Strategic Investment Options

Shaping Subtransmission

South Wales – March 2019

WESTERN POWER DISTRIBUTION

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Contents

1 – Executive Summary

WPD's South Wales licence area, as part of a wider trend across Great Britain, now has a significant proliferation of connected Distributed Generation (DG) and other Distribution Energy Resources (DER). There is now almost 2.2 GW of generation connected to WPD's South Wales distribution network. This contrasts against an annual maximum demand of more than 1.9 GW and minimum demand of less than 0.9 GW.

Changes to renewable subsidies have seen a reduction in the volume of DER seeking connection, however there is still over 900 MW of predominately low carbon generation waiting to build out within the region. Much of this is made up of on-shore wind connections, demonstrating Wales' continued commitment to reducing the carbon content of its energy supply.

Traditionally, connection costs for generation customers have been kept low by using the capacity inherent in a network designed to support demand. As this capacity was used up, DG connection applications resulted in requirements to reinforce our network. While some customers have agreed to contribute to the cost of reinforcement in order to connect to our network, other customers have sought alternative connection arrangements. The Transmission network has been equally affected by the greater volumes of DG being connected, with National Grid's responses to WPD's South Wales Statement of Works (SoW) submissions highlighting that DG output in some areas is limited by the capability of transmission network components.

WPD has committed to the rolling out of Active Network Management (ANM) across all its licence areas by 2021 in order to manage the output of generators to reduce reinforcement requirements. With the majority of the South Wales network now under ANM, managing both distribution and transmission constraints, customers who are able to reduce output under certain conditions can directly benefit from quicker and more efficient connections.

This report documents the processes that WPD is following to give visibility to network capacity issues in advance of connection applications. With the assistance of Regen, we have developed scenarios for the growth of demand and DG in South Wales from 2018 to 2032. These scenarios correspond to National Grid's 2017 Future Energy Scenarios: Steady State, Slow Progression, Consumer Power and Two Degrees. They cover the growth of conventional demand, several types of generation and the electrification of transport and heating. Continued uptakes of renewables as the technology continues to drop in price is likely to affect South Wales ahead of most areas due to its favourable position. The addition of energy storage to maximise the renewable resources also brings significant challenges as unlike other intermittent forms of DG, its output is not dictated by weather and seasons, but by the commercial business case of the developer. This may be coincident with times of local peak demand for electricity, but could also be related to the balancing position of an electricity supplier or the frequency of the National Electricity Transmission System. Furthermore, the business case of the developer may change over time, depending on its contractual requirements or needs of the market.

The scenarios were used as inputs to network studies, analysing the impact of future DG and demand connection. This was applied to the Subtransmission components of the WPD South Wales network, which consist of Grid Supply Points (GSPs), Bulk Supply Points (BSPs), 66 kV Primary Substations and the 132 kV and 66 kV networks. In these studies we have moved away from traditional 'edge-case' modelling, where only the network condition which is deemed to be most onerous is analysed. Instead we have analysed network behaviour throughout the day for:

- **Winter Peak Demand**, with minimum coincident generation – an assessment of the network's capability to meet peak demand conditions;
- **Summer Peak Demand** and **Intermediate Warm Peak Demand**, with minimum coincident generation – an assessment of the network's capability to meet maintenance period demand conditions;
- **Summer Peak Generation**, with minimum coincident demand – an assessment of the network's capability to handle generation output.

This methodology highlighted that although many onerous network conditions occur at the expected peaks; this is not always the case. In particular, some thermal constraints are met first in spring or autumn rather than summer or winter. Reactive power constraints are often met when the network is lightly loaded. As WPD's network becomes more variable due to changing consumer behaviour, there will an increasing importance on new roles as a Distribution System Operator (DSO) and this will require more analysis of this type to manage the network in real time.

The studies confirmed the justification for WPD's planned Subtransmission reinforcement projects such as reactive compensation in mid-Wales and the reprofiling of various 132 kV and 66 kV lines. The studies also identified the requirement for significant further reinforcement by 2022 including new transformers, line reconductoring and cable overlays if the expected growth in both DG and demand occurs.

It is expected that some – but not all – generation-driven reinforcement could be alleviated by using ANM or other measures to curtail the output of DG to prevent network overstressing. It is important to note that ANM is not capable of mitigating all types of network constraints; furthermore it does not have an unlimited ability to mitigate constraints unless significant pre-fault curtailment of output is applied to avoid protection operation or equipment damage prior to the operation of ANM.

WPD is now exploring the use of Demand Side Response (DSR) to manage network loadings and in 2019 is actively procuring 93.4 MW from flexibility providers across a total of 80 primary substations. By contracting with industrial and commercial customers who can adjust or shift their electricity consumption at key times, DSR can be used to defer demand-driven reinforcement, or maintain network compliance during reinforcement.

While the projected reinforcement requirements were dominated by the growth of domestic, commercial and industrial demand, the growth of DG and electrification of transport and heating also had a significant impact. The studies are particularly sensitive to electric vehicle (EV) usage patterns, which may change dramatically as electric vehicles are more widely adopted.

As always, it remains our intention to revisit these studies and the underlying scenarios on a two-yearly basis.

2 – Objective of this Report

The overall aim of this report is to:

- Assess the potential growth in Distributed Generation (DG) by:
    - fuel type
    - general location
    - year of connection
- Consider potential demand changes that come from:
    - the electrification of transport
    - the electrification of heating and cooling
    - growth in industrial, commercial and domestic demand
- Identify thermal and voltage constraints that may occur on our 66 kV and 132 kV network which will limit the ability of those connections to take place
- Assess options for reinforcement
- Provide recommendations for ‘low regret’ investment, noting the Ofgem consultation on ‘quicker and more efficient connections’ that raised questions on the role of strategic reinforcement funded by the wider customer base

Given the uncertainty in the growth of DG and changes in demand, the study has been undertaken using a scenario based approach to seek to identify an envelope of likely outcomes and understand the changes needed within that envelope.

We have used the four background Energy Scenarios developed by National Grid (NGET) in their Future Energy Scenarios (FES) for 2017 as a framework to develop detailed scenarios for the growth of demand and DG in South Wales. South Wales was divided geographically into the areas supplied by distinct sections of our Subtransmission network; bespoke scenarios were developed for each area. These scenarios were applied to electrical models of the Subtransmission network to assess their impact on the network.

3 – Background

South Wales Licence Area

Western Power Distribution (WPD) is the Distribution Network Operator for South Wales. The area covers approximately 11,800 square kilometres and extends from Pembrokeshire in the West, to Monmouth in the East and from the South coast of Wales up to the towns of Aberaeron and Rhayader in mid-Wales. The area is largely rural but includes the cities and towns of Cardiff, Swansea, Newport, Abergavenny, Brecon, Carmarthen and Pembroke as well as many other coastal resorts. This area has just over 1 million customers.

There is a wide spread of industrial and commercial activities within the area, with a significant amount of "new" industry replacing the more traditional coal mining and steel making industries. Tourism and farming are also important to the local communities, more so in mid and West Wales. Business activity is generally concentrated along the M4 corridor and the South Wales valleys. The area also includes some of the most sparsely populated areas in the UK, including the Brecon and Pembrokeshire National Parks and Areas of Outstanding Natural Beauty.

Current Network

Western Power Distribution receives supplies from National Grid at nine Grid Supply Points in South Wales:

- Aberthaw (132 kV)
- Cardiff East (132 kV)
- Margam (66 kV)
- Pembroke (132 kV)
- Pyle (132 kV)
- Rassau (132 kV)
- Swansea North (132 kV)
- Upper Boat (132 kV & 33 kV)
- Uskmouth (132 kV & 33 kV)

These GSPs are in turn supplied from the interconnected 275 kV and 400 kV National Grid network in South Wales.

Most GSPs in South Wales are normally operated independently, but Aberthaw and Cardiff East are normally operated in parallel at 132 kV. The 132 kV and 33 kV networks supplied from Upper Boat GSP are remotely coupled by a 132/33 kV Grid Transformer (GT) at Mountain Ash Bulk Supply Point.

