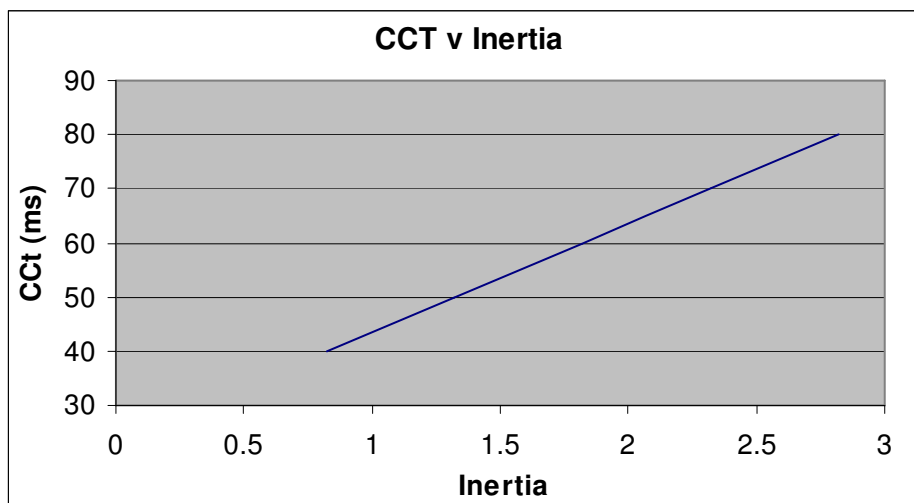
Double Circuit Combination	Critical Fault Clearance Time
Weston – Hinkley Point 400kV 1 & 2	40ms
Weston – Seabank 400kV 1 & 2	46ms
Penarth - Aberthaw 400kV 1 & 2	50ms
Penarth – Weston 400kV 1 & 2	50ms
Melksham – Bramley 400kV 1 & 2	54ms
Hinkley Point – Bridgwater – Melksham 1 & 2	60ms
Rassau – Cilfynydd, Walham – Rhigos 400kV	118ms

Table 5.5.1 Table of Critical Fault Clearance times

The normal fastest fault clearance times considered by National Grid is no quicker than 80ms, although 140ms is considered worst case viable fault duration. Therefore, to maintain a stable system consideration needs to be given to improving these clearance times. It is evident that stability in South Wales is improved by this design, but the stability in the South West area is much worse. This is mainly due to no longer having the additional connection between Bridgwater and Nursling.

Improving Inertia Constant

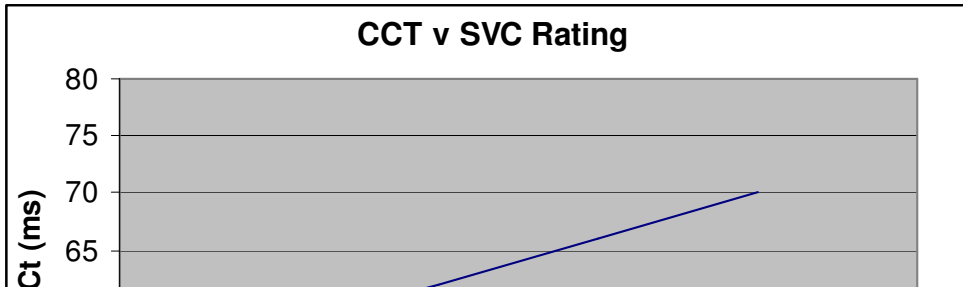
For the worst case fault clearance time for the Weston – Hinkley Point 400kV double circuit the graph 5.5.1 below, shows how an increase of the generator inertia constant can provide improved fault clearance times. Therefore an inertia constant of 2.7 MWs/MVA would achieve the minimum



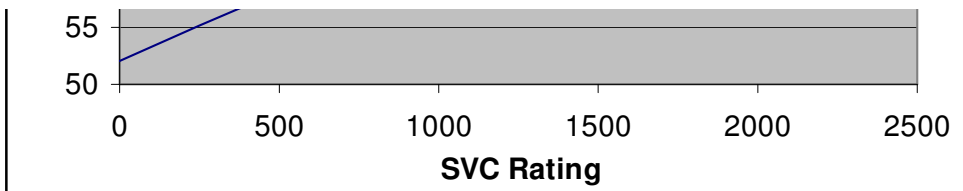
clearance time with the fast protections available. However it is not known if it is possible to source generators of the type required with inertia constants of this value.

Use of SVCs at Generator Connection Point

The SVC performance against improvement of critical clearance times remains the same as that in section 4. Graph 5.5.2 below shows the SVC capacity that would need to be installed at both



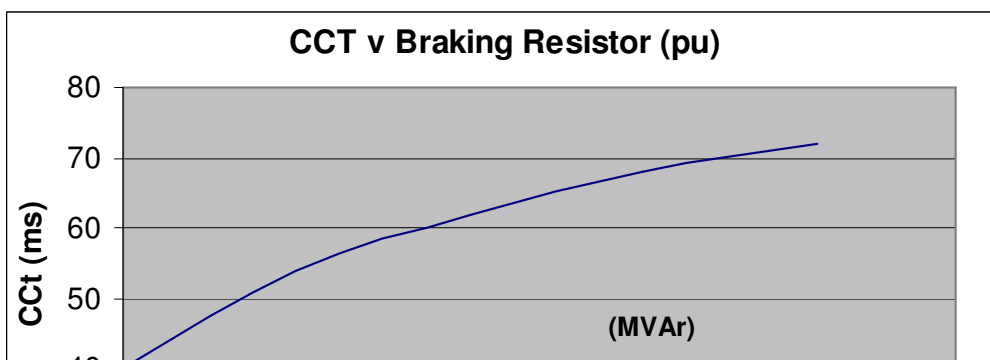
Graph 5.5.1 Improvement of Critical Fault Clearance Time by increased Inertia



Graph 5.5.2 Improvement of Critical Fault Clearance Time by SVC installation

Penarth and Weston substations, again to improve the critical clearance time for the Weston – Hinkley Point 400kV double circuit. It is clear from this graph that a significant amount of SVC capacity needs to be installed to achieve clearance times anywhere close to 80ms and the costs associated with this solution would be excessive.

Use of Braking Resistors at Generator Connection Point



As opposed to section 4 braking resistors are far more effective in this configuration with circuits across the barrage. Graph 5.5.3 below shows the braking resistor per unit size that would need to

be installed at both Penarth and Weston substations, again to improve the critical clearance time for the Weston – Hinkley Point 400kV double circuit.

DC transmission circuit connections across the barrage circuits

A possible variation to AC transmission circuits across the barrage is to replace them by HVDC which would necessitate converter stations on either side of the Barrage at Weston and Penarth. The use of Voltage Source Converter (VSC) technology can have a significant effect on stability by prioritising the VSC reactive power over the real power. The choice of how this is done will depend on the particular circumstances, and in this case it's apparent that reducing real power only whilst maximising reactive power is the most beneficial in increasing critical fault clearance times.

Results for a 4GW HVDC VSC link gave an increase in fault clearance times to 88ms, therefore this solution appears to give critical fault clearance times which are much closer to those required. Despite the relatively high cost of the VSC equipment, this option therefore

Graph 5.5.3 Improvement of Critical Fault Clearance Time by Braking Resistor installation vide
provide reactive support when required, and improvement to stability would not be demonstrable from conventional LCC HVDC equipment.

Stability Conclusions

It is clear that this solution would require further work to be undertaken to improve system stability to make the connection compliant with AC transmission circuits and certainly more so than that detailed in section 4. However, a combination of the options listed above, i.e. generator inertia constant, SVCs or braking resistors could be used to provide system compliance, as well as other alternatives yet to be identified.

Pumping operation was also considered as part of this study; however this function is very sensitive to the levels of pumping capacity. If pumping is to match the generation output level then the issues are very similar to those for generating and additional measures would need to be undertaken to improve stability of the system.

A better way to possibly improve the stability of this option is to consider using DC connections for the generation with AC transmission across the barrage; or for National Grid to consider using DC VSC transmission circuits across the barrage. Two DC transmission circuits would be required each with a capacity of about 2.25GW to cover the double circuit loss from Penarth – Aberthaw. However it may be possible for them to be slightly smaller if 4 circuits remained connected between Penarth and Aberthaw.

5.6 Generation Connection Substations

To facilitate the connection of the generation onto the transmission system National Grid would construct and commission two new substations. One substation would be constructed on the English side to the south of Weston-Super-Mare as shown in Figure 5.6.1 AC transmission circuit option and figure 5.6.3 for the DC transmission circuit option. The other would be constructed on the Welsh side to the south of Penarth as shown in Figure 5.6.2 AC transmission circuit option and figure 5.6.4 for the DC transmission circuit option.

As stated earlier in this report, the substation to the south of Penarth would remain the same size for this option except for the addition of shunt reactors to manage voltage gain and switching in and out of large AC cables. However the substation to the south of Weston Super-Mare would need to be increased by two bays to accommodate the additional barrage circuits as well as the shunt reactor requirements.

If DC transmission circuits were to be selected to resolve the more onerous stability issues associated with AC barrage circuits, there would be a requirement to provide additional space for converter stations on both the English and Welsh sides of the estuary. These converter stations are of significant size and likely to be larger than the substation but would once again be of an indoor design.

The layout of the substation is determined by the infrequent infeed loss risk currently 1320MW. However for the purposes of this report is assumed that the current proposal to raise this to 1800MW will have been achieved by the connection date. If this was not achieved an additional generator bay would be required, along with further section breakers.

The infrequent infeed loss risk also determines the number of circuit connections required into the connection substation. To reduce the number of circuits below three the generation at any individual connection point would have to be reduced below 1800MW (or 1320MW if the infrequent infeed loss risk is not increased).

It is also worth noting, as discussed in the Stability section, there may be a requirement for additional bays and space for either SVCs or breaking resistors at each substation. The space and bay requirements cannot be determined until the actual proposed machine parameters are available and all alternative stability options have been considered.

Both of these substations are likely to be of indoor Gas insulated Substation (GIS) construction, this is because of their proximity to the saline estuary, and National Grid's pollution policy determines that indoor equipment is to be specified where this is within 5km of a saline environment. Saline pollution creates substantial flash-over risks and premature aging of asset due to corrosion and failure if located outdoors.

Middle Barrage with AC Circuits across Barrage (WESTON SUPER-MARE Substation Connections)

WESTON SUPER-MARE SUBSTATION 400kV (With circuits the Barrage)
New GIS 400kV, 4000A, 63kA switchgear

Key

-  Existing Asset
-  New Generation Connection Asset
-  New Asset

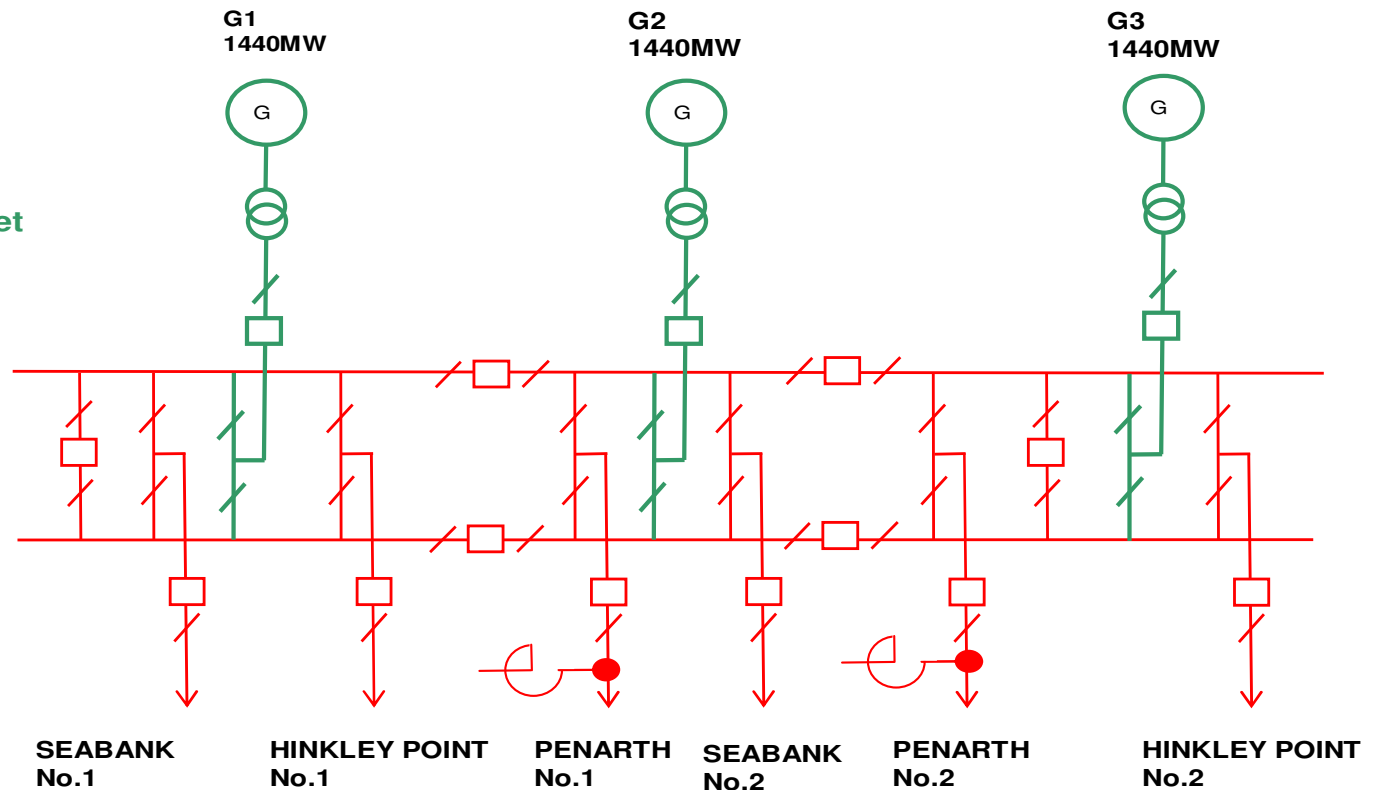


Figure 5.6.1 Generation Connection Substation at Weston-Super-Mare for Middle Barrage with AC transmission circuits across the barrage.

Middle Barrage with AC Circuits across Barrage (PENARTH Substation Connections)

PENARTH 400kV (With circuits across the Barrage)
New GIS 400kV, 4000A, 63kA switchgear

Key

-  Existing Asset
-  New Generation Connection Asset
-  New Asset

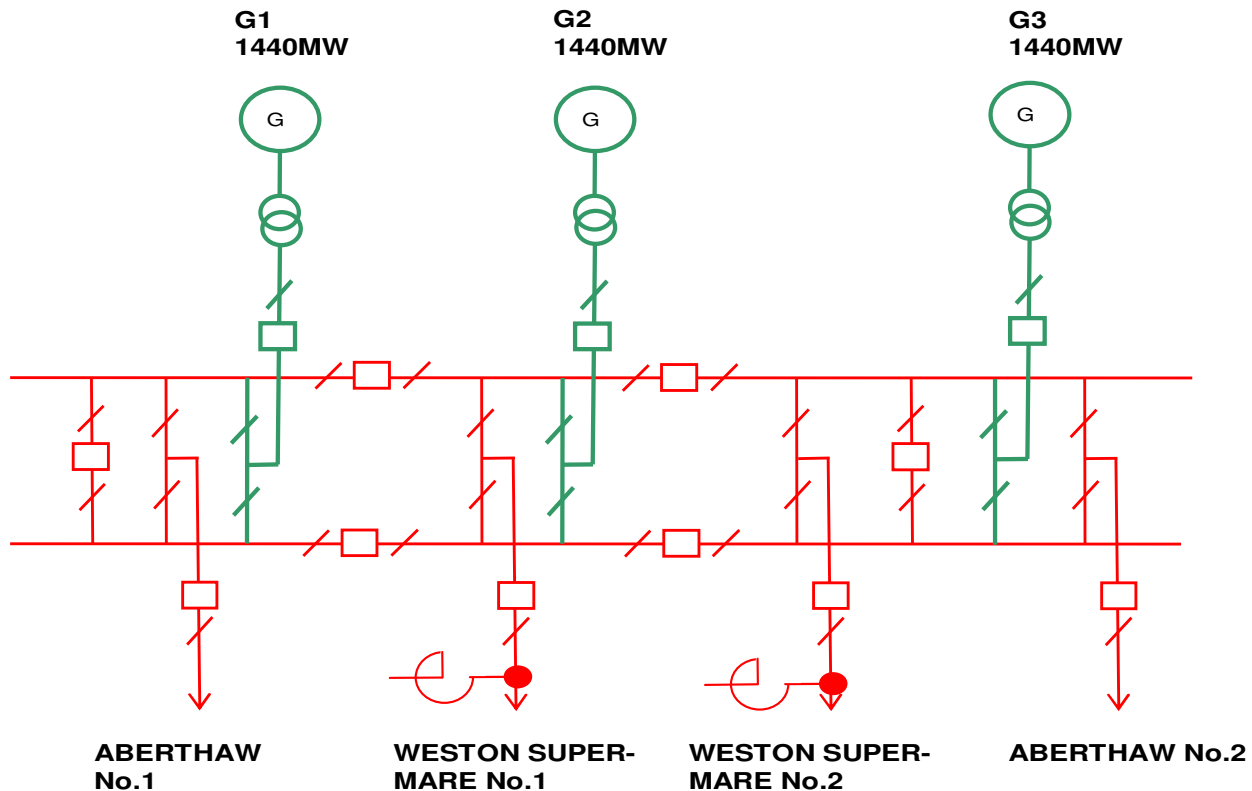


Figure 5.6.2 Generation Connection Substation at Penarth for Middle Barrage with AC transmission circuits across the barrage.