The South Wales network also includes two areas where 66 kV networks perform all or part of the conventional role of 132 kV networks:

- The Llynfi Valley 66 kV network, supplied directly from Margam GSP; and
- The East Wales 66 kV network, supplied via the 132 kV network at Abergavenny, Llantarnam and Panteg BSPs. This network supplies a particularly large geographical area, stretching from the outskirts of Newport in the south to rural mid-Wales in the north. This network can be further subdivided into:
    - The Mid-Wales 66 kV ring, originating at Abergavenny BSP;
    - The Southern 66 kV ring, interconnecting Abergavenny and Panteg BSPs; and

- The Llantarnam 66 kV network, supplying Rogerstone Primary Substation and part of Pontypool North Primary Substation.

132 kV and 66 kV are both treated as Subtransmission networks. Establishing or reinforcing 132 kV and 66 kV networks is often a protracted and expensive process, making long-term planning a necessity.

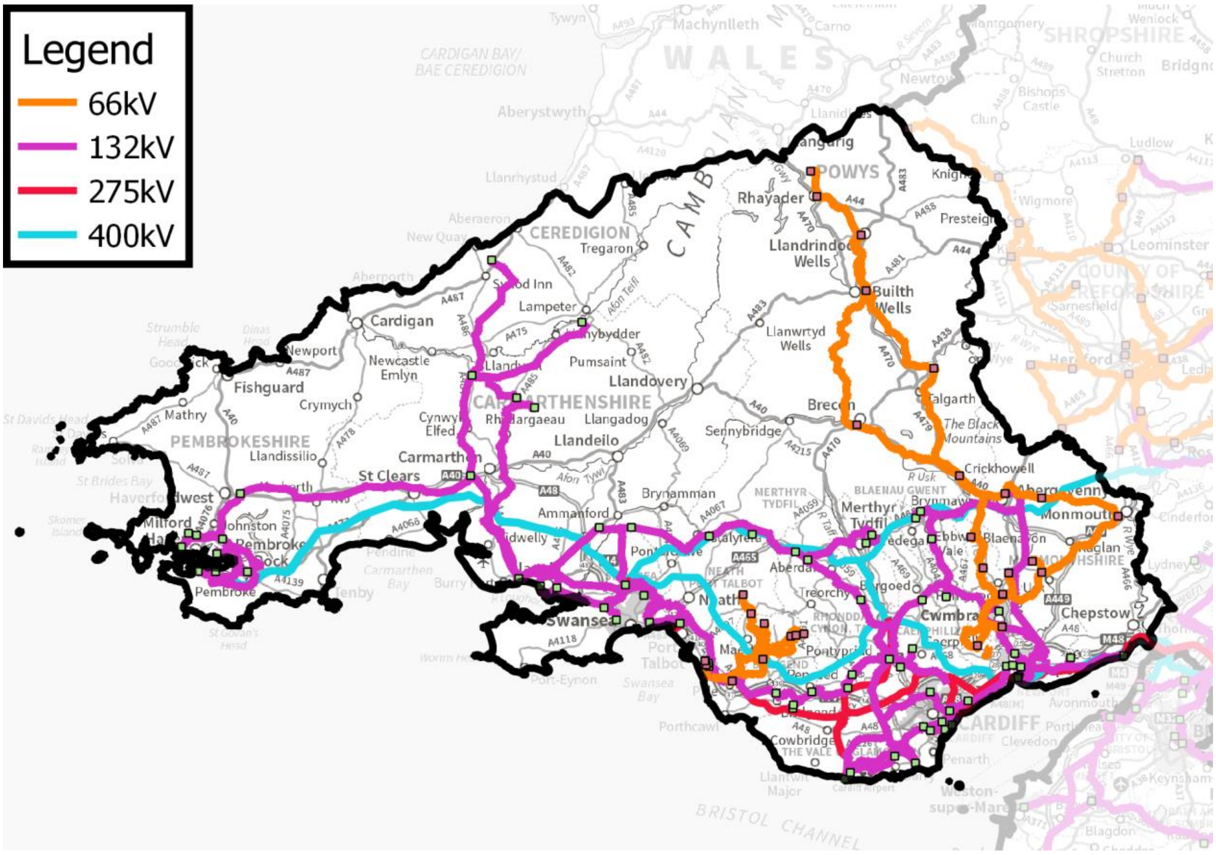

Figure 1: Network in South Wales showing 400 kV, 275 kV, 132 kV and 66 kV networks.

Demand Usage of the Network

Traditionally, distribution networks were designed for the optimal delivery of power from the transmission network to demand customers. Historic system maximum demands are shown in Figure 2.

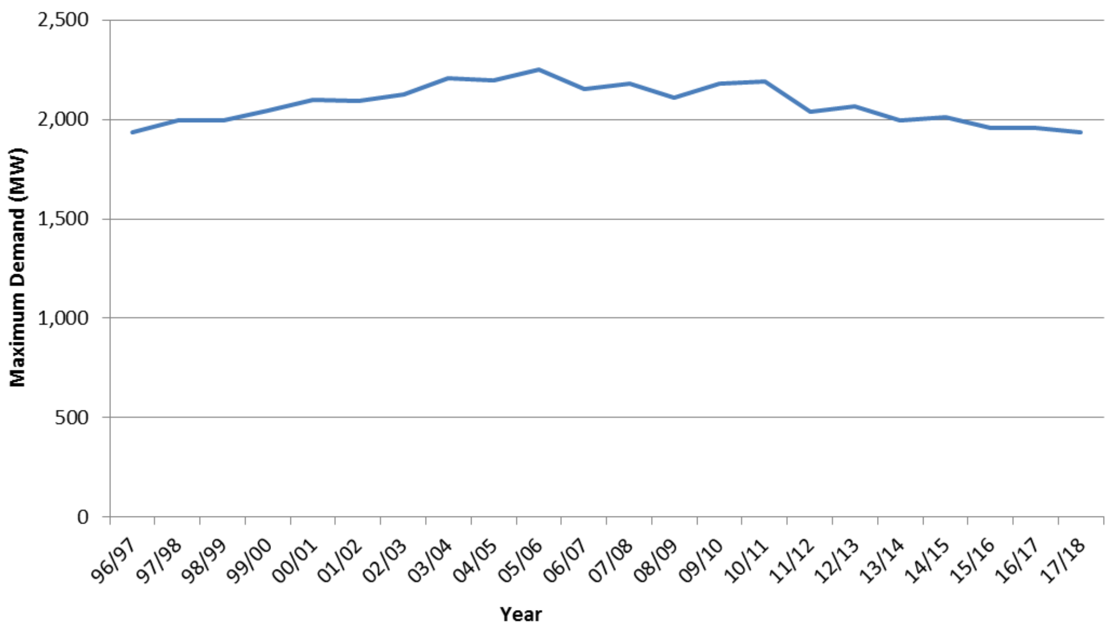

Figure 2: Historic system maximum demand in South Wales

Flexibility rollout

With the growth of new electrical demand from technologies such as Electric Vehicles (EVs) and Heat Pumps (HPs) we also expect to see changes to demand profiles. The opportunity to deploy Demand Side Response (DSR) solutions, allowing demand profiles to be modified by network operators and suppliers will be a key solution to managing demand growth in a cost efficient and intelligent manner.

Through its Flexible Power offering, to date WPD has sought to procure DSR across 10% of its network where there are identified constraints and cost benefits from deferred reinforcement. WPD is committed to offering flexibility first ahead of traditional solutions and will continue to roll out Flexible Power further across its network, both for reinforcement deferral and capacity sharing.

More information on Flexible Power is available at www.flexiblepower.co.uk

Flexible Power is open to participation for all of WPDs customers. We recognise that further development should be carried out to assist domestic and community customers in best taking advantage of DSR both through Flexible Power and wider opportunities. As a result we have developed a range of innovation projects which aim to develop WPDs understanding of domestic and community customer led DSR, such as *Community Energy Action*, *ECHO* and *Sunshine Tariff*.

For more information on our innovation projects please visit our innovation website, www.westernpowerinnovation.co.uk

Signposting

Facilitating new neutral markets around flexibility is a key objective in WPD's DSO Strategy. As the energy system becomes more active, an important role for WPD will be to provide the right information to signal the needs of the electricity distribution network to the markets. This will require us to provide a greater level of information on the performance characteristics of our network than ever before and in a format which is understandable and transparent. The information we present will inform the market ahead of us requesting tenders for flexibility and allow flexibility providers to understand our potential requirements for demand side response.

WPD's latest signposting information can be found at www.westernpower.co.uk/signposting.

Growth in Distributed Generation

At privatisation, in 1990, there were virtually no generators connected to distribution networks. Those that existed were mainly embedded within customer-owned internal networks and primarily used for standby purposes. Since then there has been a moderate growth of onshore wind generation supported by various subsidy arrangements, and a few large gas turbine connections.

In addition, NGET have developed various contracted services which has led to the growth in diesel- and gas-fuelled distribution-connected plant to provide these services, generally being required to operate at or around times of peak national demand.

Since around 2010, there has been a significant growth in solar photovoltaic (PV) connections, both in the volume of small roof top systems and large, MW scale, ground mounted systems.

More recently, battery-based energy storage systems have started to be connected to the distribution network. This has been driven by the falling cost of storage, reduced subsidies for renewable technologies, the growing value of flexibility in timing of import/export to the network and NGET seeking frequency support services.

The current distributed generation position in South Wales is shown in Table 2. This shows the breakdown between those connected to the distribution network, those with accepted contracts to connect and those with outstanding offers for connection.

Table 1: Connected, Accepted and Offered Distributed Generation in WPD South Wales at the end of January 2019

Generator type	Connected [MVA]	Accepted [MVA]	Offered [MVA]	Total [MVA]
Photovoltaic	631.7	341.0	46.5	1,019.2
Wind	503.0	242.8	15.4	761.2
Landfill Gas, Sewage Gas, Biogas and Waste Incineration	51.3	76.8	-	128.1
Combined Heat and Power (CHP)	3.0	30.1	-	33.2
Biomass and Energy Crops	47.1	80.0	-	127.1
Hydro, Tidal and Wave Power	10.7	1.7	3.1	15.5
Storage	0.1	21.1	0.1	21.3
All Other Generation	946.6	123.8	10.0	1,080.4
Total	**2,193.6**	**917.3**	**75.0**	**3,186.0**

Issues Resulting from the Growth of DG and Demand in South Wales to 2018

Distribution Network Constraints

Some parts of the South Wales distribution network have become constrained due to the growth of DG. Several reinforcements have already been built, and more are planned. In particular, transformers have been replaced with higher rated units at several substations, and several overhead lines have been reprofiled to increase their ratings.

ANM zones are now active to manage parts of Swansea North GSP and Pembroke GSP. A third ANM zone is open to applications in Rassau GSP, and a fourth is planned for Pyle GSP.

Transmission Network Constraints

All changes to demand or generation on the distribution network have some effect on the transmission system. National Grid's Connection and Use of System Code has a requirement in it to seek National Grid's assessment of the impact and any necessary works that they need to undertake where it is deemed that there will be an impact. An initial assessment is carried out via a Statement of Works submission which presently takes the form of an Appendix G submission, which is a trial process whereby every month WPD assess acceptances, connections and withdrawals on a Grid Supply Point (GSP) basis. NGET assess the Appendix G submission to determine the impact upon the transmission network and identifies if transmission works are required and/or if there are specific operating conditions needed before customers can connect. This may then lead to a requirement for Project Progression or a further Modification Application.

Operating conditions presently required include:

- Each generator connection must have a reactive capability between 0.95 power factor leading and 0.95 power factor lagging. The initial power factor setting will be:
    - 0.95 leading on DG capable of significant output overnight, and
    - 0.98 leading on DG only capable of generating during the day.
- Emergency disconnection facility to be provided to allow WPD to de-energise on instruction from National Grid.
- All generation connections in the Pyle, Swansea North, Rassau or Upper Boat 33 kV GSP areas will be required to participate in an ANM scheme to manage reverse power flow through the Super Grid Transformers (SGTs).

The outcome of a previous SoW submission in May 2016 resulted in notification from NGET which confirmed that the transmission network in South Wales has reached capacity under winter peak demand conditions. As a result, the short term measure was to delay any connection of Thermal Generation technologies which can generate at times of peak demand. Modification Offers received from NGET on 19th January 2017 have confirmed that Thermal Generation technologies which can generate at times of peak demand in South Wales will be unable to connect and energise before October 2026. Full scope of transmission reinforcement works can be found on our website:

https://www.westernpower.co.uk/docs/connections/Generation/Statement-of-Works/South-Wales/WPD-South-Wales-Statement-of-Works-Update-March-20.aspx

Non-thermal, renewable generation such as solar and wind are still able to connect to utilise the existing capacity, with NGET investigating solutions that may increase the short term capacity.

4 – Scenarios

National Grid produces Future Energy Scenarios each year which provides a range of credible energy futures for the United Kingdom. The scenarios are formed of a:

- Document covering the model inputs to the scenario analysis, new technologies, social and economic developments, government policies and progress against targets.
- Set of scenarios which can be used to frame discussions and perform stress tests. These scenarios are projected out from the present to 2050. The scenarios form the starting point for all transmission network and investment planning. They are also used in analysis to identify future operability challenges and potential solutions to meet those challenges.
- A document covering developments in electricity generation and demand, and gas supply and demand.

In order to assess the future challenges facing the South Wales distribution network, WPD commissioned Regen to produce a set of forecasts for the growth of DG and demand in the South Wales.

Figure 3: National Grid's Future Energy Scenarios[1]

These scenarios are named after and correspond to those developed by National Grid in the FES 2017. The four scenarios resemble a different level of green ambition and economic prosperity in the United Kingdom. Each scenario was forecast for each year from baseline in 2017 to 2032.

[1] – From National Grid's Future Energy Scenarios in five minutes, July 2017

Table 2: Key DG, storage and demand technologies which were assessed by the WPD and Regen forecasts

Electricity Generation Technologies	New Demand Technologies
• Solar PV – ground mounted • Solar PV – roof mounted • Onshore wind – large scale • Onshore wind – small scale • Anaerobic digestion (AD) – electricity production • Hydropower • Energy from waste (EfW) • Diesel • Gas • Other generation • Deep geothermal • Floating wind • Tidal steam and wave energy	• Electric vehicles • Heat pumps (domestic) • Domestic air conditioning **Conventional Demand Technologies** • Domestic • Industrial and Commercial (I&C) **Energy (electricity) storage** • High Energy Commercial and Industrial • Domestic and community own use • Energy trader • Generation co-location • Reserve service • Response service

Forecasting the long term growth of any generation or demand technology is complex owing to the multiple variables that can affect the market and determine growth.

Distributed Generation and Storage Forecasting

For each DG technology shown in Table 2, the growth assessment was split into three distinct phases:

1. Baseline – WPD and Regen SW's databases of Connected DG were correlated and confirmed to give a baseline in April 2018 with a high degree of accuracy;

2. Pipeline – WPD's database of Accepted-not-yet-Connected DG was combined with an assessment of the Department for Business, Energy & Industrial Strategy (BEIS) Renewable Energy Planning Database, current market conditions and recent policy changes, to give a forecast shared between all scenarios of what is expected to connect in the next two to four depending on technology; and

3. Scenario projection – each FES scenario was assessed and interpreted to take into consideration the specific local resources, constraints and opportunities for that technology in WPD's South Wales licence area under that scenario.

New Demand Technology Forecasting

The new demand technology forecasted consisted of electric vehicles, heat pumps and domestic air conditioning, all considered to be disruptive technologies with high growth potential. The forecasted data did not include a pipeline section; instead the forecasts were purely scenario based from 2018 to 2032.