Middle Barrage with DC Circuits across Barrage (WESTON SUPER-MARE Substation Connections)

WESTON SUPER-MARE SUBSTATION 400kV (With circuits the Barrage)
 New GIS 400kV, 4000A, 63kA switchgear

Key

- Existing Asset
- New Generation Connection Asset
- New Asset

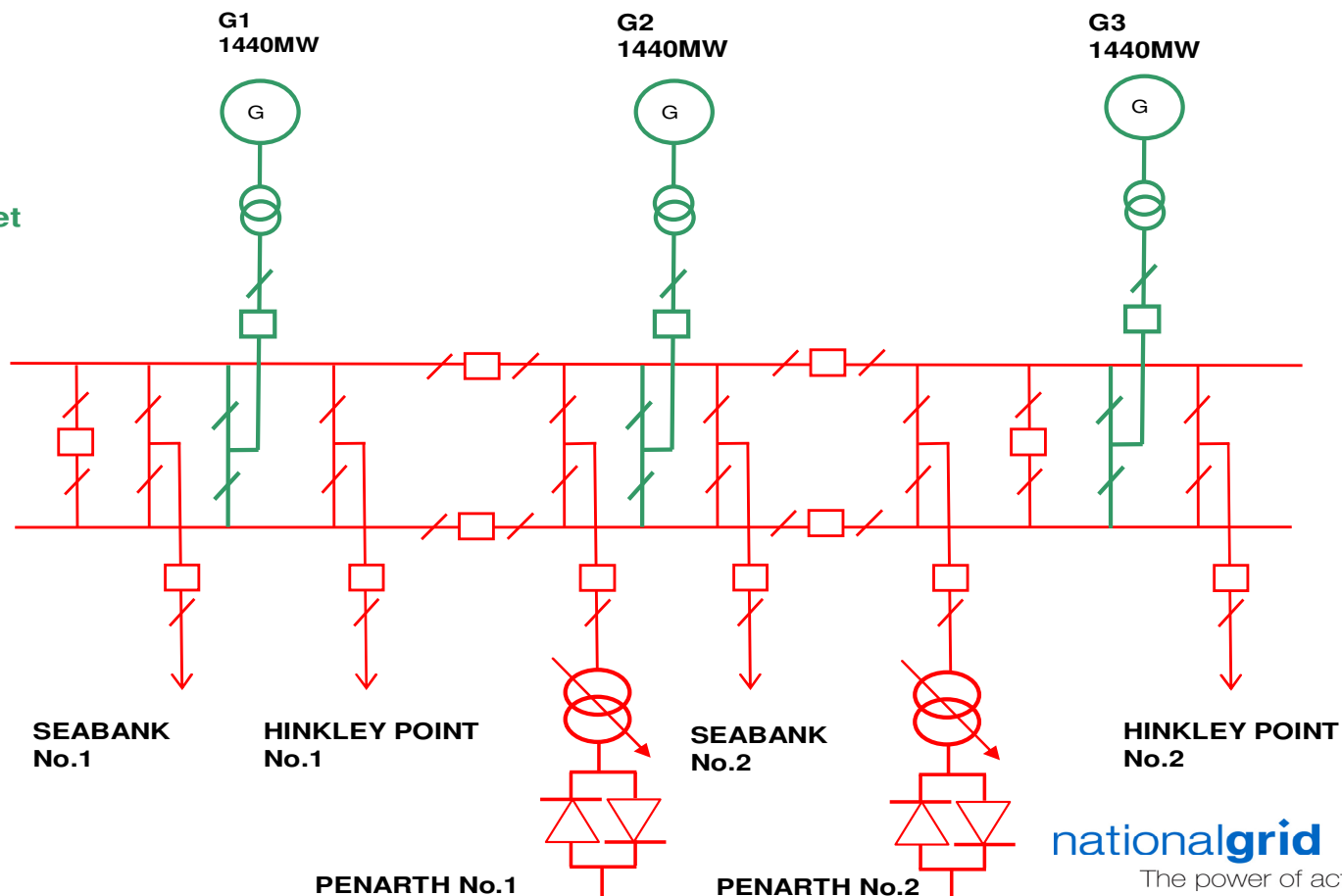


Figure 5.6.3 Generation Connection Substation at Weston-Super-Mare for Middle Barrage with DC transmission circuits across the barrage.

Middle Barrage with DC Circuits across Barrage (PENARTH Substation Connections)

PENARTH 400kV (With circuits across the Barrage)
New GIS 400kV, 4000A, 63kA switchgear

Key

-  Existing Asset
-  New Generation Connection Asset
-  New Asset

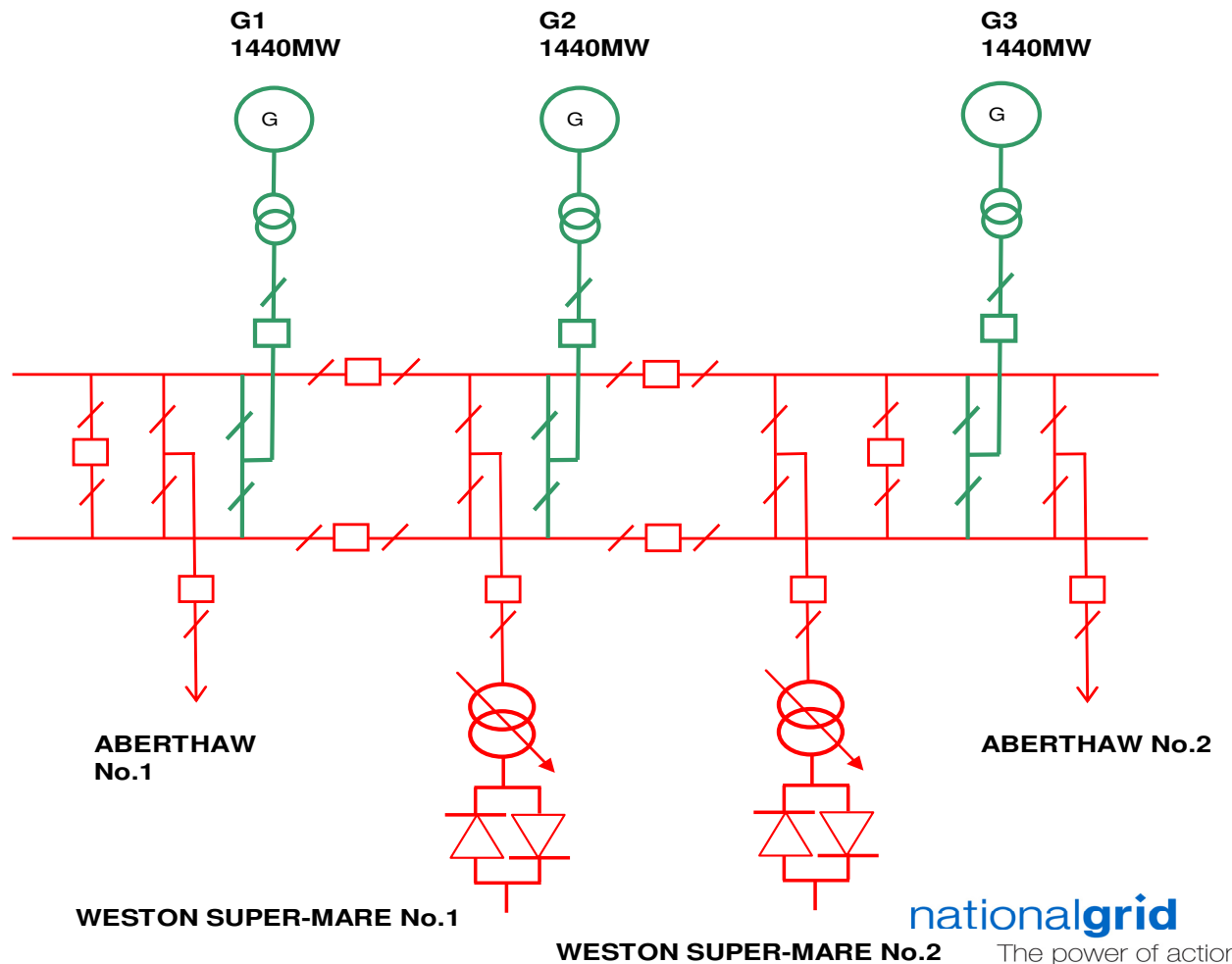


Figure 5.6.4 Generation Connection Substation at Penarth for Middle Barrage with DC transmission circuits across the barrage.

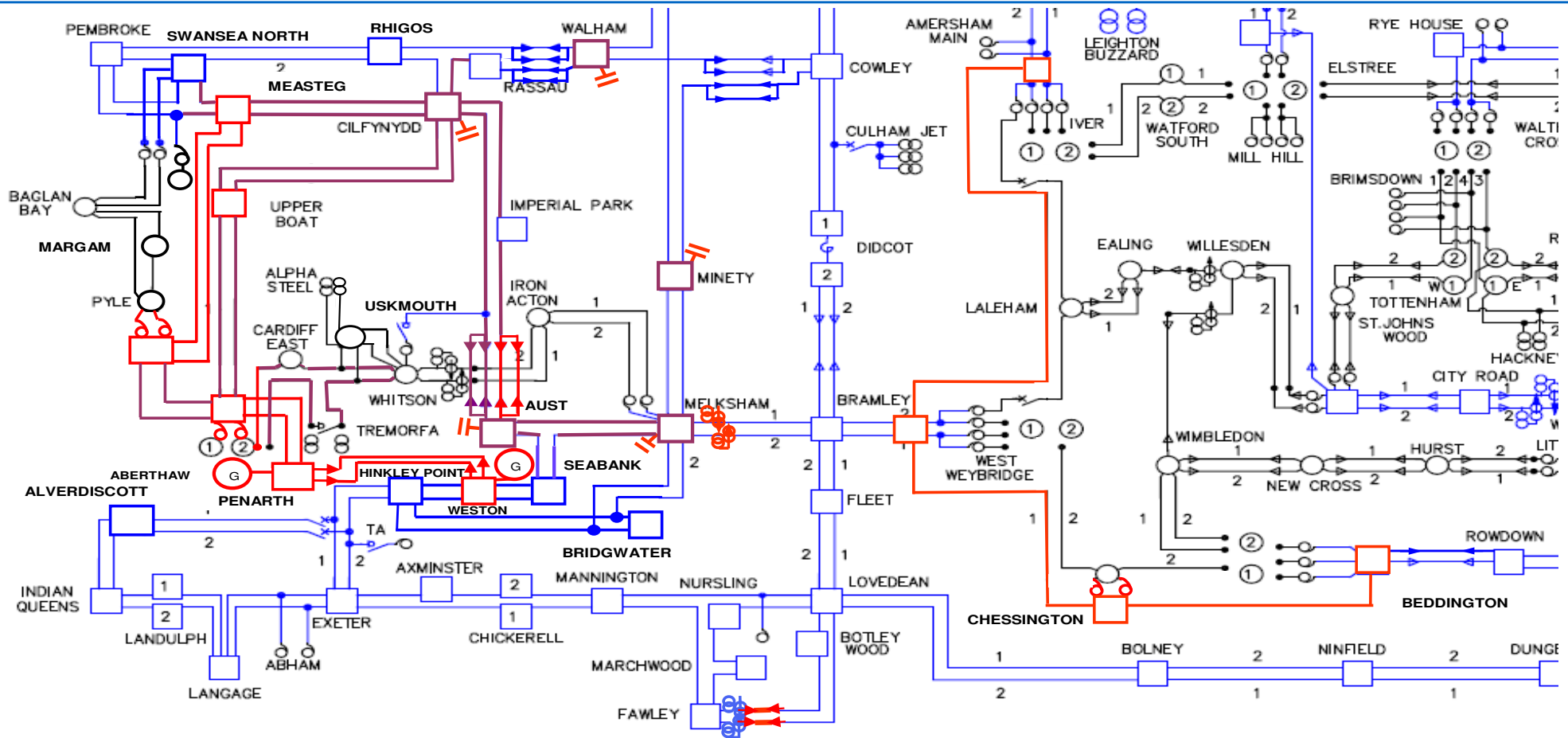
5.7 Full Description of Local and Wider Transmission reinforcement

Figures 5.7.1 and 5.7.2 show a schematic and geographical representation of the total transmission works required to allow the connection of a middle barrage to the transmission system. These representations include all of the works identified from the studies described in the previous parts of section 5 of this report.

Table 5.7.1 has a summarised description of the work required to make the connection to the middle barrage with no circuits across the barrage. **Appendix 2** has a full description of works required. However in high level summary the full local and wider transmission reinforcement works consist of:

- ◆ **Substations and Equipment**
 - ◆ 10 New substations required.
 - ◆ 3600MVar of Mechanically Switched Capacitors (MSC) capacity required at 5 substation locations.
 - ◆ 2 x -75/150MVar Static Var Compensators (SVC) required at Nursling.
 - ◆ 2 x 2750MVA 400kV Quad Boosters (QB) required at Melksham.
 - ◆ 4 x 200MVar Shunt Reactors at Penarth and Weston
 - ◆ 35% Series Compensation at Bridgwater, Mintey and Melksham for the following circuits.
 - ◆ Nursling – Bridgwater
 - ◆ Minety – Cowley/Feckenham
 - ◆ Melksham – Bramley
- ◆ **OHL and Cables**
 - ◆ Approximately 78km route kms of new overhead line routes
 - ◆ Approximately 220km route kms of existing overhead line reconductoring
 - ◆ Doubling of cables within an existing tunnel (Chilling)
 - ◆ Construction of a new cable tunnel (Severn)
 - ◆ Installation of 25km of double circuit cables across the barrage

Middle Barrage – Circuits Across Barrage



KEY

- 275kV
- 400kV
- NEW ASSETS
- CHANGES TO EXISTING ASSETS
- HOTWIRING
- G BARRAGE GENERATION

Figure 5.7.1 Total Transmission Works Middle Barrage – With Circuits Across Barrage

Geographical Middle Barrage – Circuits across Barrage

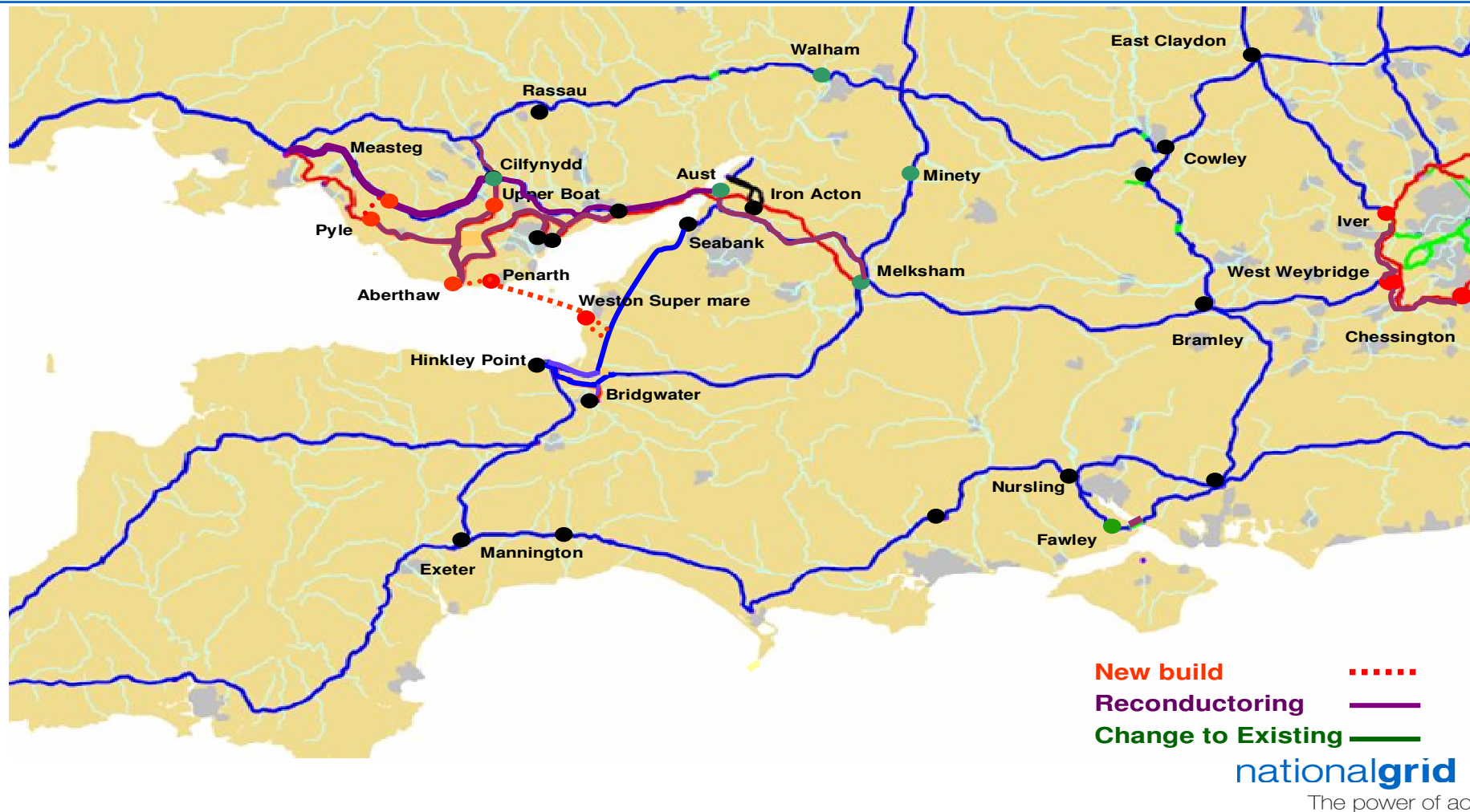


Figure 5.7.2 Geographical Total Transmission Works Middle Barrage – With Circuits Across Barrage

Description of Work Middle Barrage – Circuits Across Barrage

◆ Generators

- Middle Barrage
8.6GW
- Penarth Side
4.3GW
- Weston Side
4.3GW

Key

F = Feeder

GEN = Generator skeletal bay

BC = Bus Coupler

BS = Bus Section

SR = Shunt Reactor Bay

SGT = Super Grid Transformer & Bay

PFC = Post Fault Continuous

Red = changes from previous option

Ghosted Writing = Ghosted Writing Not required by this option

◆ New Works

◆ New Substations

- Measteg 400kV (6F, 2BC, BS)
- Pyle 400kV (4F, 2SGT, 2BC, BS)
- **Aberthaw 400kV (6F, 2SGT, 2BC, 4BS)**
- Upperboat 400kV (4F, 3SGT, BC, BS)
- Bridgwater 400kV (4F, 2SGT (bay only), 3C BS)
- West Weybridge 400kV (4F, 2SGT (bay only), 2BC, BS)
- Iver 400kV (3F, 2SGT (bay only), 2BC, BS)
- Beddington 400kV (3F, 3SGT (bay only), 2BC, BS)
- Chessington 400kV (1MESHCB, 2SGT)
- Penarth 400kV (4F, 3GEN (skel), 2BC, 4BS, **2SR**)
- **Weston 400kV (6F, 3GEN (skel), 2BC, 4BS, 2SR)**
- Punton tee 400kV line breakers (3F)

◆ New Equipment

- 2 x 225Mvar MSCs Aust
- 2 x 225Mvar MSCs Cilfynydd
- 2 x 225Mvar MSCs Walham
- **4 x 225Mvar MSCs Minety**
- **6 x 225Mvar MSCs Melksham**
- 2 x -75/150 MVar SVC's at Nursling
- Quad boosters at Melksham 400kV (2750MVA PFC)
- 35% series compensation at Bridgewater, Minety and Melksham
- **2 x 200MVar shunt reactor Penarth**
- **2 x 200MVar Shunt reactor Weston Super - Mare**

◆ New Lines

- Pyle – Measteg 9km 400kV (2820MVA summer, PFC)
- Bridgwater – Nursling 125km (2820MVA summer PFC)
- Single Circuit Penarth – Aberthaw 18km (2820MVA summer PFC)
- Aberthaw – Cardiff East 19km (1010MVA winter PFC)
- 2 x Double Circuits Weston Spur (Hinkley Point – Seabank) 9km each (2820 summer PFC)

◆ New Cable Routes

- 2nd Severn Cable tunnel and Circuit (IMPP-AUST, CILF-WHSO-AUST 3000MVA cyclic year round rating)
- Double cables in chilling tunnel (FAWL-BOTW, FAWL-LOVE 3000MVA cyclic year round rating)
- **Weston – Penarth 1 & 2 400kV across barrage**
- **(3000MVA cyclic rating each)**

◆ Changes to Existing

– Substations

- Nursling 400kV (3F, 3SGT (bay only), 2BC, 1BS)

– Reconductoring

- Measteg – Cilfynydd 400kV 1 & 2 (2980MVA summer, PFC)
- Aust - Whitson – Cilfynydd & Aust – Imperial Park, Imperial Park – Cilfynydd 400kV (2980MVA summer, PFC)
- Aust – Melksham & Aust – Seabank, Seabank Melksham L6 sections 1(2980MVA summer, PFC)
- Aberthaw – Pyle 400kV 1 & 2 (re-rating from 275kV (2820MVA summer,PFC)
- Aberthaw – Upper Boat 400kV 1 & 2 (re-rating from 275kV) (2820MVA summer,PFC)
- Cilfynydd – Upper Boat 400kV 1 & 2 (re-rating from 275kV) (2820MVA summer,PFC)
- Mannington – Nursling 400kV 1 & 2 (2980MVA summer, PFC)
- Nursling – Fawley & Fawley – Marchwood, Marchwood - Nursling 400kV 1 & 2 (2980MVA summer, PFC)
- Lovedean – Nursling 400kV 1 & 2 (2980MVA summer, PFC)
- Chessington – Beddington 400kV single cct (up-rate from 275kV) (2980MVA summer, PFC)
- Chessington – West Weybridge 400kV single cct (up-rate from 275kV) (2980MVA summer, PFC)
- West Weybridge – Iver 400kV single cct (up-rate from 275kV) (2980MVA summer, PFC)
- Cilfynydd to Rassau (2960MVA summer PFC)
- Hinkley Point – Taunton – Exeter 1 & 2 (2960MVA summer PFC)
- Exeter – Axminster – Chickerell 1 & 2 (2980MVA summer PFC)
- Chickerell – Mannington 1 & 2 (2960MVA summer PFC)
- Aberthaw – Cardiff East – Uskmouth – Whitson & Aberthaw – Tremorfa – Uskmouth – Whitson (including USK crossing) 275kV (1010MVA winter PFC)

– Hotwire

- None Currently Identified

Table 5.7.1 Description of Total Transmission Works Middle Barrage – With Circuits Across Barrage

5.8 Design Options Considered

During the consideration of the middle barrage with transmission circuits across the barrage multiple options have been considered including varying the generation on each side of the estuary. Of the **8.64GW** of generation the optimum solution was to consider **4.32GW** flowing into both Penarth and Weston.

With circuits across the barrage it is easier to consider **6.48GW** of power injection into South Wales and only **2.16GW** being injected into the South West. With the interconnection capacity increased out of South Wales by the inclusion of barrage circuits, it is possible to get more power out of the transmission group. However post fault voltages, stability and fault levels are all significantly worse in this configuration and again the additional reinforcement required to overcome these issues would prove neither economic nor efficient.

When **6.48GW** was injected into South West and only **2.16GW** was injected into South Wales, with no Bridgwater – Nursling 400kV circuit, this option becomes even more difficult to manage for the voltage and Stability problems. These issues become even more complicated to resolve and are not considered to be economic nor efficient.

Connection of the generation via DC connections would also be an alternative to relieve some of the significant stability and fault level issues associated with a project of this magnitude. With such a low generator inertia constant and, if no improvement is forthcoming, such solutions should be seriously considered.

As proposed in the stability section 5.5, National Grid could consider using DC VSC transmission circuits across the barrage. Two DC transmission circuits would be required each with a capacity of about 2.25GW to cover the double circuit loss from Penarth – Aberthaw. However it may be possible for them to be slightly smaller if 4 circuits remained connected between Penarth and Aberthaw. Currently VSC technology has not exceeded 1000MW in capacity, however the technology is improving all the time and in the timescales of a large tidal project could possibly achieve the required capacity.

5.9 Conclusions

The transmission reinforcement necessary to accommodate this scheme represents a significant amount of amount of system access and resource to complete. The initial cost estimate of this work is **£2.253bn** (in 2009 prices) for the AC transmission circuit option and **£2.256bn** (in 2009 prices) for the HVDC transmission circuits, a high level breakdown of the costs is provided in section 11.

As opposed to the option set out in section 4 this option has significant stability issues to overcome in particular, however, these issues are not insurmountable. The use of HVDC VSC technology for the circuits across the barrage should be seriously considered to overcome the stability issues. This technology also has the advantage that the space requirements for the cables is much reduced from that of AC, and may present significant benefits from a civil construction perspective. However, as with section 4, with the current committed background and significant amounts of generation in South Wales and the South West, further detail would be required to take all the transmission issues into account.

6 Inner Barrage feasibility

6.1 Background

The inner Shoots barrage option spans the Severn estuary to the South of the Second (new M4) Severn road crossing. The barrage is proposed to make landfall on the Welsh side just to the south of Caldicot and on the English side to the north of Avonmouth. This barrage has been assumed to generate up to **1.36GW** of energy at peak output, to take into account similar design capacities being considered for tidal Lagoons in similar locations.

National Grid does have 400kV transmission overhead lines on each side of the river in close proximity to the landing points. However, the nearest existing (or proposed) connection infrastructure substations are:-

- English side (north of Avonmouth) – Seabank 400kV 3km, Aust 400kV 9km
- Welsh side (south of Caldicot) – Whitson 275kV 16km

With a much lower generation power injection there is no need to consider bringing transmission cable circuits across the estuary for any of these options.

6.2 Thermal Study Considerations – (including variation of power injection points)

Unlike the options identified for the middle barrage in Sections 4 and 5 of this report the thermal studies for this option showed that only reinforcement works to the South West Transmission system would be required in addition to the studied 2018 background. There was no requirement for reinforcement works in South Wales or outer London for the optimum solution. The chosen option is based upon the whole tidal generation output being injected into the South West transmission system. The issues associated with injecting power into South Wales shall be discussed following the description of optimum South West works.

South West

The South West network consists solely of 400kV assets. Figure 6.2.1 showing the contracted background post 2018 and Figure 6.2.2 showing thermal works required to make the South West compliant with the NETS SQSS following the connection of **1.36GW** of the barrage generation to a substation at Aust 400kV.

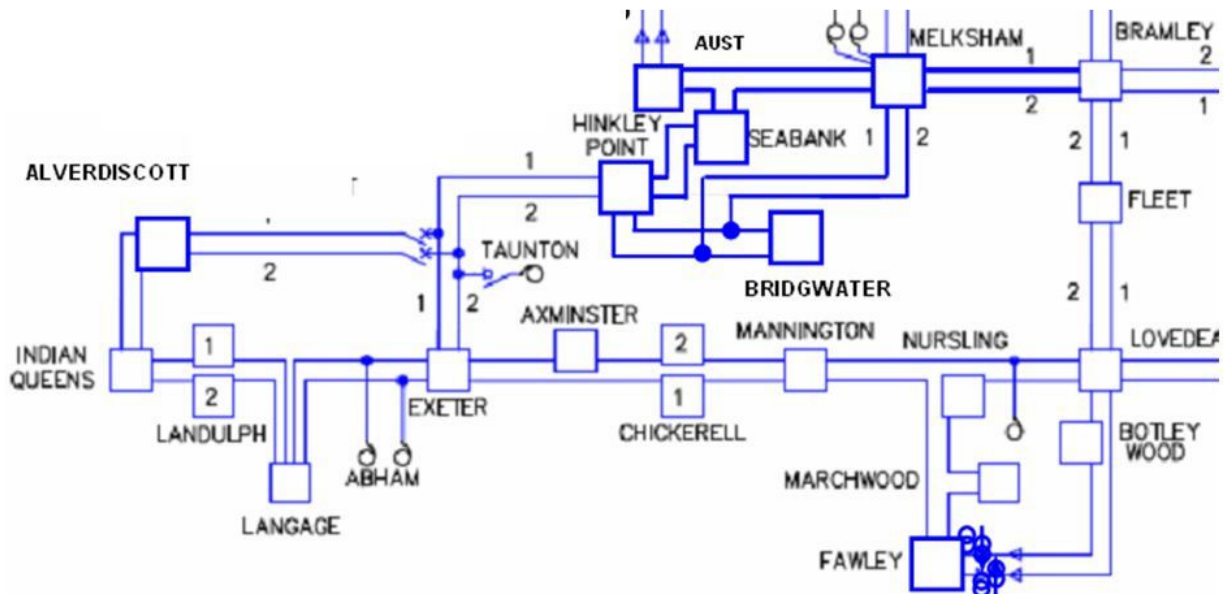
Aust 400kV is a substation that is required to be constructed as part of the 2018 contracted background works, and is to be constructed of a design that will be easily adapted to a double busbar substation capable of connecting the tidal generation.

Although Aust 400kV substation is further away than Seabank 400kV by 5km, due to space restrictions and heavy thermal flows under fault, Seabank 400kV cannot be used to connect this generation. Further overhead lines in parallel to existing routes and further bays would be required to make the connection into Seabank 400kV substation, this would be at a significantly higher cost than bringing the generation the additional 5km to Aust 400kV.

The Aust 400kV connection does require the existing turn-in lines of Seabank – Melksham 400kV and Seabank – Aust 400kV to be turned into Aust. However to do this means paralleling the

existing Melksham – Aust circuits for a relatively short distance of 5km. This would create the following circuit connections.

- Melksham – Aust 400kV 1 & 2
- Aust – Seabank 400kV 1 & 2



Along with some upgrading of these circuits this represents the maximum extent of work required to connect the tidal generation to the South West transmission system.