Conventional Demand Forecasting

One of the key findings from the East Midlands, West Midlands and South West Shaping Subtransmission studies was the effects of increasing demand growth, in addition to the generation growth considered in the previous round of South Wales studies. As a result, this study also included conventional demand growth in domestic, industrial and commercial developments.

For the conventional demand forecasting, Regen used a variety of data sources to identify areas of domestic and non-domestic development out to 2032. A key input was the local development and infrastructure development plans published by local authorities. As part of the South Wales study, Regen and Western Power Distribution hosted a demand stakeholder engagement event to gain feedback from local authorities and other stakeholders. The forecast data did not include a pipeline; instead the forecasts were based on two different scenarios from 2018 to 2032. The two scenarios chosen were based wholly on economic prosperity, effectively grouping Consumer Power/Two Degrees and Slow Progression/Steady State into two scenarios.

Mapping the Forecasts to our Network

In order to map scenarios for demand and DG growth to the distribution network, the South Wales licence area was divided into 124 Electricity Supply Areas (ESAs). Each ESA represents a block of demand and generation as visible from the Subtransmission network. Each is one of:

- The geographical area supplied by a Bulk Supply Point (or group or part thereof) providing supplies at a voltage below 66 kV;
- The geographical area supplied by a 66 kV Primary Substation (or group or part thereof);
- A customer directly supplied at 132 kV or 66 kV (or by a dedicated BSP or 66 kV Primary Substation); or
- A Future Wind Development Zone.

The BSP and Primary Substation ESAs are shown geographically in Figure 4. It should be noted that ESA boundaries do not necessarily follow local authority or other administrative boundaries. Four ESAs represent areas on the border with England which are supplied by 11 kV circuits from 66 kV Primary Substations in WPD's West Midlands licence area.

Two additional ESAs outside the South Wales licence area have been included to represent SP Energy Networks' Aberystwyth and Rhydlydan BSPs, and Cefn Croes Wind Farm. These are supplied from WPD's Swansea North 132 kV network.

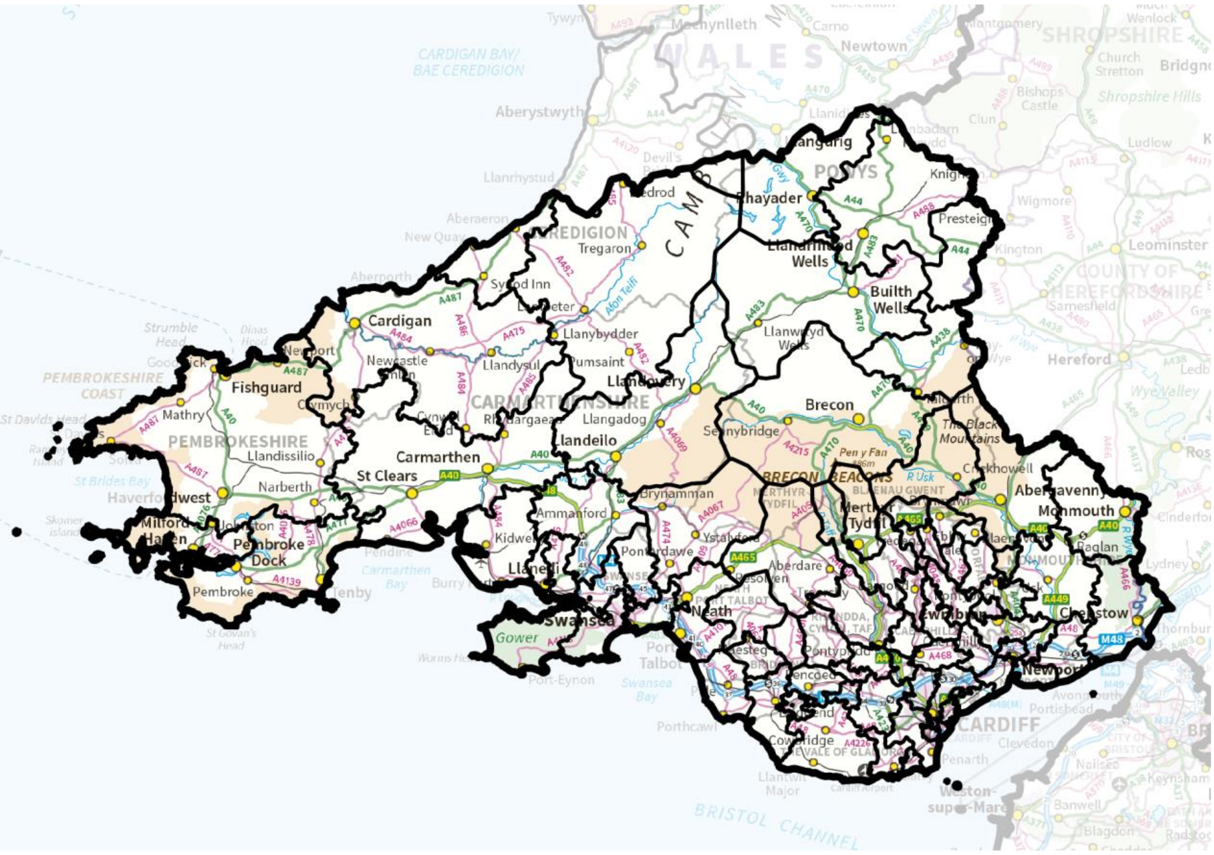

Figure 4: South Wales geographical ESAs.

Scenarios were developed for each ESA, taking into account historic and planned DG developments, local industry, population and natural resources. The results of the assessment are presented in each of the technology chapters in the Regen report and provide a projection of annual capacity deployment, by technology and scenario, for the period from 2018 to 2032. The complete Regen report, *Distribution Future Energy Scenarios -Technology growth scenarios to 2032, South Wales licence area 2018,* is available from our website at:

www.westernpower.co.uk/netstratswales

A summary of the DG forecasts is shown in Figure 5. From the baseline profiled capacity for a summer peak generation representative day of circa 2.3 GW in April 2018. This grows to 5.8 GW by 2032 under the most ambitious Two Degrees scenario. Growth estimates for the other scenarios, Consumer Power, Slow Progression and Steady State are lower overall. However, even under the lowest Steady State scenario, there is an expected growth pathway to 3.4 GW of DG capacity by 2032. Figure 6 shows a half hourly profile of the generation export for the South Wales licence area for a summer peak generation representative day, which was used in the baseline studies. Figure 7 shows the same breakdown for a Two Degrees scenario in 2032.

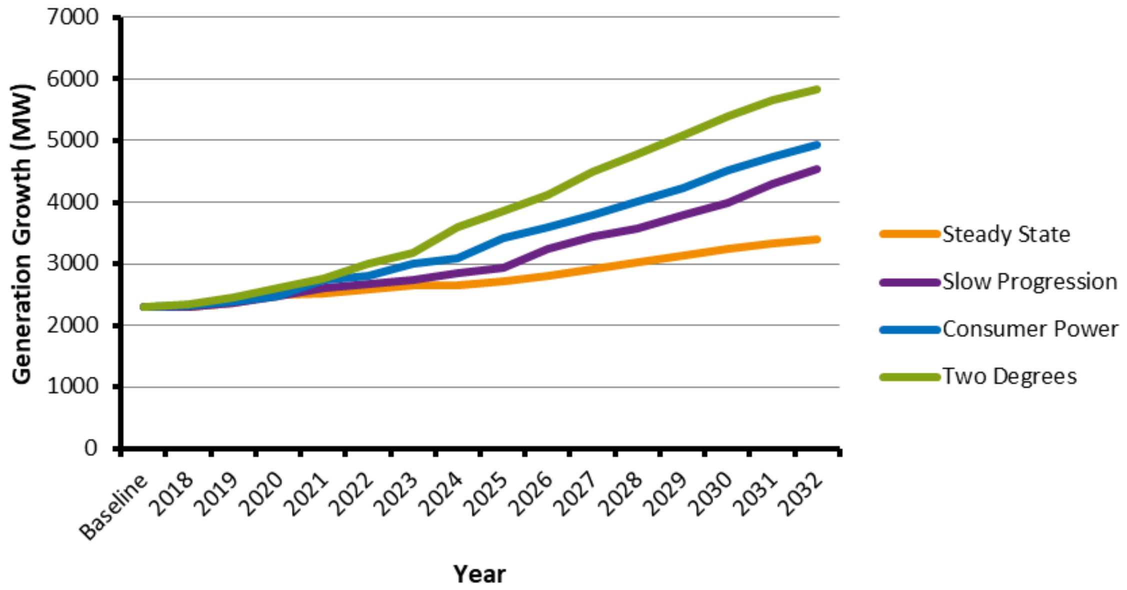

Figure 5: Total Distributed Generation capacity growth in WPD South Wales licence area from Baseline to 2032 under each scenario