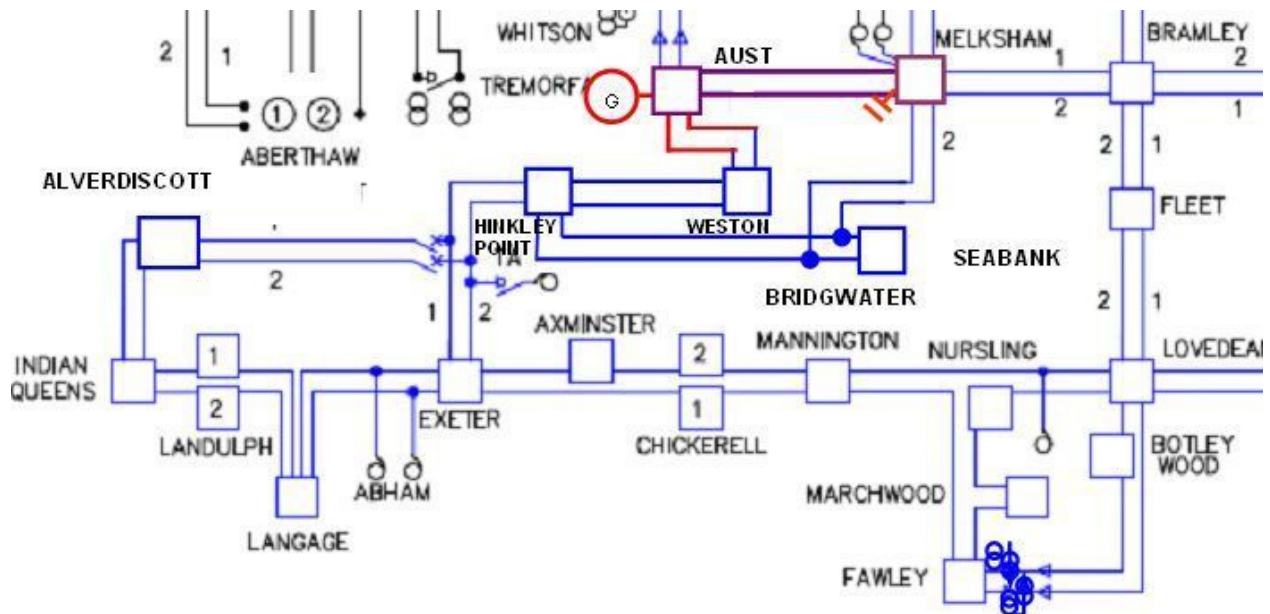


Figure 6.2.1 Existing South West Transmission System Post 2018

South Wales Connection Issues

Any connection being made to South Wales above 50MW on current contracted backgrounds would require the uprating of the 400kV Severn cable tunnel as described in sections 4 and 5, at an estimated cost >£100m (in 2009 prices). Also any connection in Wales would require the construction of a new 400kV substation in the vicinity of the landing point at an estimated cost of >£20m (in 2009 prices).

Due to the contracted background flows, transmission reinforcement in South West would remain the same as described above for connection of any tidal generation made in South Wales. **Therefore it is not economic and efficient to connect in South Wales, as the South Wales costs would be in addition to the South West costs for making such a connection.**

6.3 Voltage Study Considerations

The inner barrage option has a much lessened affect on Voltage and as Table 6.3.2 below shows the only site with non compliant voltage is Melksham 400kV substation. The NETS SQSS requires steady state voltages to remain within the planning limits set out in Table 5.3.1 below:-

Nominal Voltage	Minimum	Maximum
400kV	380kV (0.950 per unit)	410kV (1.025 per unit)
275kV	248kV (0.900 per unit)	289kV (1.050 per unit)

Table 6.3.1 Steady State Voltage limits in planning timescales

400kV Node	Before connecting MSCDN	After connecting MSCDN
	per unit voltage	per unit voltage
Melksham 400kV	0.942	0.980

Table 6.3.2 List of Worst Case Post Fault Voltages

To resolve the non compliance of voltage at Melksham 400kV substation additional reactive compensation needs to be installed. The problems experienced on the transmission system following the connection of the tidal generation tend to be post fault low voltage issues. These problems are generated by extremely high power flows on remaining circuits, in this case the Melksham – Bramley 400kV circuit, leading to a large increase in reactive losses. This can be overcome in the main by the installation of Mechanically Switched Capacitors with Damping Networks (MSCDNs) and Static VAR Compensators (SVCs). Table 4.3.3 shows the compensation required restore system compliance

Compensation location	MSCDNs	SVCs
Melksham 400kV	1 x 225MVAR (450MVAR)	
TOTAL MVARs	225MVAR	

Table 6.3.3 Compensation Requirements

The compensation is required to keep voltages within statutory supply limits and also prevent voltage collapse, which can lead to a partial or in extreme cases total loss of the transmission system.

6.4 Fault Level Considerations

With 39 turbines and an associated electrical network there is significant fault infeed at Aust 400kV substation, although the infeed is significantly less than that compared to the Middle Barrage. However there is still an affect on the local transmission system.

Table 6.4.1 on the next page shows the switchgear which has be worst affected by the connection of the tidal generation scheme. The table shows the Route Mean Square (RMS) fault level at the 2018 contracted background level and fault levels following the tidal generation connection. The study is carried out on a peak system demand background and is at a busbar level only. The fault levels following the connection of the tidal generation connection and include all the possible operational split substation arrangements being in service.

The columns in table 6.4.1 show;

- The first section of busbar which is affected and the type of fault causing the rating issue, single or three phase fault.
- The green column shows the RMS rating of the breaker given by the manufacturer;
- The purple column shows the de-rated capability based on the DC time constant seen on the transmission system verses that at which the circuit breaker was tested.
- The yellow column is the RMS duty of the breaker seen during the analytical study, which the breaker would see during operation.
- The blue column shows how the output of the study, yellow column, compares with the derated RMS figure, purple column.

The results for the inner barrage show that there is a fault level issue with the locally connected infrastructure only when the system is run solid. If both Aust and Seabank substations are operated split then the fault infeed falls within the ratings of the breakers. All except Cardiff East 132kV which still has fault levels in excess of the existing equipment.

		Contractedf				Inner Barrage				
Fault Node	Fault Type	Breaker Rating RMS (kA)	DC time Derating RMS (kA)	Fault Duty RMS (kA)	% of derated rating	Breaker Rating RMS (kA)	DC time Derating RMS (kA)	Fault Duty RMS (kA)	% of derated rating	% Increase on contracted
AUST40	ONE	63	60	37	61.79%	63	55	77	140.10%	78.31%
SEAB40	ONE	63	54	42	78.37%	63	55	60	109.71%	31.34%
CARE10	ONE	25	25	25	99.32%	25	22	24	109.32%	10.01%
SEAB40	THREE	63	54	45	82.25%	63	51	55	108.06%	25.81%
AUST40	THREE	63	55	43	78.59%	63	56	60	105.99%	27.41%
CARE10	THREE	20	20	20	96.82%	20	18	18	100.65%	3.83%
ABTH21	ONE	32	31	30	98.57%	32	31	30	99.15%	0.59%
MAGA20	THREE	32	28	28	97.95%	32	28	28	98.38%	0.43%

Table 6.4.1 Table of worst fault Level affected substation switchgear (solid running arrangement)

6.5 Stability Study Considerations

During the stability considerations it became very clear that the low inertia constant of the proposed generation units has a significant affect on the transmission system. However for the inner barrage the situation is far improved as can be seen from table 6.5.1. Table 6.5.1 shows a list of the critical fault clearance times required for the relevant double circuit faults to prevent system instability.

Double Circuit Combination	Critical Fault Clearance Time
Aust – Seabank 400kV 1 & 2	100ms
Aust – Melksham 400kV 1 & 2	106ms
Minety – Melksham 400kV 1 & 2	140ms
Melksham - Bramley 400kV 1 & 2	140ms

Table 6.5.1 Table of Critical Fault Clearance times

The normal fastest fault clearance times considered by National Grid are no quicker than 80ms, although 140ms is considered worst case viable fault duration. So to maintain a stable system consideration needs to be given to ensuring protection shall operate quicker than 140ms (in the 80-100ms range) for all scenarios or improving these critical clearance times depending upon the most economic option.

Stability Conclusions

Achieving stability compliance with the chosen generator design for the inner barrage should represent an easier task when compared to the middle barrage, especially if a higher generator inertia constant can be achieved.

6.6 Generation Connection Substations

To facilitate the connection of the generation onto the transmission system, National Grid shall extend and commission the new Aust 400kV substation. Aust 400kV substation is located on the English side of the estuary next to the Aust junction of the M48, the substation layout is shown in Figure 6.6.1.

The layout of the substation shows two generator bays as it allows the operator flexibility during outages. However if the infrequent infeed loss risk currently 1320MW, rises to 1800MW, then technically only one generator bay would be required.

It is also worth noting as discussed in the Stability section above that there may be a requirement for additional bays and space for either SVCs or breaking resistors at each substation. The space and bay requirements can not be determined until the actual proposed machine parameters are available and all alternative stability options have been identified.

Aust 400kV substation is likely to be of indoor Gas insulated Substation (GIS) construction, this is because of their proximity to the saline estuary, and National Grid’s pollution policy determines that indoor equipment is to be specified where this is within 5km of a saline environment. Saline pollution creates substantial flash-over risks and premature aging of asset due corrosion and failure if located outdoors.

Inner Barrage: (Aust Substation Connections)

AUST SUBSTATION 400kV
New GIS 400kV, 4000A, 63kA switchgear

Key

-  Existing Asset
-  New Generation Connection Asset
-  New Asset

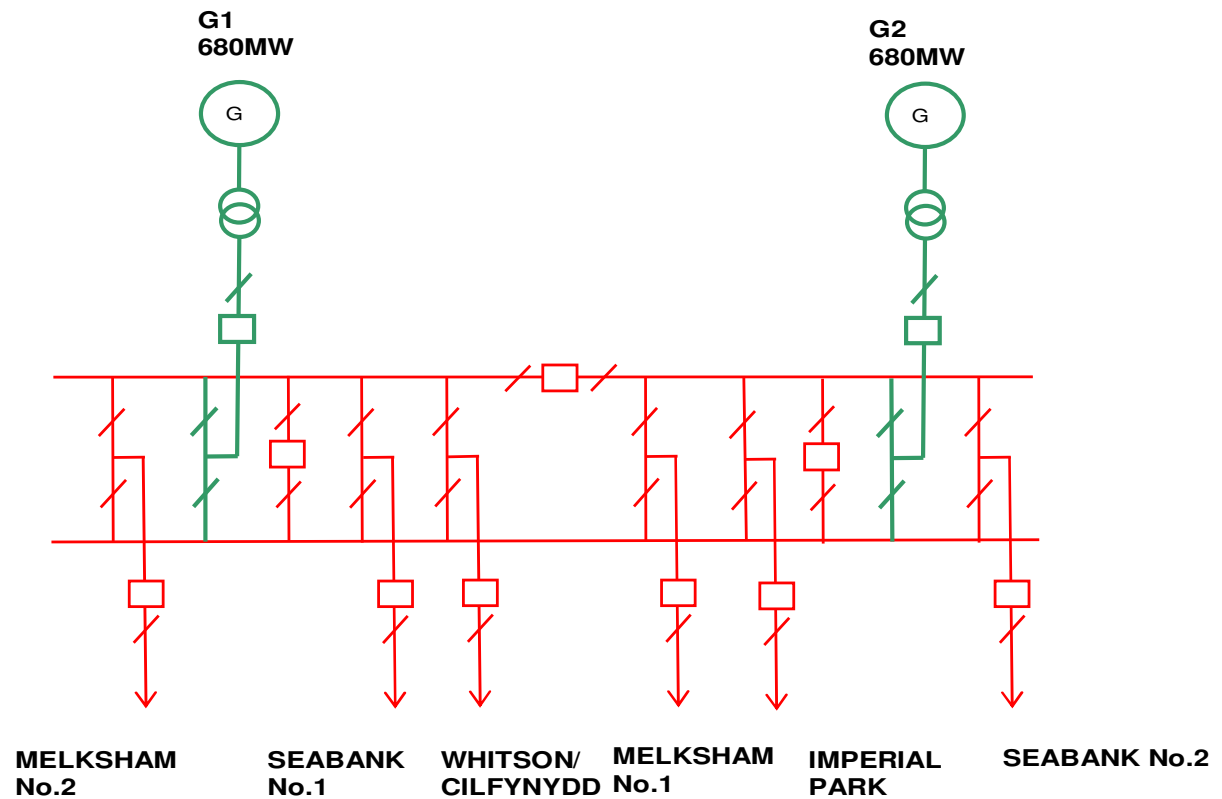


Figure 6.6.1 Generation Connection Substation at Aust for Inner Barrage.

6.7 Full Description of Local and Wider Transmission reinforcement

Figures 6.7.1 and 6.7.2 show a schematic and geographical representation of the total transmission works required to allow the connection of the inner barrage to the transmission system. These representations include all of the works identified from the studies described in the previous parts of section 6 of this report.

Table 6.7.1 has a summarised description of the work required to make the connection to the inner barrage. **Appendix 3** has a full description of works required. However in high level summary the full local and wider transmission reinforcement works consist of: -

- ◆ **Substations and Equipment**
 - ◆ 0 New substations required
 - ◆ Only extensions to Aust substation required
 - ◆ 225MVAR of Mechanically Switched Capacitors (MSC) capacity required at 1 substation location

- ◆ **OHL and Cables**
 - ◆ Approximately 5km new overhead line routes (Seabank – Aust)
 - ◆ Approximately 51km of existing overhead line reconductoring
 - ◆ No Cable Works

Inner Barrage: Aust Connection

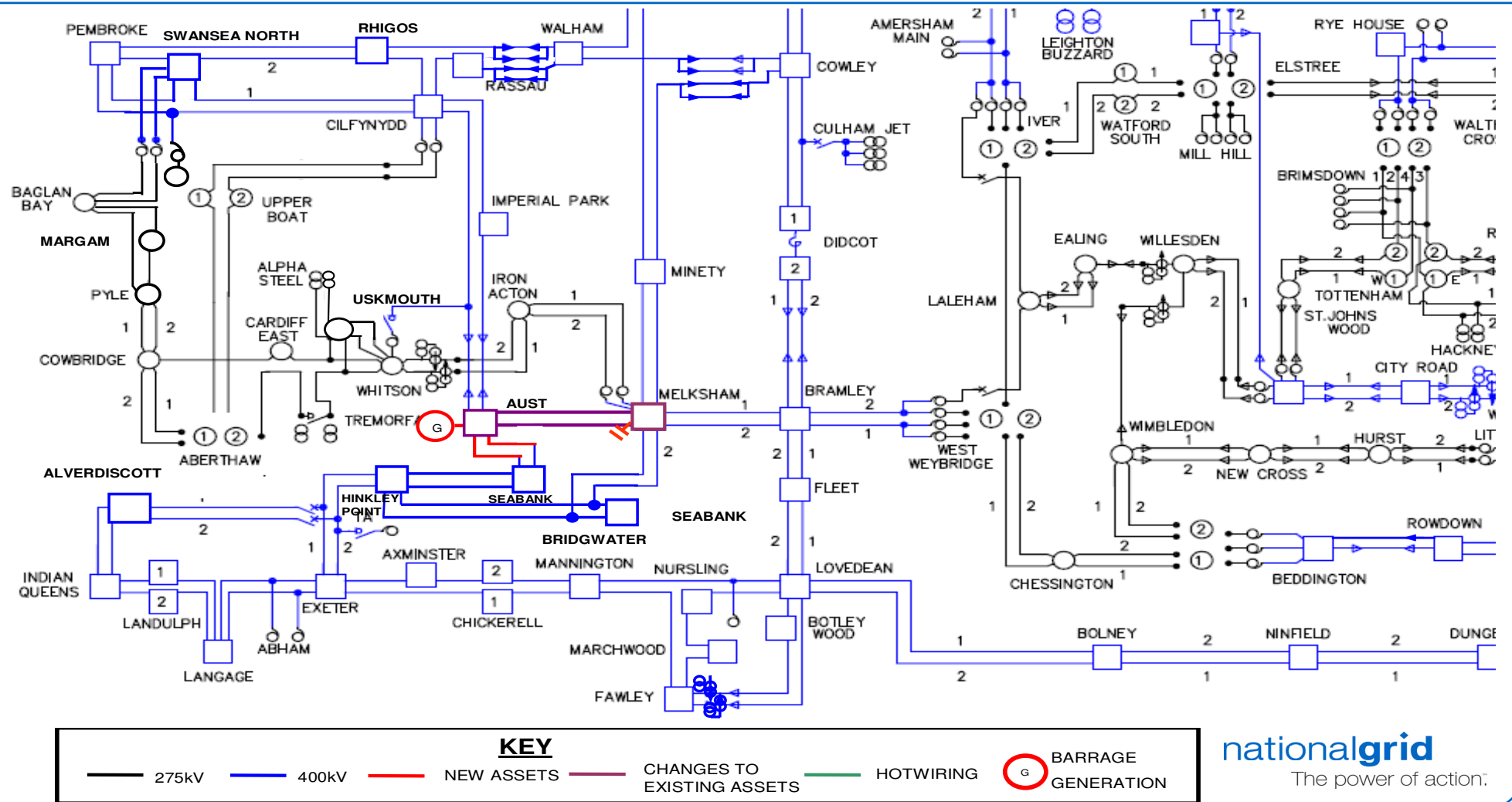


Figure 6.7.1 Total Transmission Works Inner Barrage – Aust Connection

Description of Works Inner Barrage: Aust Connection

◆ Generators

- Inner Barrage
- Aust (English Side)
1.36GW

◆ New Works

-New Substations

- None Identified

-New Equipment

- 2 x 225Mvar MSCs Melksham

-New Lines

- Seabank - Aust 5km (new section from exiting line turn-in to Aust substation) (2820MVA summer, PFC)

-New Cable Routes

- None Identified

◆ Changes to Existing

-Substations

- Aust 400kV (6F, 3GEN (skel), banked bays convert from planned 4 Switch Mesh)

-Reconductoring

- Aust – Melksham 1 & 2 400kV (2980MVA summer, PFC)

-Hotwire

- None Currently Identified

Key

F = Feeder

GEN = Generator skeletal bay

BC = Bus Coupler

BS = Bus Section

SR = Series Reactor Bay

SGT = Super Grid Transformer & Bay

PFC = Post Fault Continuous

Table 6.7.1 Description of Total Transmission Works Inner Barrage – Aust Connection

6.8 Design Options Considered

Any connection being made to South Wales above 50MW on current contracted backgrounds would require the uprating of the 400kV Severn cable tunnel as described in sections 4 and 5, at an estimated cost **>£100m** (in 2009 prices). Also any connection in Wales would require the construction of a new 400kV substation in the vicinity of the landing point at an estimated cost of **>£20m** (in 2009 prices).

Due to the contracted background flows, transmission reinforcement in South West would remain the same as described above for connection of any tidal generation made in South Wales. Therefore it is not economic and efficient to connect in South Wales, as the South Wales costs would be in addition to the South West costs for making such a connection.

6.9 Conclusions

This option of an inner barrage requires far less transmission infrastructure work to accommodate the connection of tidal generation and should be achievable in much shorter timescales than the options in sections 4 and 5. The initial cost estimate of this work is **£292m** and a high level breakdown of the costs is provided in section 11.

7 Changes in Contracted Background since Commencing Feasibility

Since commencing the feasibility study for the inner and middle barrage options National Grid has made offers which have been subsequently accepted by generation applicants. National Grid has an application process that is open to any entity seeking to connect generation to the transmission system at any point during the year. National Grid is obliged to provide an applicant with an offer of connection within 3 months of application, subject to the receipt of an application fee. When an offer is accepted by the applicant the generator moves into National Grid's contracted background. The generator is placed on the Transmission Entry Capacity (TEC) Register on National Grid's website so that public access to the information about proposed connections is available.

The applicants that National Grid has made offers to, subsequent to the commencement of this feasibility include in the South West: -

• Seabank 3 CCGT	–	950MW
• Eon Oldbury-on-Severn EPR nuclear	–	1600MW
• NDA Oldbury-on-Severn EPR nuclear	–	1600MW
• TOTAL	–	4150MW

If these generators were to be considered in the background they would have significant affect upon the design. Given that the contracted background can change at any time of the year this also shows that the design provided in the feasibility is only valid for the given background under which studies were undertaken.

Further additional detailed engineering studies would be required to fully re-evaluate the middle barrage reinforcement works as a result of these subsequent generation applications. Such additional work is currently outside the scope of National Grid study, however, set out below are the initial thoughts on the effect on the inner barrage additional works and with further comments regarding the middle barrage.

7.1 Inner Barrage Consequences

Figure 7.1.1 below shows the current connection design for Oldbury on Severn connections for two new connections and shows how the connection would have to change to accommodate the connection of **1.36GW** of tidal generation in excess of the contracted background. Figure 7.1.2 shows how these requirements affect the geographical system.

If these elements are included in the contracted background, as a minimum the following works will be required: -

- ♦ **Substations and Equipment**
 - ♦ 1 New substations required.
 - ♦ Extensions to Aust substation required
 - ♦ 1800MVar of Mechanically Switched Capacitors (MSC) capacity required at 2 substation location

- ♦ **OHL and Cables**

-
- ◆ Approximately 46km new overhead line routes (Seabank – Aust and Iron Acton Melksham)
 - ◆ Approximately 91km of existing overhead line reconductoring
 - ◆ No Cable Works

Table 7.1.1 below has a summarised description of the work required to make the connection to the inner barrage if the Oldbury and Seabank generation are included.

Affect on the Inner Barrage Connection due to the Movement in Contracted Background Since Commencing Feasibility

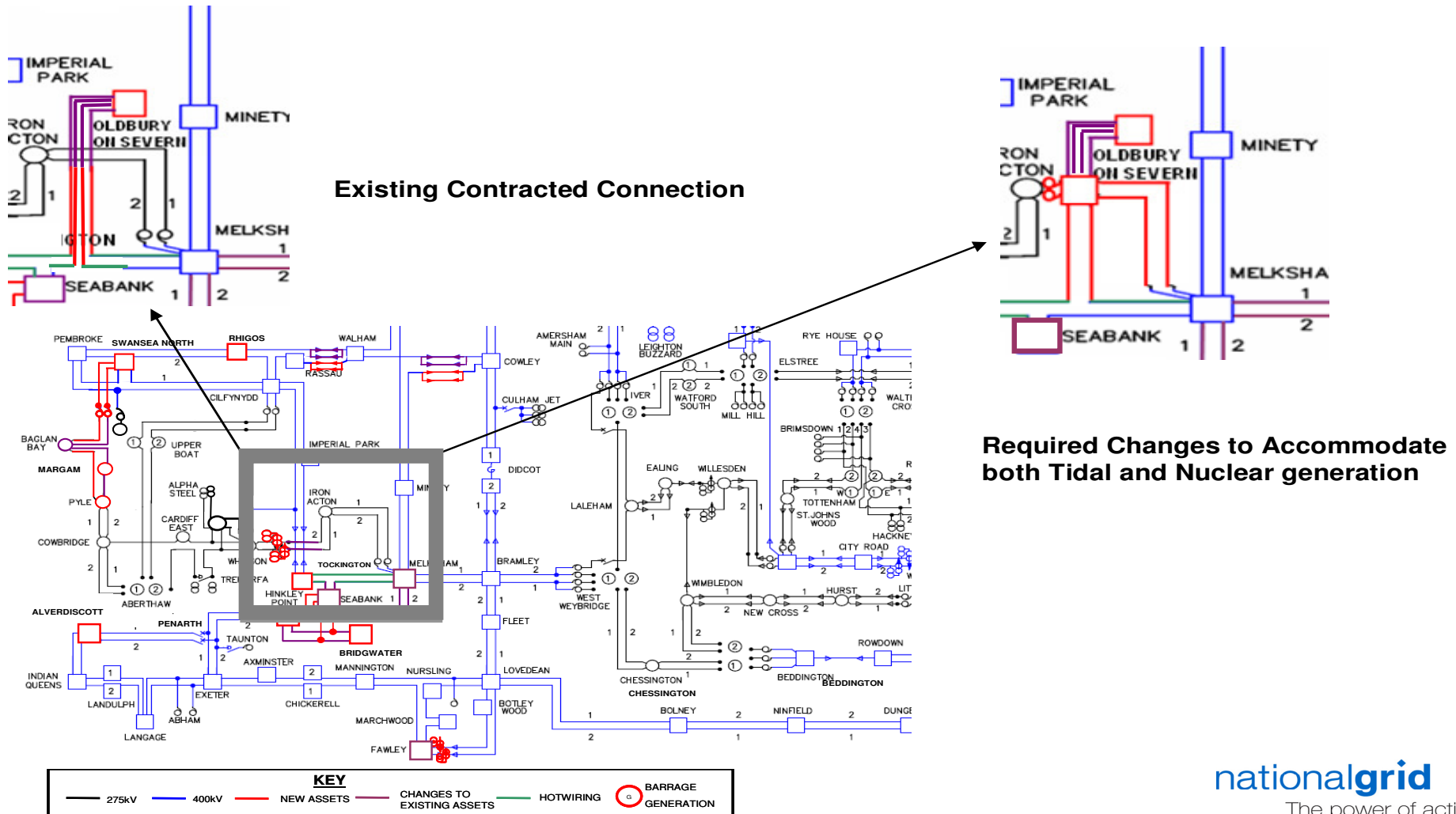


Figure 7.7.1 Affect on the Inner Barrage Connection due to the Movement in Contracted Background Since Commencing Feasibility

Geographical Affect on the Inner Barrage Connection due to the Movement in Contracted Background Since Commencing Feasibility

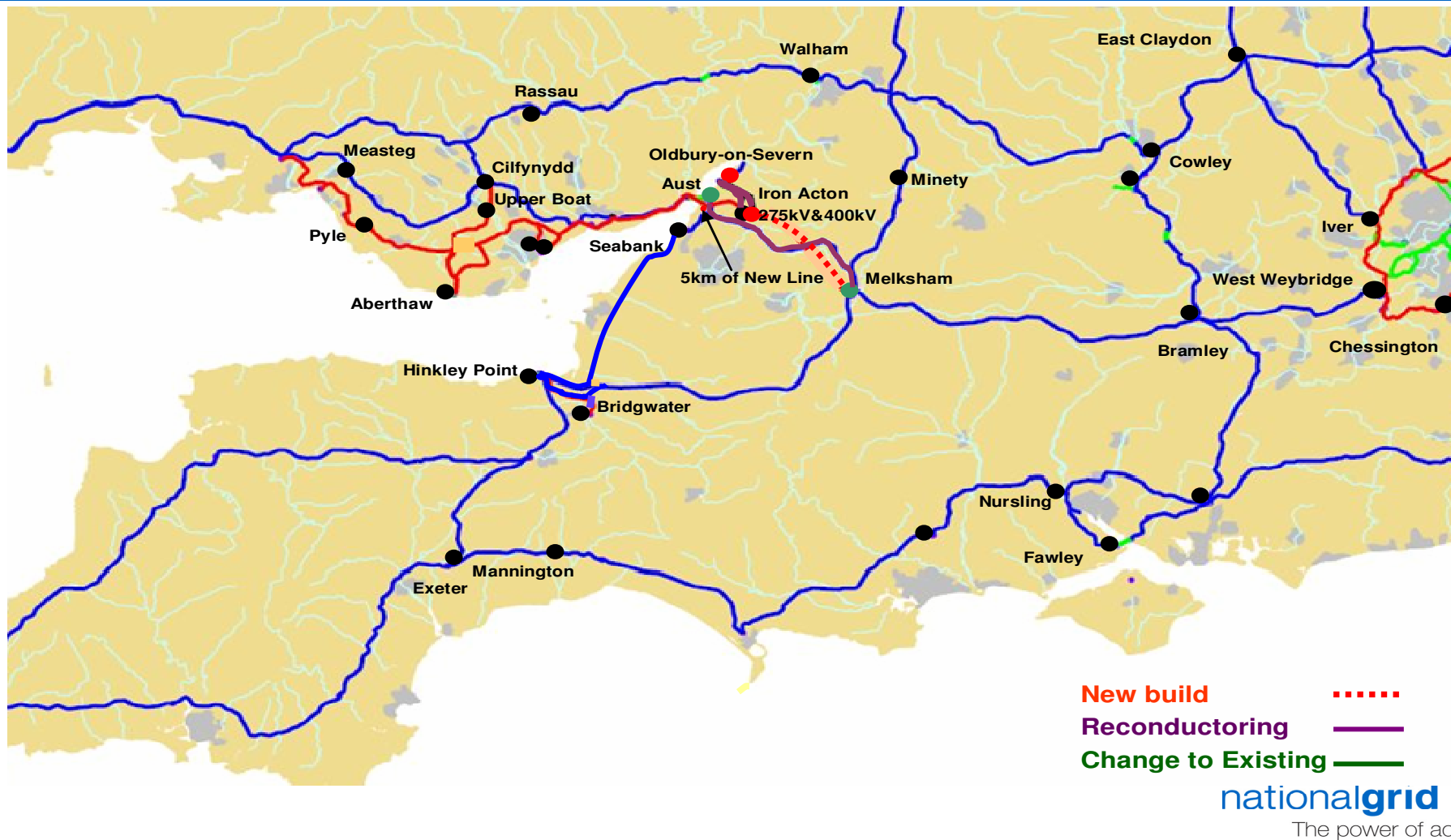


Figure 7.7.2 Geographical Affect on the Inner Barrage Connection due to the Movement in Contracted Background Since Commencing Feasibility

Description of Works inner Barrage If Oldbury and Seabank Contracted Generation Were to be Included

◆ Generators	◆ New Works	◆ Changes to Existing
<ul style="list-style-type: none"> – Shoots Barrage 1.36GW – Aust (English Side) 1.36GW 	<ul style="list-style-type: none"> – New Substations <ul style="list-style-type: none"> ▪ Iron Acton 400kV (8F, 2SGT, 4BS, 2BC) – New Equipment <ul style="list-style-type: none"> ▪ 4 x 225Mvar MSCs Melksham ▪ 2 x 225Mvar MSCs Minety – New Lines <ul style="list-style-type: none"> ▪ Seabank - Aust 6km (new section from exiting line turn-in to Aust substation) (2820MVA summer, PFC) ▪ Complete off-line Rebuild Iron Acton – Melksham at 400kV L12 towers (2820MVA summer, PFC) – New Cable Routes <ul style="list-style-type: none"> ▪ None Identified 	<ul style="list-style-type: none"> – Substations <ul style="list-style-type: none"> ▪ Aust 400kV (6F, 3GEN (skel), banked bays convert from planned 4 Switch Mesh) – Reconductoring <ul style="list-style-type: none"> ▪ Aust – Melksham 1 & 2 400kV (2980MVA summer, PFC) – Hotwire <ul style="list-style-type: none"> ▪ None Currently Identified

Key

F = Feeder

GEN = Generator skeletal bay

BC = Bus Coupler

BS = Bus Section

SR = Series Reactor Bay

SGT = Super Grid Transformer & Bay

PFC = Post Fault Continuous

Red = changes from previous inner barrage option

Table 7.7.1 Description of Works inner Barrage If Oldbury and Seabank Contracted Generation Were to be Included

There is space and land at Iron Acton to be able to build the required new 400kV substation. However, the more complex element of these possible transmission reinforcement works would be the overhead line works. The overhead line between Iron Acton 275kV and Melksham 400kV is currently an L3 275kV route.

L3 transmission towers are of smaller and structurally lighter construction and as such are not capable of being uprated to 400kV. Any 400kV route between the new Iron Acton 400kV and Melksham 400kV shall require new transmission towers to be constructed. As it would not be possible to take a double circuit outage for the duration of the construction period on the existing 275kV route, it is likely that any new overhead line would have to be constructed off line, adjacent to the existing. This means that land space and routing options would be required for this overhead line which would be very difficult to achieve.