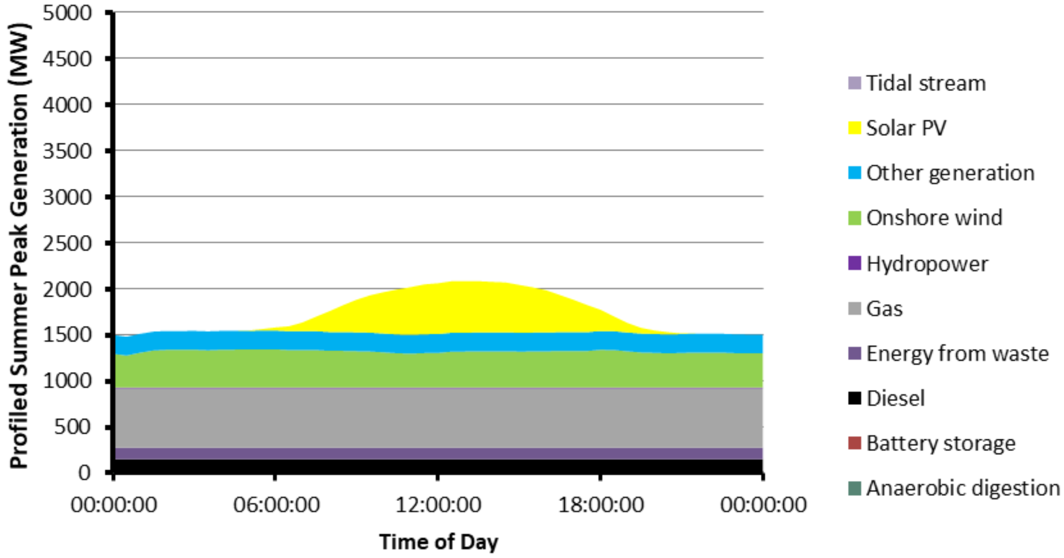

Figure 6: A half hourly profile of the South Wales licence area generation export for a summer peak generation representative day, as used in the baseline studies

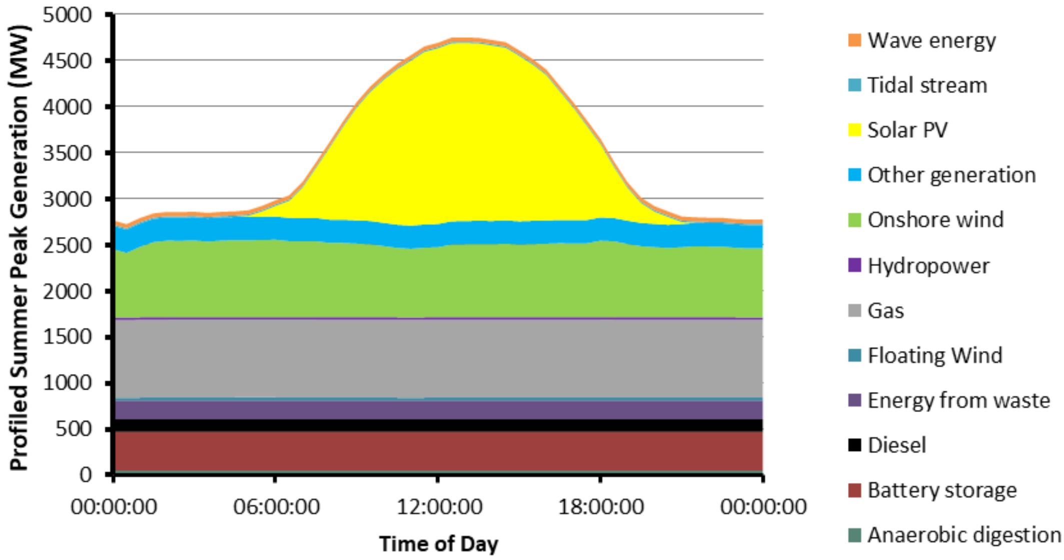

Figure 7: A half hourly profile of the South Wales licence area generation export for a summer peak generation representative day, under a Two Degrees scenario in 2032

A summary of peak demand growth across the South Wales licence area is shown in Figure 8. The demand growth is based on the growth of EVs, HPs and conventional demand growth. The total demand in the baseline studies was approximately 2.3 GW. Demand is expected to increase to as much as 4.1 GW by 2032. Figure 9 shows a half hourly demand profile for the South Wales licence area for a winter peak demand representative day, which was used in the baseline studies. Figure 10 shows the same breakdown for a Two Degrees scenario in 2032.

The key factor affecting the growth rate of new developments is the economic environment. The level of green ambition will have little relevance to the number of developments. For this reason Two Degrees and Consumer Power were combined into one scenario that assumes high growth rates. Slow Progression and Steady State scenarios were combined into a second scenario with a lower growth rate.

The divergence between the high and low growth conventional demand scenarios is due to the heat pump and electric vehicle growths, which were forecast for all scenarios separately, as green ambition and economic factors will both impact uptake. Two Degrees and Slow Progression assumes a Time of Use Tariff (TOUT) for the electric vehicle profiles that offsets the higher number of forecasted electric vehicles at time of network peak demand.

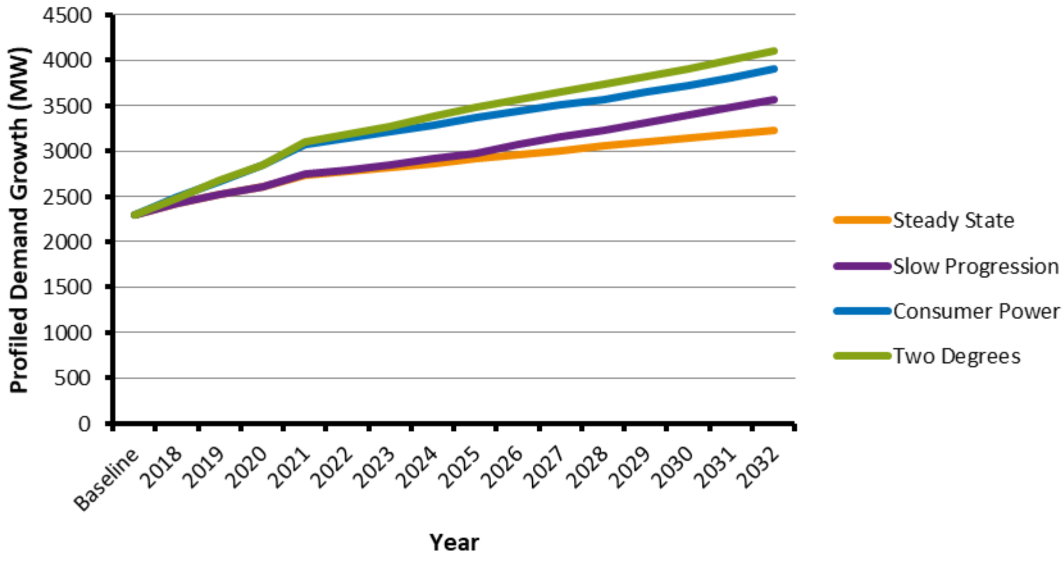

Figure 8: Total peak demand growth in WPD South Wales licence area from baseline to 2032 under each scenario

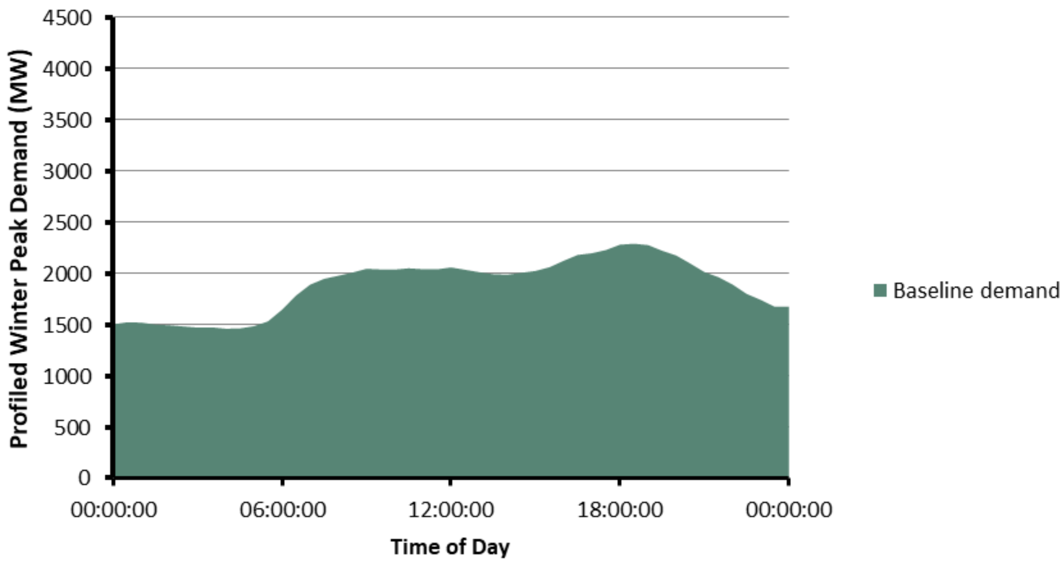

Figure 9: A half hourly demand profile of the South Wales licence area for a winter peak demand representative day, as used in the baseline studies

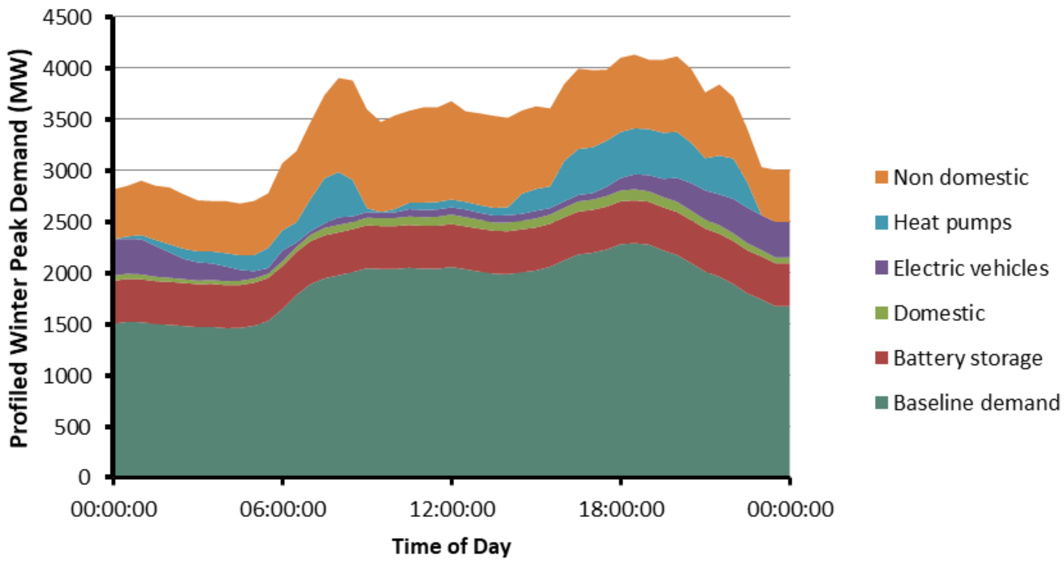

Figure 10: A half hourly demand profile of the South Wales licence area for a winter peak demand representative day under a Two Degrees scenario in 2032

It should be noted that since the demand forecasts are derived from local development plans, any further demand growth not captured in these plans will not be included in these studies. This could include new towns or major industrial/commercial developments.

5 – Network Analysis Technique and Inputs

An analysis technique was devised to assess the impact of the four scenarios on WPD South Wales Subtransmission network. The Subtransmission network was focussed upon due to the long timescales required to reinforce it.

Traditionally distribution networks are assessed using 'edge-case' modelling, where only the network condition which is deemed to be most onerous is analysed. As the installed capacity and behaviour of demand, generation and storage is rapidly changing, it has become difficult to predict what network condition will be most onerous. A detailed overview of modelling methodology can be found in the appendix. For this project, a broader approach was taken. The network was assessed in detail for each of the four scenarios, for Baseline, 2022, and 2027.

To cover a range of likely onerous cases, each half-hour of four representative days was analysed for:

- **Winter Peak Demand**, with minimum coincident generation – an assessment of the network's capability to meet peak demand conditions;
- **Summer Peak Demand** and **Intermediate Warm Peak Demand**, with minimum coincident generation – an assessment of the network's capability to meet maintenance period demand conditions;
- **Summer Peak Generation**, with minimum coincident demand – an assessment of the network's capability to handle generation output.

Demand, generation and storage were aggregated by ESA to be modelled at the appropriate node(s) to assess the impact on the Subtransmission network.

A half-hourly power profile for each representative day was developed for each demand, generation and storage category. The profiles are described in *Demand, Generation and Storage Profiles* below. The profiles were combined with the forecasts for demand, generation and storage at ESA level.

For each combination of scenario, year, day and half-hour the network was assessed for thermal issues, voltage violations and lost load under intact and credible outage conditions.

Demand, Generation and Storage Profiles

To model the daily and seasonal variation in power flow, it was necessary to develop power profiles for the various categories of demand and DG connected to the network.

Each profile was normalised around the unit of measure used for that type of demand or DG:

- Underlying demand is measured in MW of peak demand;
- EVs and heat pumps are measured in number of units installed;
- Domestic conventional demand growth is measured as the number of houses installed; and,
- Non-domestic conventional demand growth is measured in m^2 of floor space categorised by development type; and
- Each type of DG is measured in MW of installed capacity.

Some profiles were derived from measurements taken on the South Wales network. Date-stamped readings were reconciled to the representative days using the seasons proposed for a future revision of the ENA standard for overhead line ratings, ER P27:

- **Summer:** June-August,

- **Winter:** December-February,
- **Intermediate Warm:** May, September and October, and
- **Intermediate Cool:** March-April and November.

Demand Profiles

Profiles for underlying demand were derived from measured power flows at major substations in the South Wales network. Profiles for heat pumps, electric vehicles and conventional demand growth were derived from various innovation projects.

Underlying Demand

The underlying demand profiles used to represent a major substations demand have been derived from real, measured data, obtained from a sample of substations in the South Wales licence area. A demand profile, made-up of 48 data points (48 half hourly average readings) to represent a 24 hour period, was obtained for each of the representative days and each substation type to be studied. For each of the real power demand profiles produced, a corresponding reactive power demand profile was also produced, so that the reactive power and voltage behaviour of the network could be considered more accurately.

In order to obtain realistic substation demand profiles to impose on the network model, three different substations profile types where produced to represent different levels of population density and are listed below. Each substation was assessed against the population density in the area it supplies electricity to (i.e. its ESA):

- **Urban,** representing BSP's supplying areas with high densities of domestic, commercial and light to medium industrial demand.
- **Rural**, representing BSP's supplying areas with low densities of domestic demand, medium industrial demand and agricultural demand.
- **Mixed**, represent a mix of urban and rural demands.