7.2 Middle Barrage Consequences

As a minimum the works described above for the inner barrage are also going to be required for the Middle barrage. It is very likely that additional transmission reinforcement work would be required, possibly requiring the re-inclusion of the Bridgwater – Nursling 400kV line in addition to circuits across the barrage. Voltage and Stability issues are also likely to be significantly worse with an additional **4.1GW** of generation exporting from the South Wales and South West transmission groups.

8 Fault Level Impacts on interfaces with Distribution Network Operators

This section identifies the effects on third party Distribution Network Operator (DNO) Grid Supply Points (GSP) as a consequence of the considered connection options.

- Table 8.1 shows effects due to the middle barrage with no transmission circuits across it
- Table 8.2 shows effects due to the middle barrage with AC transmission circuits across the barrage
- Table 8.3 shows effects due to the inner barrage option

The columns in tables 8.1, 8.2 and 8.3 show;

- The first section of busbar which is affected and the type of fault causing the rating issue, single or three phase fault
- The green column shows the RMS rating of the breaker given by the manufacturer;
- The purple column shows the de-rated capability based on the DC time constant seen on the transmission system verses that at which the circuit breaker was tested.
- The yellow column is the RMS duty of the breaker seen during the analytical study, which the breaker would see during operation
- The blue column shows how the output of the study, yellow column, compares with the derated RMS figure, purple column.

It is clear to see that some of the GSPs show increases to fault infeed. It is highly likely that there will be a significant effect to the DNO's network also, which may require additional reinforcement by the relevant DNO.

The DNO's most likely to be affected by the connection of the tidal generation schemes in the Severn estuary are: -

- Western Power Distribution – South Wales
- Western Power Distribution – South West
- Scottish and Southern Energy – South England.

Each of these DNO's would likely have to complete full assessment of their systems following the acceptance an offer made by National Grid. The additional works required by the DNO would normally be classed as third party works, to be resolved between the applicant and DNO.

		Contracted				Middle Barrage without Transmission circuits				
Fault Node	Fault Type	Breaker Rating RMS (kA)	DC time Derating RMS (kA)	Fault Duty RMS (kA)	% of derated rating	Breaker Rating RMS (kA)	DC time Derating RMS (kA)	Fault Duty RMS (kA)	% of derated rating	% Increase on contracted
BEDD11	ONE	15	14	14	98.65%	15	12	13	115.73%	17.08%
CARE10	ONE	25	25	25	99.32%	25	22	25	111.81%	12.49%
MANN10	ONE	32	29	28	99.10%	32	25	28	110.36%	11.26%
BEDD12	ONE	15	14	13	93.75%	15	12	13	110.11%	16.36%
CARE10	THREE	20	20	20	96.82%	20	18	19	103.21%	6.39%
CHIC10	ONE	15	12	12	97.80%	15	12	12	97.88%	0.09%

Table 8.1 DNO fault level increases for Middle Barrage with no circuits across the barrage

		Contracted				Middle Barrage with Transmission circuits				
Fault Node	Fault Type	Breaker Rating RMS (kA)	DC time Derating RMS (kA)	Fault Duty RMS (kA)	% of derated rating	Breaker Rating RMS (kA)	DC time Derating RMS (kA)	Fault Duty RMS (kA)	% of derated rating	% Increase on contracted
BEDD11	ONE	15	14	14	98.65%	15	12	13	115.65%	17.00%
CARE10	ONE	25	25	25	99.32%	25	22	25	112.28%	12.97%
BEDD12	ONE	15	14	13	93.75%	15	12	13	110.03%	16.28%
CARE10	THREE	20	20	20	96.82%	20	18	19	103.73%	6.91%
PEMB10	ONE	18	14	14	98.19%	18	14	14	98.55%	0.36%
CHIC10	ONE	15	12	12	97.80%	15	12	11	97.32%	-0.48%

Table 8.2 DNO fault level increases for Middle Barrage with circuits across the barrage

		Contracted				Inner Barrage				
Fault Node	Fault Type	Breaker Rating RMS (kA)	DC time Derating RMS (kA)	Fault Duty RMS (kA)	% of derated rating	Breaker Rating RMS (kA)	DC time Derating RMS (kA)	Fault Duty RMS (kA)	% of derated rating	% Increase on contracted
CARE10	ONE	25	25	25	99.32%	25	22	24	109.32%	10.01%
CARE10	THREE	20	20	20	96.82%	20	18	18	100.65%	3.83%

Table 8.3 DNO fault level increases for Inner Barrage

9 Stability Issues Associated with all Severn Tidal Options

As noted in the earlier sections of this report, the maintenance of power system stability during system disturbances is a major issue. This issue is attributable in part to the very low inertia constant of the Generating Units. During investigations with industry contacts National Grid has established that bulb type generators as proposed for use in the Severn Tidal Project are available with inertia constants of approximately 1.5 MWs/MVA.

When the Severn Tidal Project was originally investigated by the Central Electricity Generating Board (CEGB), inertia constants in the region of 1.6 to 1.8MWs/MVA were considered desirable. National Grid would also comment that an increase in the inertia constant would help to relive some of these most onerous issues.

There are a number of ways in which the stability issues can be resolved, some of which can be achieved by changes to the generating unit design (for example increasing the inertia constant, improved excitation, fast valving) or the installation of additional ancillary equipment such as SVC's or Breaking Resistors.

As indicated in the main study sections, it should be possible to overcome some, if not all, of the stability issues through a range of measures. Of those measures studied, an improvement in the inertia constant together with the installation of ancillary equipment such as SVC's and/or braking resistors would substantially improve the situation. However as part of an overall optimum design, National Grid would need to consider all possible stability enhancements including the options available to the Generating Unit manufacturers.

Some of the barrage options indicated very fast Critical Clearance times in the order of 40ms would be required. National Grid would not consider anything faster than 80ms as this would require substantial protection issues to be resolved to provide confidence in this protection operating time. National Grid would normally consider worst case credible protection operating times in the order of 140ms. Therefore as part of the detailed design of any such connection, these issues would need to be resolved.

As an alternative to mitigate fault level and stability issues, one solution would be consideration of a DC System to facilitate connection of the Generation, thereby isolating the barrage from the main AC Transmission System. However, the costs and technical issues associated with such a scheme would need to be considered and assessed before it is progressed further.

10 Comments on Utilisation of Alternative Transmission Technologies

There are several technologies contained within this feasibility study that National Grid does not currently have installed upon its transmission system. However, it is expected that through improvements in design, technology and economic viability, these items will be used in increasing numbers on the National Grid transmission system. The technologies specifically referred to in this feasibility include series compensation and HVDC Voltage Source Converter (VSC) technology.

Series Compensation

For the middle barrage options, there is a requirement to install 35% series compensation for stability purposes on the following overhead line routes.

- Nursling – Bridgwater 400kV (No circuits across the barrage only)
- Minety – Cowley/Feckenham 400kV
- Melksham – Bramley circuits 400kV

Series compensation is used elsewhere in the world quite successfully, albeit the vast majority of applications are on long radial transmission circuits. National Grid is considering the use of series compensation for other issues on its network, in the case of Severn tidal its main purpose would be to resolve stability issues, although it does also improve thermal flows on the network.

A significant challenge presented by the utilisation of this technology is its dynamic interaction with other equipment on the transmission network and on those connected to the transmission network. National Grid must carefully evaluate the required performance metrics to ensure installation of these devices does not have an adverse impact upon its assets, those of its customers or upon network reliability and resilience.

These technical issues, within the timescales of a proposed barrage project, are considered to be resolvable and National Grid is currently investigating the technology in detail.

HVDC Voltage Source Converter (VSC) technology

The options identified for circuits across a middle barrage included the possible use of HVDC VSC technology. This proposal was made to better manage system stability and contain fault levels, as compared to solutions using AC circuits. For the AC solutions, system stability is particularly difficult to manage and may require substantial additional expenditure to resolve.

HVDC VSC technology has currently not been designed at capacities above 500 MW and this project would need a capacity in the order of 2-4GW. However National Grid is again looking into the technology in great detail and would seek to engage the HVDC suppliers in achieving a viable solution for this option if it is proved to be economic.

Current Source HVDC technology would not be suitable in this case, where system stability issues are the main driver. The reactive support the VSC technology provides during transmission faults is essential to maintain system stability.

Conclusions

The two technologies identified are not an exhaustive list of technologies being considered by National Grid, however they are the main areas of focus required for connecting Severn Tidal technologies of the magnitude proposed. National Grid is constantly reviewing technologies to make appropriate use of any suitable innovations which prove economic whilst having no detrimental or adverse affect on the Transmission System and its connected customers.

11 Indicative Costs

Costs produced in this report are done on the basis of National Grid's Investment Procedure level 1 (IP1) documents. These IP1 documents are desk top high level costing exercises using the equipment identified during the studies and ascertaining costs based on historical costs. These IP1 models cannot take into account the unique nature of each physical site proposed and costs associated with elements which will only be defined in detailed design.

The IP1 model's forecast costs are in 2009 prices.

Table 11.1 below shows the indicative cost for each option based upon the National Grid IP1 costs.

Equipment Type	1 (Middle Barrage - No circuits across barrage) (£m)	2 (Middle Barrage - With circuits across barrage) (£m)	2A (Middle Barrage – With Circuits across the barrage DC option) (£m)	3 (Inner Barrage) (£m)
New Substations + Equipment	£739.31m	£725.19m	£725.19m	£0
Existing Substations + Equipment	£334.81m	£297.27m	£297.27m	£67.68m
New Lines	£334.19m	£88.32m	£88.32m	£12.64m
Reconductoring	£588.66m	£288.99m	£288.99m	£53.00m
Cable Upgrades	£44.07m	£44.07m	£44.07m	£0
New Cables and Tunnels (including DC convertors and cables in DC option)	£144.51m	£646.21m	£648.99m	£0
River Crossings	£4.01m	£4.01m	£4.01m	£0
TOTAL (£m)	£2,190m	£2,094m	£2,097m	£133m
Minimal Additional costs for changes in contracted background set out in Section 7	£158.92m	£158.92m	£158.92m	£158.92m
TOTAL + Contractual (£m)	£2,349m	£2,253m	£2,256m	£292m

Table 11.1 Severn Tidal Generation Options indicative IP1 costs

Middle Barrage Cost Commentary

As table 1.1 indicates, costs for the middle barrage options are broadly similar. The highest cost option is the middle barrage with no transmission circuits across the structure. This cost difference is mainly due to the amount of circuit infrastructure reinforcement required throughout the South West, which falls away under options with transmission circuits across the barrage.

The AC and DC circuits across the barrage have a broadly similar cost. The AC circuits would have to span some 25km of the barrage structure, and would include at least two cables per phase. There would also need to be a short section of Gas insulated Busbar (GIB) in any AC circuits to traverse the shipping locks located within the barrage structure.

With the number of cables, GIB and additional substation infrastructure required with an AC option, the indicative costs with a DC option fall broadly in line with AC. However, it should be noted, that the final construction cost of Voltage Source Converter (VSC) technology is an unknown at this time and the costs of a converter of the size proposed in this report are based on indicative supplier costs for such technology.

Inner Barrage Cost Commentary

Table 1.1 shows the indicative costs for the inner barrage are much lower due to the reduced power injection seen for this option. These costs are an order of magnitude below the middle barrage option. However the costs do increase significantly if the current contracted background including Oldbury and Seabank generation are included due to the increased reinforcement requirements.

12 Construction Timescales and High Level Issues

As stated in the earlier sections of this report, National Grid has significant current contracted positions initially between 2009 and 2018. With the recent changes to the contracted position this now extends even further into the early 2020s. The existing contracted generation has firm connection dates, which they have accepted and as such National Grid has a contractual commitment to deliver their connections.

Access to the transmission system is determined by the work on any transmission assets in any one year and the requirement to meet the NETS SQSS while this work is being undertaken. As such it is only possible to work on a finite number of assets in any one year within each region of the transmission system. As an example the contracted works within the south west out to 2018, utilises the full outage availability between 2012 – 2018.

Works for the proposed tidal generation, especially for any of the middle barrage options, would take multiples of years to complete. **The system access required for a single generation project would be unprecedented and would significantly restrict access to any other generation applicants in South Wales and the South West for a number of years.**

Each option is discussed below in turn and the high level issues shall be raised. However, given the current options have been considered at a desk top level only, the indicative dates represent National Grid's best view at this time and would be reconsidered as part of any application.

12.1 Middle Barrage without transmission circuits across the barrage

Given the current National Grid transmission access requirements needed to meet the existing contracted background between 2009 and 2018 in particular, it is not possible to meet a connection date of 2021 for the middle barrage.

The main issues driving the connection date for this option are the requirements to construct a number of new overhead line routes and new substations. The overhead line routes in particular shall require significant investigation and option development before they could proceed to the Infrastructure Planning Committee (IPC). As the longest of these lines between Bridgwater and Nursling, are likely to need to traverse Sites of Special Scientific Interest (SSSI), some of the routing and design issues will take a significant amount of time.

Reconductoring of the South West overhead line circuits between Hinkley Point – Taunton – Exeter – Axminster – Chickerell – Mannington, and all the South Wales overhead line works would require consecutive years of system access to complete. However the access to the South Wales system could be accommodated sooner, as the current South Wales contracted position does not extend beyond 2016 at the time of writing this report.

The new connection substations to the South of Weston-Super-Mare and the South of Penarth, with their associated lines would represent the most onerous new substation builds. This is because the majority of the other substations proposed for this option are at, or adjacent to, existing National Grid substations, however the new connection points represent unknown quantities to National Grid.

The proposed indicative connection date based on studied contracted background and desktop analysis for this option would be 2024-2026.

12.2 Middle Barrage with AC or DC transmission circuits across the barrage

The advantage of this scheme based on the studied background is that the majority of South West transmission works falls away. Therefore access to the transmission system and resource issues are not as great. **However, it may still not be possible to meet a connection date of 2021 for the middle barrage.**

The main issues driving the connection date for this option remain the requirements to construct a number of new overhead line routes and new substations. However, with the new overhead line routes in particular being reduced for this option, the investigation and option development before the Infrastructure Planning Committee (IPC) would be less onerous.

The new connection substations to the South of Weston-Super-Mare and the South of Penarth, with their associated lines would still represent the most onerous new substation builds. This is because the majority of the other substations proposed for this option are at, or adjacent to, existing National Grid substations, however the new connection points represent unknown quantities to National Grid.

With the HVDC transmission option there would also be a requirement to establish Voltage Source Converter (VSC) stations at the substations South of Penarth and Weston-Super-Mare. This would require a sizable amount of additional land at each location and would add to the significant design implications at each site.

The proposed indicative connection date based on studied contracted background and desktop analysis for this option would be **2021-2023**.

12.3 Inner Barrage

The inner barrage option has the least amount of transmission reinforcements associated with it. However the biggest risk to meeting the preferred connection date for this option is the new works required when Oldbury-on-Severn and Seabank connection schemes are considered in the background. These issues could be managed but the requirement for a new line between Iron Acton and Melksham at 400kV would be difficult to achieve.

The proposed indicative connection date based on studied contracted background and desktop analysis for this option would be **2019-2021**.

12.4 Construction Conclusions

All of the options should be constructible and all have particular consents issues which shall need to be overcome. The biggest risk to providing a deliverable date shall be subsequent changes in the contracted background prior to the receipt of an application for any Severn Tidal Generation. Table 12.4.1 below gives the overview for the proposed connection date for each option.

Tidal Generation Option	1 (Middle Barrage - No circuits across barrage)	2 (Middle Barrage - With circuits across barrage)	2A (Middle Barrage – With Circuits across the barrage DC option)	3 (Inner Barrage)
Indicative Connection Dates	2024-2026	2021-2023	2021-2023	2019-2021

Table 12.4.1 Severn Tidal Generation Options indicative connection dates

13 High Level Consents View

The scope of works outlined in this Report has not included consideration of the planning and environmental issues that would be associated with the various transmission reinforcements. Nevertheless, there would be significant environmental and planning issues associated with many of the reinforcements described.

Currently the installation of any new overhead transmission line requires the consent of the Secretary of State and new substations generally require planning permission from the relevant local planning authority. Following the implementation of the Planning Act 2008 in England and Wales, overhead transmission lines are defined as 'Nationally Significant Infrastructure Projects' and a 'Development Consent Order' would be required from the Infrastructure Planning Commission (IPC). Associated development works at new or existing substation sites can be included in DCO applications for related overhead line works and determined by the IPC in England. In Wales, it will continue to be necessary to apply for planning permission for substation development to the relevant local planning authority.

The Planning Act and related Regulations place significant onus on the developer to robustly consider all alternative solutions and undertake an extensive consultation process. National Grid also has a statutory duty to consider amenity issues when developing new works and is strongly committed to the adoption of best practice in these respects. National Grid's commitments are set out in its Stakeholder, Community and Amenity policy document, a copy of which is included at Appendix 4.

A Development Consent Order or Orders (and other statutory consents) would clearly be required for many of the reinforcements discussed in this Report. For any significant new works this is likely to involve in-depth consideration of options, routeing or siting studies (including confirmation of viable system solutions), extensive stakeholder consultation, and formal environmental impact assessment. These processes are likely to take several years to complete and give rise to widespread public interest.

National Grid would suggest that the environmental and community impacts of the possible works to the *transmission system* associated with each of the barrage designs should be considered, at an appropriate level, as part of any Strategic Environmental Assessment for the barrage and when selecting a final design. The environmental impact of the transmission system works should also be considered as an *associated effect* of any specific barrage proposal and the related *cumulative effects* assessed.

14 Conclusions and Recommendations

This feasibility study has considered three main options for connecting tidal generation in the Severn Estuary to the National Grid Transmission System. The options considered are as follows: -

- **8.64GW** Middle Barrage without Transmission Circuits Across the barrage.
- **8.64GW** Middle Barrage with either AC or DC Transmission Circuits Across the barrage.
- **1.365GW** Inner Barrage.

Each of these options has been considered in detail looking at the analytical system issues, required reinforcements, Investment Procedure Level 1 costs, construction and consents issues. Table 14.1 summarises the indicative latest contractual background cost and indicative proposed connection dates for each option.

	1 (Middle Barrage - No circuits across barrage)	2 (Middle Barrage - With circuits across barrage)	2A (Middle Barrage – With Circuits across the barrage DC option)	3 (Inner Barrage)
	(£m)	(£m)	(£m)	(£m)
Generation MW	8.64GW	8.64GW	8.64GW	1.365GW
Indicative Connection Dates	2024-2026	2021-2023	2021-2023	2019-2021
TOTAL + Contractual (£m)	£2,349m	£2,253m	£2,256m	£292m

Table 14.1 Severn Tidal Generation Options indicative costs and indicative connection dates

Middle Barrage

The middle barrage options, both with and without transmission circuits across the barrage structure, would represent significant reinforcement projects for National Grid. To maintain compliance with the NETS SQSS a significant amount of the South Wales and South West transmission system requires upgrading. In addition to this a significant amount of new transmission infrastructure is required including a number of new overhead lines.

If no transmission circuits are taken across the barrage, a significant new overhead line will be required from Bridgwater – Nursling 400kV. This is envisaged to be a highly contentious overhead line route as it would be 125km in length and could need to cross Sites of Special Scientific Interest.

To avoid the requirement to construct an overhead line between Bridgwater and Nursling the use of AC or DC transmission circuits should be considered crossing the barrage structure. This option also relieves the need to undertake significant infrastructure work throughout the South West and, as Table 14.1 indicates, an earlier connection date could be achievable.

Both Middle Barrage options have significant stability issues to overcome to maintain compliance with the NETS SQSS. As such, serious consideration needs to be given to ensuring any generator selected for the tidal project has an inertia constant in the order of 1.5 MWs/MVA as a minimum. In addition to this National Grid shall need to consider the use of series compensation, static variable compensators or other technology to ensure system stability is maintained.

An alternative to overcoming some of the stability issues by conventional AC means, National Grid can consider the use of Voltage Source Converter (VSC) HVDC technology for circuits across the barrage. This option would help maintain stability of the transmission system and does have a reduced space requirement for cables being contained within the barrage.

The best balance of power injection for all middle barrage options is to split the generation equally between Wales and England. Further increases of power generated on either side represent significant increases in fault levels and stability issues for all options.

Inner Barrage

The inner barrage option has far less infrastructure work associated with it due to the much lower power injection. However, there is a requirement to ensure all the power is injected on the English side to minimise infrastructure works.

Any connection being made to South Wales above 50MW on current contracted backgrounds would require the uprating of the 400kV Severn cable tunnel as described in sections 4 and 5, at an estimated cost >£100m (in 2009 prices). Also any connection in Wales would require the construction of a new 400kV substation in the vicinity of the landing point at an estimated cost of >£20m (in 2009 prices).

Due to the contracted background flows, transmission reinforcement in South West would remain the same as described above for connection of any tidal generation made in South Wales. Therefore it is not economic and efficient to connect in South Wales, as the South Wales costs would be in addition to the South West costs for making such a connection.

The Inner Barrage option also has stability issues to overcome to maintain compliance with the NETS SQSS. As such, serious consideration needs to be given to ensuring any generator selected for the tidal project has an inertia constant in the order of 1.5 MWs/MVA as a minimum. An inertia constant of this magnitude may be large enough to overcome all the stability issues associated with the inner barrage scheme.

All options

The selection of a generator type for all the options with the provision of network data for any subsequent application shall be key to ensuring a viable connection offer can be made.

The contracted background is subject to change at any time, however from the feasibility assessment carried out for tidal generation in the Severn Estuary, National Grid should be able to provide a viable connection solution for all options studied subject to gaining the required consents.

15 Appendices

Appendix 1: The proposed wider transmission reinforcement works for the Middle Barrage without transmission circuits across the barrage option are:-

- ◆ **New Works**
 - ◆ **New Substations**
 - ◆ **Pyle 400kV**
(4 Feeder Circuits, 2 Super Grid Transformers and Bays, 2 Bus Couplers and 1 Bus Section)
 - ◆ **Measteg 400kV**
(6 Feeder Circuits, 2 Bus Couplers and 1 Bus Section)
 - ◆ **Aberthaw 400kV**
(8 Feeder Circuits, 2 Super Grid Transformers and Bays, 2 Bus Couplers and 4 Bus Sections)
 - ◆ **Upperboat 400kV**
(4 Feeder Circuits, 3 Super Grid Transformers and Bays, 1 Bus Coupler and 1 Bus Section)
 - ◆ **Bridgwater 400kV**
(4 Feeder Circuits, 2 Super Grid Transformer Bays and 1 Bus Section)
 - ◆ **West Weybridge 400kV**
(4 Feeder Circuits 2 Super Grid Transformer Bays, 2 Bus Couplers and 1 Bus Section)
 - ◆ **Iver 400kV**
(3 Feeder Circuits 2 Super Grid Transformer Bays, 2 Bus Couplers and 1 Bus Section)
 - ◆ **Beddington 400kV**
(3 Feeder Circuits, 3 Super Grid Transformer Bays, 2 Bus Couplers and 1 Bus Section)
 - ◆ **Chessington 400kV**
(1 mesh Circuit Breaker, 2 Super Grid Transformers and Bays)
 - ◆ **Penarth 400kV**
(4 Feeder Circuits, 3 Generator Skeletal Bays, 2 Bus Couplers and 4 Bus Sections)
 - ◆ **Weston 400kV**
(4 Feeder Circuits, 3 Generator Skeletal Bays, 2 Bus Couplers and 4 Bus Sections)
 - ◆ **Puriton tee 400kV Line breakers**
(6 Feeder Circuits)
 - ◆ **New Equipment**
 - ◆ 2 x 225Mvar MSCs Aust
 - ◆ 2 x 225Mvar MSCs Cilfynydd
 - ◆ 2 x 225Mvar MSCs Walham
 - ◆ 2 x 225Mvar MSCs Minety
 - ◆ 4 x 225Mvar MSCs Melksham
 - ◆ 2 x -75/150 MVA SVC's at Nursling
 - ◆ Quad boosters at Melksham 400kV (2750MVA PFC)
 - ◆ **New Lines**
 - ◆ Pyle – Measteg 9km 400kV (2820MVA summer, PFC)
 - ◆ Bridgwater – Nursling 125km (2820MVA summer PFC)
 - ◆ 2 x Double Circuits Penarth – Aberthaw 18km each (2820MVA summer PFC)
 - ◆ Aberthaw – Cardiff East 19km (1010MVA winter PFC)
 - ◆ 2 x Double Circuits Weston Spur (Hinkley Point –Seabank) 9km each (2820 summer PFC)

-
- ◆ **New Cable Routes**
 - ◆ 2nd Severn Cable tunnel and Circuit (IMPP-AUST, CILF-WHSO-AUST 3000MVA cyclic year round rating)
 - ◆ Double cables in chilling tunnel (FAWL-BOTW, FAWL-LOVE 3000MVA cyclic year round rating)

 - ◆ **Changes to Existing Substations**
 - ◆ Nursling 400kV (8 Feeder circuits, 3 SGT(bay only), 2 Bus couplers and 1 Bus section)

 - ◆ **Reconductoring**
 - ◆ Measteg – Cilfynydd 400kV 1 & 2 (2980MVA summer, PFC)
 - ◆ Aust – Melksham & Aust – Seabank, Seabank Melksham L6 sections 1(2980MVA summer, PFC)
 - ◆ Aust - Whitson – Cilfynydd & Aust – Imperial Park, Imperial Park – Cilfynydd 400kV (2980MVA summer, PFC)
 - ◆ Aberthaw – Pyle 400kV 1 & 2 (re-rating from 275kV (2820MVA summer,PFC)
 - ◆ Aberthaw – Upper Boat 400kV 1 & 2 (re-rating from 275kV) (2820MVA summer,PFC)
 - ◆ Cilfynydd – Upper Boat 400kV 1 & 2 (re-rating from 275kV) (2820MVA summer,PFC)
 - ◆ Mannington – Nursling 400kV 1 & 2 (2980MVA summer, PFC)
 - ◆ Nursling – Fawley & Fawley – Marchwood, Marchwood - Nursling 400kV 1 & 2 (2980MVA summer, PFC)
 - ◆ Lovedean – Nursling 400kV 1 & 2 (2980MVA summer, PFC)
 - ◆ Chessington – Beddington 400kV single cct (up-rate from 275kV) (2980MVA summer, PFC)
 - ◆ Chessington – West Weybridge 400kV single cct (up-rate from 275kV) (2980MVA summer, PFC)
 - ◆ West Weybridge – Iver 400kV single cct (up-rate from 275kV) (2980MVA summer, PFC)
 - ◆ Cilfynydd to Rassau (2960MVA summer PFC)
 - ◆ Hinkley Point – Taunton – Exeter 1 & 2 (2960MVA summer PFC)
 - ◆ Exeter – Axminster – Chickerell 1 & 2 (2960MVA summer PFC)
 - ◆ Chickerell – Mannington 1 & 2 (2960MVA summer PFC)
 - ◆ Aberthaw – Cardiff East – Uskmouth – Whitson & Aberthaw – Tremorfa – Uskmouth – Whitson (including USK crossing) 275kV (1010MVA winter PFC)

 - ◆ **Hotwire**
 - ◆ None currently identified

Appendix 2: The proposed wider transmission reinforcement works for the Middle Barrage with transmission circuits across the barrage option are:-

- ◆ **New Works**
 - ◆ **New Substations**
 - ◆ **Measteg 400kV**
(6 Feeder Circuits, 2 Bus Couplers and 1 Bus Section)
 - ◆ **Pyle 400kV**
(4 Feeder Circuits, 2 Super Grid Transformers and Bays, 2 Bus Couplers and 1 Bus Section)
 - ◆ **Aberthaw 400kV**
(6 Feeder Circuits, 2 Super Grid Transformers and Bays, 2 Bus Couplers and 4 Bus Section)
 - ◆ **Upperboat 400kV**
(4 Feeder Circuits, 3 Super Grid Transformers and Bays, 1 Bus Coupler and 1 Bus Section)
 - ◆ **West Weybridge 400kV**
(4 Feeder Circuits, 2 Super Grid Transformer Bays, 2 Bus Couplers and 1 Bus Section)
 - ◆ **Iver 400kV**
(3 Feeder Circuits, 2 Super Grid Transformer Bays, 2 Bus Couplers and 1 Bus Section)
 - ◆ **Beddington 400kV**
(3 Feeder Circuits, 3 Super Grid Transformer Bays, 2 Bus Couplers and 1 Bus Section)
 - ◆ **Chessington 400kV**
(1 mesh circuit breaker and 2 Super Grid Transformers and Bays)
 - ◆ **Penarth 400kV**
(4 Feeder Circuits, 3 Generator Skeletal Bays, 2 Bus Couplers, 4 Bus Sections and 2 Shunt Reactor Bays)
 - ◆ **Weston 400kV**
(6 Feeder Circuits, 3 Generator Skeletal Bays, 2 Bus Couplers, 4 Bus Sections and 2 Shunt Reactor Bays)
- ◆ **New Equipment**
 - ◆ 2 x 225Mvar MSCs Aust
 - ◆ 2 x 225Mvar MSCs Cilfynydd
 - ◆ 2 x 225Mvar MSCs Walham
 - ◆ 4 x 225Mvar MSCs Minety
 - ◆ 6 x 225Mvar MSCs Melksham
 - ◆ 2 x -75/150 MVAR SVC's at Nursling
 - ◆ Quad boosters at Melksham 400kV (2750MVA PFC)
 - ◆ 2 x 200MVAR shunt reactor Penarth
 - ◆ 2 x 200MVAR Shunt reactor Weston Super - Mare
- ◆ **New Lines**
 - ◆ Pyle – Measteg 9km 400kV (2820MVA summer, PFC)
 - ◆ Single Circuit Penarth – Aberthaw 18km (2820MVA summer PFC)
 - ◆ Aberthaw – Cardiff East 19km (1010MVA winter PFC)
 - ◆ 2 x Double Circuits Weston Spur (Hinkley Point – Seabank) 9km each (2820 summer PFC)
- ◆ **New Cable Routes**
 - ◆ 2nd Severn Cable tunnel and Circuit (IMPP-AUST, CILF-WHSO-AUST 3000MVA cyclic year round rating)
 - ◆ Double cables in chilling tunnel (FAWL-BOTW, FAWL-LOVE 3000MVA cyclic year round rating)
 - ◆ Weston – Penarth 1 & 2 400kV across barrage (3000MVA cyclic rating each)

◆ **Changes to Existing**

◆ **Substations**

- ◆ Nursling 400kV (8 Feeder circuits, 3 Super Grid Transformer Bays, 2 Bus Couplers and 1 Bus Section)

◆ **Reconductoring**

- ◆ Aust - Whitson – Cilfynydd & Aust – Imperial Park, Imperial Park – Cilfynydd 400kV (2980MVA summer, PFC)
- ◆ Aberthaw – Pyle 400kV 1 & 2 (re-rating from 275kV (2820MVA summer, PFC)
- ◆ Aberthaw – Upper Boat 400kV 1 & 2 (re-rating from 275kV) (2820MVA summer, PFC)
- ◆ Cilfynydd – Upper Boat 400kV 1 & 2 (re-rating from 275kV) (2820MVA summer, PFC)
- ◆ Chessington – Beddington 400kV single cct (up-rate from 275kV) (2980MVA summer, PFC)
- ◆ Chessington – West Weybridge 400kV single cct (up-rate from 275kV) (2980MVA summer, PFC)
- ◆ West Weybridge – Iver 400kV single cct (up-rate from 275kV) (2980MVA summer, PFC)
- ◆ Cilfynydd to Rassau (2960MVA summer PFC)
- ◆ Aberthaw – Cardiff East – Uskmouth – Whitson & Aberthaw – Tremorfa – Uskmouth – Whitson (including USK crossing) 275kV (1010MVA winter PFC)

◆ **Hotwire**

- ◆ None currently identified

Appendix 3: The proposed wider transmission reinforcement works for the Inner Barrage option are:-

- ◆ **New Works**
 - ◆ **New Substations**
 - ◆ None currently identified
 - ◆ **New Equipment**
 - ◆ 2 x 225Mvar MSCs at Melksham
 - ◆ **New Lines**
 - ◆ Seabank - Aust 5km (new section from exiting line turn-in to Aust substation) (2820MVA summer, PFC)
 - ◆ **New Cable Routes**
 - ◆ None currently identified
- ◆ **Changes to Existing**
 - ◆ **Substations**
 - ◆ Aust 400kV (6 Feeder Circuits, 3 Generator Skeletal banked bays convert from planned 4 Switch Mesh)
 - ◆ **Reconductoring**
 - ◆ Aust – Melksham 1 & 2 400kV (2980MVA summer, PFC)
 - ◆ **Hotwire**
 - ◆ None currently identified

Appendix 4: Consents Legislation



National Grid's commitments when undertaking works in the UK

Our stakeholder, community and amenity policy

Draft for consultation

nationalgrid

The power of action.™

This note sets out National Grid's ten commitments when undertaking electricity and gas works in the UK (see page six). It covers how we will meet our amenity responsibilities and our commitments to effectively involving stakeholders and communities.