Note: it was identified that a fourth substation type may exist in South Wales, a midday-peaking substation. This substation type would be representative of substations that have a midday peak as opposed to an early evening peak. These substations would typically be in urban areas that supply predominantly industrial and commercial demand. Inclusion of this substation type will be considered in future reports.

Each substation type was assessed for each representative day to produce twelve real and reactive power demand profiles which could be applied to the network model.

Figure 11 through Figure 18 show the normalised real and reactive power demand profiles created. Because these curves are normalised, as described below in *Demand Profiles – Methodology*, a multiplying factor can be applied to them to represent the actual demand at a particular major substation.

Demand Profiles – Methodology

The major substation demand profiles are based on measured data from 2017/18. For each of the substation categories (urban, rural and mixed), three substations from the South Wales licenced area were selected to form the data sample. The annual measured MW and MVAr demand data for the three substations forming the sample, was aggregated by each half hourly reading. Table 3 shows the substations that were selected to produce the demand profiles.

Table 3: ESA category demand samples

ESA Category	ESAs in sample
Urban	• Energlyn Grid • Grangetown • Trowbridge
Rural	• Builth Well • Brecon • Crickhowell
Mixed	• Blaenavon • Llynfi • Pencoed

Once the data had been aggregated, the aggregated DG output for generators connected to the respective substations was removed to obtain the true, unmasked, underlying demand. The real and reactive demand profiles were then normalised around the annual real power peak so that the final real power profiles had a peak value of 1pu.

Next, data for the four representative days was selected from the annual demand data in the following way:

- **Winter Peak Demand day:** The 24-hour demand data (48 half hourly average readings) was selected from the annual demand data for the day where the peak demand occurred. Only data from the months December, January and February was considered. These months align with the seasons proposed for a future revision of the ENA standard for overhead line ratings, ER P27.
- **Summer Peak Demand day:** The 24-hour demand data was selected from the annual demand data for the day where peak demand occurred. Only data from the months June, July and August was considered. These months align with the seasons proposed for a future revision of the ENA standard for overhead line ratings, ER P27.
- **Summer Peak Generation day:** The 24-hour demand data was selected from the annual demand data for the day where the smallest peak demand occurred. Only data from the months June, July and August was considered. These months align with the seasons proposed for a future revision of the ENA standard for overhead line ratings, ER P27.
- **Intermediate Warm Peak Demand day:** The 24-hour demand data was selected from the annual demand data for the day where peak demand occurred. Only data from the months May, September and October was considered. These months align with the seasons proposed for a future revision of the ENA standard for overhead line ratings, ER P27.

Table 4: Dates selected for underlying demand representative days

Representative Day	Dates
Winter Peak Demand	Urban – 28/02/2018 Rural – 28/02/2018 Mixed – 11/12/2017
Summer Peak Demand	Urban – 14/08/2017 Rural – 24/07/2018 Mixed – 08/08/2017
Summer Peak Generation	Urban – 23/06/2018 Rural – 23/06/2018 Mixed – 27/08/2017
Intermediate Warm	Urban – 23/10/2017 Rural – 30/10/2017 Mixed – 30/10/2017

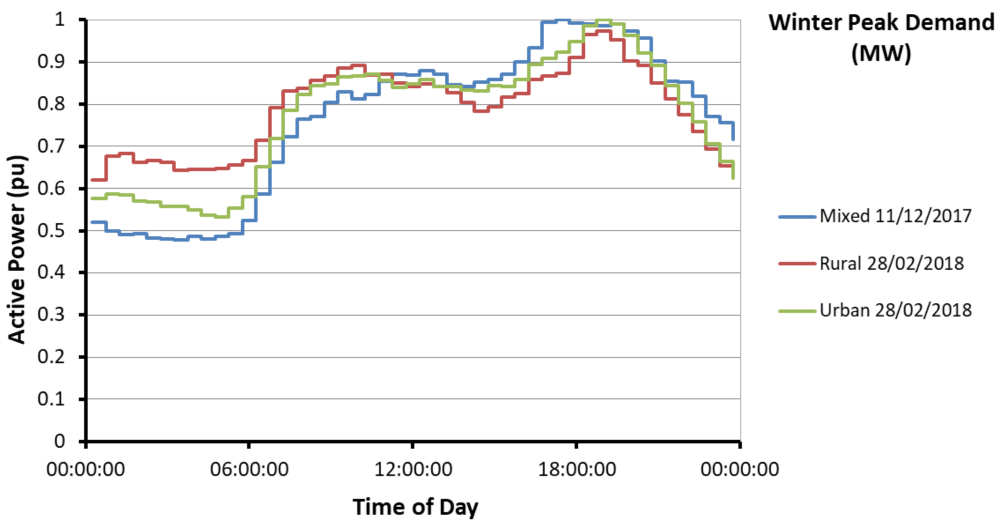

Figure 11: Real power underlying demand profiles for the Winter Peak Demand day, normalised over the peak real power annual demand

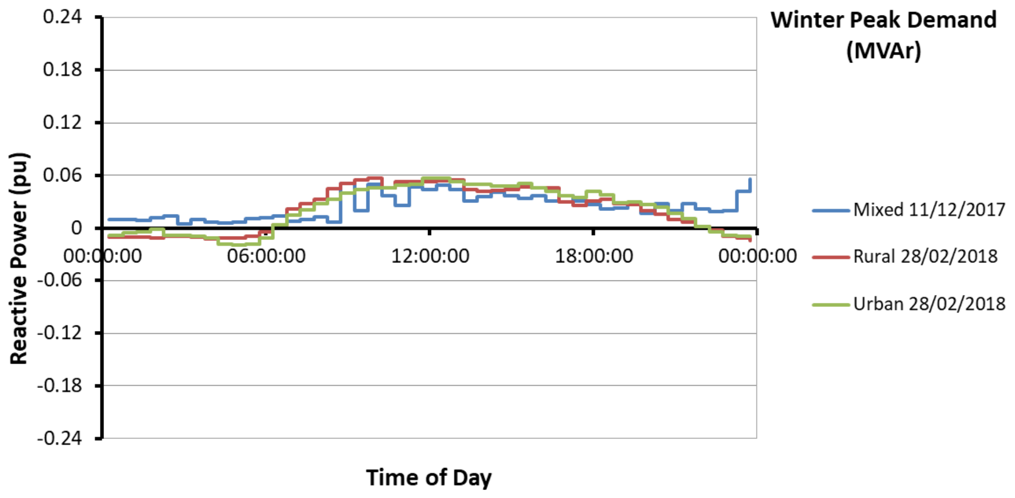

Figure 12: Reactive power underlying demand profiles for the Winter Peak Demand day, normalised over the peak real power annual demand (note: reactive power scale is not the same as the active power scale)

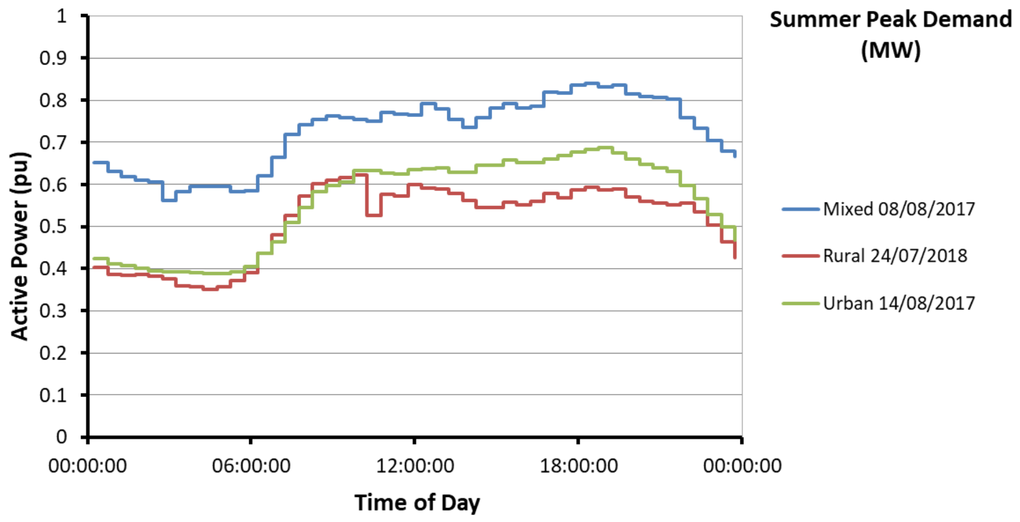

Figure 13: Real power underlying demand profiles for the Summer Peak Demand day, normalised over the peak real power annual demand