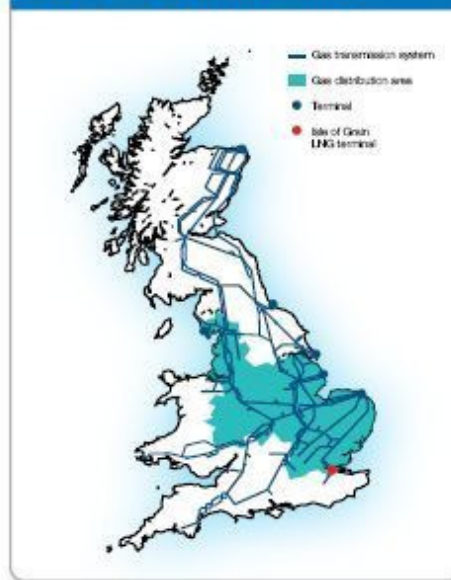
National Grid Vision

We, at National Grid, will be the foremost international electricity and gas company, delivering unparalleled safety, reliability and efficiency, vital to the well-being of our customers and communities. We are committed to being an innovative leader in energy management and to safeguarding our global environment for future generations.

Electricity Transmission UK



Gas Transmission UK and Gas Distribution UK



Who we are and what we do

National Grid is an international electricity and gas company primarily based in the UK and northeastern US. We play a vital role in delivering gas and electricity to millions of people in a safe, efficient and reliable manner.

In the UK, we take electricity from generation plants and transport it through our transmission network, all over the country to areas of demand, where we hand responsibility over to the distribution companies. In England and Wales our electricity assets comprise approximately 7,200 kilometres of overhead line, about 675 kilometres of underground cable and 337 substations at 244 sites. In Scotland, we operate but do not own the networks.

2

We own the gas national transmission system in Great Britain. We take gas from the terminals and transport it nationwide, through our transmission system, to areas of demand, where we hand over responsibility to distributors. Our transmission system comprises approximately 7,400 kilometres of high pressure pipelines and 26 compressor stations, connecting to eight distribution networks and to third party independent systems for onward transportation of gas to end consumers.

We are also the largest gas distributor in the UK, and we take gas, which is at high pressure for efficiency, and deliver it on behalf of suppliers to consumers, dropping the pressure on the way to make it safe for use. Our Gas Distribution UK segment comprises four of the eight regional gas distribution networks in Great Britain. Our networks comprise approximately 132,000 kilometres of gas distribution pipelines and we transport gas on behalf of approximately 33 active gas shippers from the gas national transmission system to around 10.8 million consumers. We are responsible for ensuring we are able to meet the varying demand each day, using storage mechanisms to compensate for a flat rate of input and constantly changing output.

National Grid is committed to working with government and other stakeholders to deliver a more sustainable, low carbon future. We will play a key role in ensuring that European and UK targets for renewable energy sources are achieved. Providing timely connections of large scale renewables to the electricity transmission system will require major system reinforcement as well as new connections. Gas will continue to play an important role in heating and clean power generation for many decades to come. With North Sea reserves declining the UK is set to import much more of its gas requirements. In response to the need for reliable and diverse gas supplies and the implications that new gas importation proposals might have, we are developing our view on how our gas transmission and distribution networks may need to evolve in response.

Our role

We are the sole holder of an electricity transmission licence for England and Wales. This licence also covers our role as system operator for the transmission networks in Great Britain. Under the Electricity Act 1989 we have a duty to develop and maintain an efficient, coordinated and economical system of electricity transmission and to facilitate competition in the supply and generation of electricity.

We also hold gas transporter licences in respect of the national transmission system and our regional gas distribution networks in Great Britain. Under the Gas Act 1986 we have a duty to develop and maintain an efficient and economical pipeline system for the conveyance of gas.

As electricity transmission owner and gas transmission and distribution owner, we own and maintain the physical assets, develop the networks to accommodate new connections and disconnections, and manage a programme of asset replacement and investment to ensure the long-term reliability of the networks.

3

To fulfil our duty to facilitate competition we must offer to connect customers (generators, direct connectees and distribution network operators) to our systems. The need for our equipment is therefore determined in the first instance by the locations chosen by our customers either individually or collectively. We must respond to customer requests by utilising our existing infrastructure more efficiently or by building new infrastructure, including new overhead lines, new pipelines, substations, compressors, plant and equipment.

With our equipment sited across Great Britain we understand that many stakeholders and communities have an interest in our activities. We believe that our long-term success is dependent upon us having a constructive and sustainable relationship with our stakeholders and those communities affected by our activities. We recognise that we can only do this by looking beyond our legal obligations.

Engaging stakeholders and communities

The development of gas and electricity networks, and their maintenance and refurbishment, can affect communities through which the networks pass. How we manage our relationships and work together with these communities and other affected stakeholders is important to us.

National Grid aspires to engage positively with stakeholders and communities. We are committed to the benefits of involving stakeholders and communities effectively in our works and recognise the benefits of doing this. We will listen, take into account views and opinions expressed and respond to these when developing and undertaking works.

The principles contained in our Commitment 2 (Involving stakeholders and communities) provide the framework that will help us to promote genuine and meaningful stakeholder and community engagement and to develop and maintain a culture that delivers this.

Our wider responsibilities

Although there is universal acceptance of the benefits of electricity – modern life is unimaginable without it – by its very nature, our business, with its necessary pylons, overhead lines, underground cables and substations, can have an impact on both the natural environment and cultural heritage. We use opportunities to protect and improve the environment, both by using technology to reduce the need for new infrastructure, and by seeking to reduce the impact on climate change of our existing and new equipment.

The visual impact of overhead lines is understandably an issue many people raise. Although compared to other countries England and Wales have a higher proportion of transmission lines placed underground, undergrounding remains the exception rather than the rule. There are strong cost, operational and environmental reasons for using overhead lines rather than underground cables, so, in common with other electricity transmission utilities world-wide, our preferred method of transmission is using overhead lines.

The impact of gas pipelines is very different to that of overhead lines as pipelines are underground, with only compression stations and other installations above ground. The main impacts on the local environment occur during construction.

4

The selection of routes and sites for overhead lines and underground pipelines is of course a critical factor in determining their impact on communities and on the environment. We therefore take routeing and siting considerations extremely seriously. As part of the routeing and siting process we will take into account responses, obtained throughout stakeholder and community engagement activities, in finalising our proposals for development.

National Grid has specific legal environmental obligations or duties, such as those contained in the Wildlife & Countryside Act 1981, Environment Act 1995, Countryside and Rights of Way Act 2000, The Conservation (Natural Habitats) Regulations 1994, National Parks (Scotland) Act 2000 and the Nature Conservation (Scotland) Act 2004. Our commitments to National Parks, in response to duties under the National Parks and Access to the Countryside Act 1949 are contained in a [statement](#) prepared with the Campaign for National Parks. Landowners and occupiers, on whose land our equipment is sited, are key National Grid stakeholders. Our [Working with You](#) publication sets out the standards we expect from staff and contractors when working on other people's land.

We also aim to have a positive impact on society through our support for a wide range of environmental and community initiatives and we support staff involvement in these activities. Our work with National Grid's [Environmental Education Centres](#) is an example of our work with environmental partners.

Application

This document applies to National Grid's transmission activities in the UK, for both electricity and gas works. It applies to all works on our gas distribution network operating above 7 bar (gauge) pressure. Gas works for networks of below 7 bar in pressure are excluded from these commitments because they are of much smaller scale, tend to be undertaken in the public highway and are controlled under the provisions of the New Roads and Street Works Act 1991 and Traffic Management Act 2004. They are also planned and implemented in much shorter timescales resulting in short-term impacts which are generally less significant and restricted to the communities in the immediate vicinity of the works.

In this document, we interpret **amenity** to mean the natural environment, cultural heritage, landscape and visual quality. We also include within this interpretation the impact of our works on communities, such as the effects of noise and disturbance from construction.

By **works** we mean constructing new transmission or distribution infrastructure such as overhead lines, underground cables, sealing end compounds and substations; pipelines compressor stations, pressure reduction installations and above ground gas installations (where all are part of networks operating above 7 bar (gauge) pressure); major refurbishment of any of these; and the dismantling and removal of any parts of the system.

By **stakeholders** we mean organisations and individuals who can affect or are affected by our works. By **communities** we include those stakeholders (organisations and individuals including residents) with a particular remit or interest in the local area affected by the works.

Our commitments

We, at National Grid, have made ten commitments to underpin our aspirations to engage positively with stakeholders and communities and to meet our amenity responsibilities when undertaking electricity and gas works.

1. Establishing need

We will only seek to build electricity lines or pipelines along new routes, or above ground installations in new locations, where our existing infrastructure cannot be technically or economically upgraded to meet system security standards and regulatory obligations, where forecasted increases in demand for electricity or gas will not be satisfied by other means, or where connections to customers are required.

2. Involving stakeholders and communities

We will promote genuine and meaningful stakeholder and community engagement. We will meet and, where appropriate, exceed the statutory requirements for consultation or engagement.

We will adopt the following principles to help us meet this commitment:

- we will seek to identify and understand the views and opinions of all the stakeholders and communities who may be affected by our works
- we will provide opportunities for engagement from the early stages of the process, where there is the greatest scope to influence the design of the works
- we will endeavour to enable constructive debate to take place, creating open and two-way communication processes
- we will ensure that benefits, constraints and adverse impacts of proposed works are communicated openly for meaningful stakeholder and community comment and discussion. We will be clear about any aspects of the works that cannot be altered
- we will utilise appropriate methods and effort in engaging stakeholders and communities, proportionate to the scale and impact of the works
- we will provide feedback on how views expressed have been considered and the outcomes of any engagement process or activity.

3. Routeing of networks and site selection

If new infrastructure is required, we will seek to avoid the following areas which are nationally or internationally designated for their landscape, wildlife or cultural significance: National Parks; Areas of Outstanding Natural Beauty; National Scenic Areas; Heritage Coasts; World Heritage Sites; Sites of Special Scientific Interest including Special Protection Areas, Special Areas of Conservation and Ramsar sites; National Nature Reserves; Scheduled Ancient Monuments; and registered parks and gardens.

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4. Minimising the effects of new infrastructure

We will seek to minimise the effects of works and new infrastructure on communities by having particular regard to safety, noise and construction traffic. We will also seek to minimise the effects of new infrastructure on sites valued for their amenity such as listed buildings, conservation areas, areas of archaeological interest, local wildlife sites, historic parks and gardens and historic battlefields. We will take into account the significance of these and other areas through consultation with local authorities and other stakeholders with particular interests in such sites.

5. Mitigating adverse effects of works

We will undertake relevant environmental investigations and report on these in any applications for consent for new works. We will use best practice environmental impact assessment techniques to assess possible effects of our works and identify opportunities for mitigation measures. In the course of this we will consult with relevant stakeholders and affected landowners. Where works are likely to have an adverse effect on amenity, we will carry out mitigation measures to reduce those effects as far as reasonably practicable.

6. Offsetting where mitigation is not practicable

Where mitigation measures cannot adequately mitigate against loss of amenity, or where mitigation is not practicable, we will offer to undertake practical offsetting measures. These measures, which will be developed in discussion with relevant stakeholders, could include landscaping and planting works or other benefits to affected communities.

7. Enhancing the environment around our works

When undertaking works, we will consider what practicable measures can be taken to enhance areas in the vicinity of the works for the benefit of local communities and the natural environment.

8. Monitoring and learning for the future

We will monitor, evaluate and review our engagement processes so that we can learn from our experiences and continue to improve engagement programmes in the future. We will carry out periodic reviews of the environmental impact of our works and consider the effectiveness of our assessment and any mitigation we have undertaken. The results of these reviews will be used to foster continuous improvement in the environmental assessment and management of works. In undertaking all reviews of our processes and procedures we will take into account stakeholder and community feedback.

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9. Reviewing these commitments

We intend to review these commitments at least every five years. Additional revisions will be made as necessary in response to new legislation, policy and guidance. As a responsible company practising good corporate governance, we will review the relevance of these commitments and report on our web site case studies illustrating our stakeholder and community engagement and our performance in preserving amenity.

10. Working with others

We require others undertaking works on our behalf to demonstrate these same commitments and we will create an environment where best practice can be shared and delivered.

Background

Meeting our duties under Schedule 9 of the Electricity Act

Electricity Act 1989
Extracts from Schedule 9
Preservation of amenity: England and Wales

Paragraph 1(1)

In formulating any relevant proposals, a licence holder or a person authorised by exemption to generate or supply electricity –

(a) shall have regard to the desirability of preserving natural beauty, of conserving flora, fauna and geological or physiographical features of special interest and of protecting sites, buildings and objects of architectural, historic or archaeological interest; and

(b) shall do what he reasonably can to mitigate any effect which the proposals would have on the natural beauty of the countryside or on any such flora, fauna, features, sites, buildings or objects.

Paragraph 2(1)

A licence holder shall within twelve months from the grant of his licence prepare, and from time to time modify, a statement setting out the manner in which he proposes to perform his duty under paragraph 1(1) above, including in particular the consultation procedures which he intends to follow.

This document sets out how National Grid, as an electricity transmission system licence holder, will meet the duty placed on it under Section 38 and Schedule 9 of the Electricity Act 1989 (see above). This duty relates to the preservation of amenity and forms only part of National Grid's wider environmental responsibilities. Information on those environmental issues not formally covered by Schedule 9, such as our role in countering climate change, in connecting new and renewable sources of electricity generation, in pollution control, and in electric and magnetic fields is available in other publications.

There is no equivalent to a Schedule 9 statement requirement in the provisions of the Gas Act 1986. However, National Grid believes that the principles in this document should apply equally to both our electricity and gas transmission and gas distribution works above 7 bar in pressure.

History

The first significant revision to our Schedule 9 Statement was prepared following a stakeholder workshop facilitated by the Environment Council in 2001. The statement and our performance in meeting the commitments were reviewed in 2006 and our statement was modified slightly as a result. In preparing that revision we consulted the bodies referred to in Schedule 9 of the Act which have statutory responsibilities for amenity, namely: Natural England; Countryside Council for Wales; CADW: Welsh Historic Monuments; and English Heritage. In addition, we consulted other non-government organisations concerned with amenity such as: Civic Trust; Council for National Parks; Tree Council; Wildlife Trusts; RSPB; CPRE; and representatives of other stakeholder groups together with our staff.

Preparing this policy

With the advent of the Planning Act 2008, we have incorporated our Schedule 9 statement duty into this wider policy, which incorporates gas works (above 7 bar in pressure), and new commitments to stakeholder and community engagement. In preparing our stakeholder and community engagement commitments we commissioned work from the consultancies, Corven and Entec UK, utilised best practice from 3G Communications Ltd., and met with a number of non-government organisations.

Consultation responses

We are keen to hear your views on this draft policy, so please let us have your written comments by 23rd June 2009.

Comments should be sent to:
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