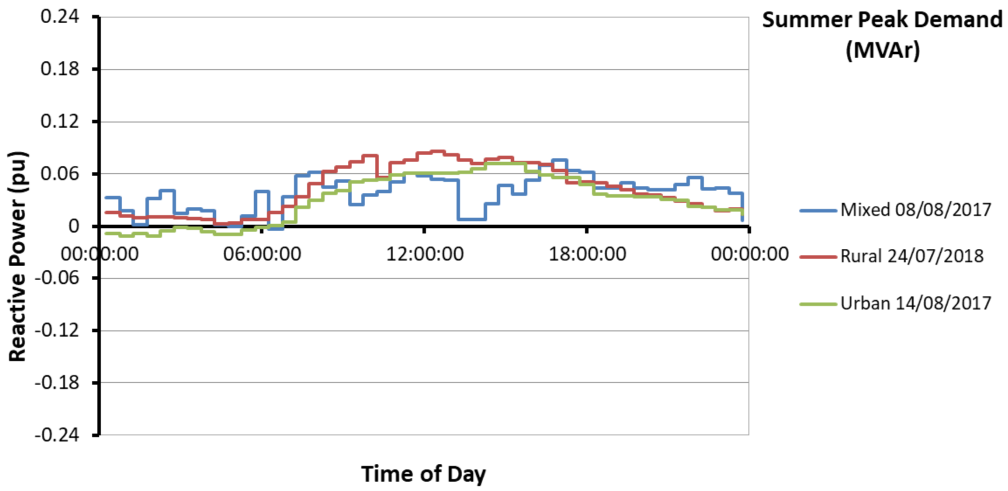

Figure 14: Reactive power underlying demand profiles for the Summer Peak Demand day, normalised over the peak real power annual demand (note: reactive power scale is not the same as the active power scale)

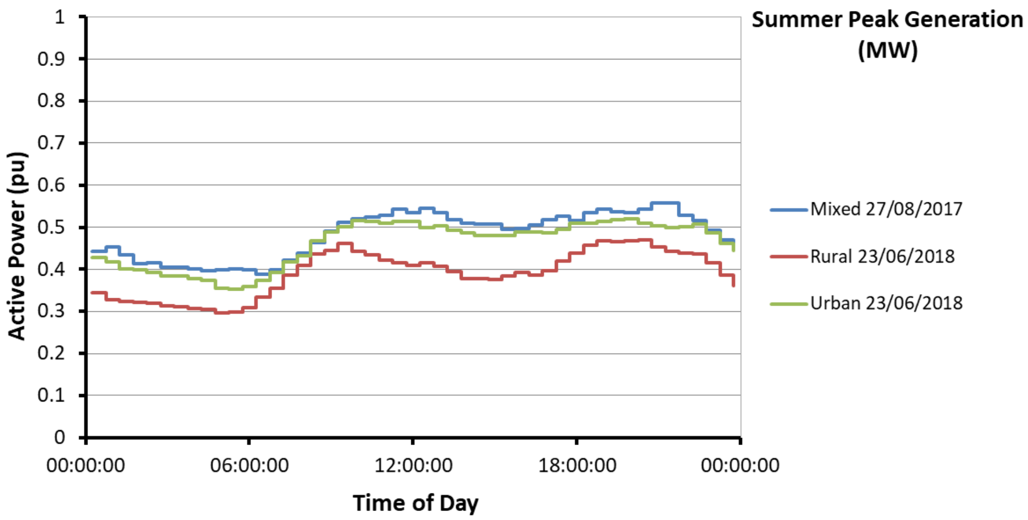

Figure 15: Real power underlying demand profiles for the Summer Peak Generation day, normalised over the peak real power annual demand

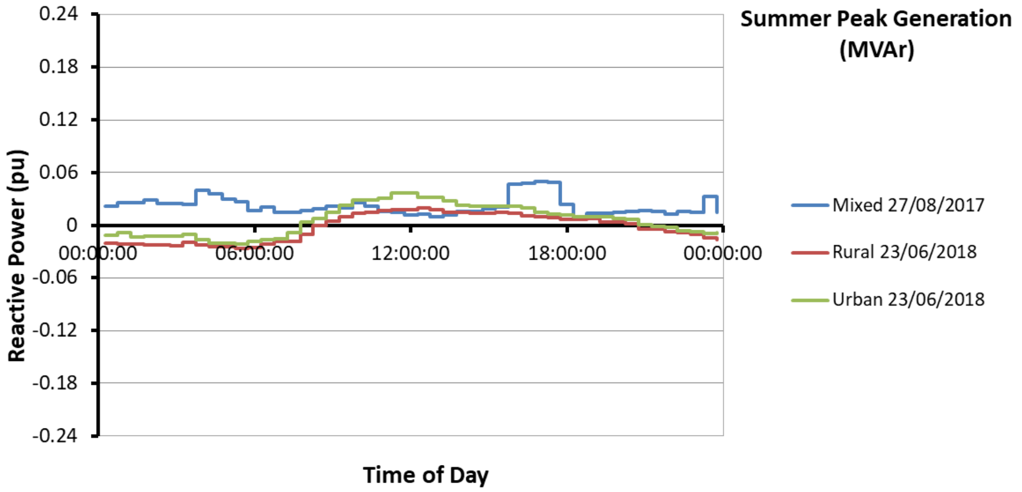

Figure 16: Reactive power underlying demand profiles for the Summer Peak Generation day, normalised over the peak real power annual demand (note: reactive power scale is not the same as the active power scale)

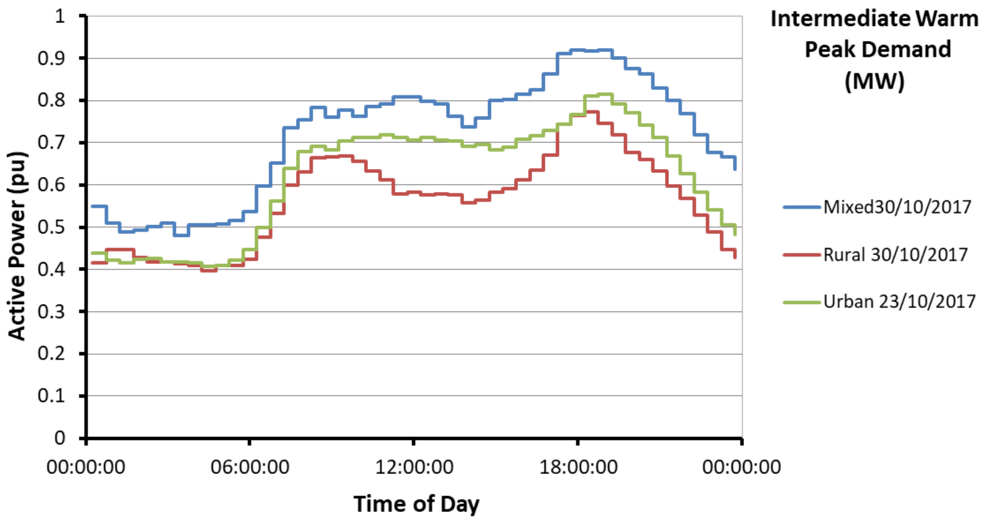

Figure 17: Real power underlying demand profiles for the Intermediate Warm Peak Demand day, normalised over the peak real power annual demand

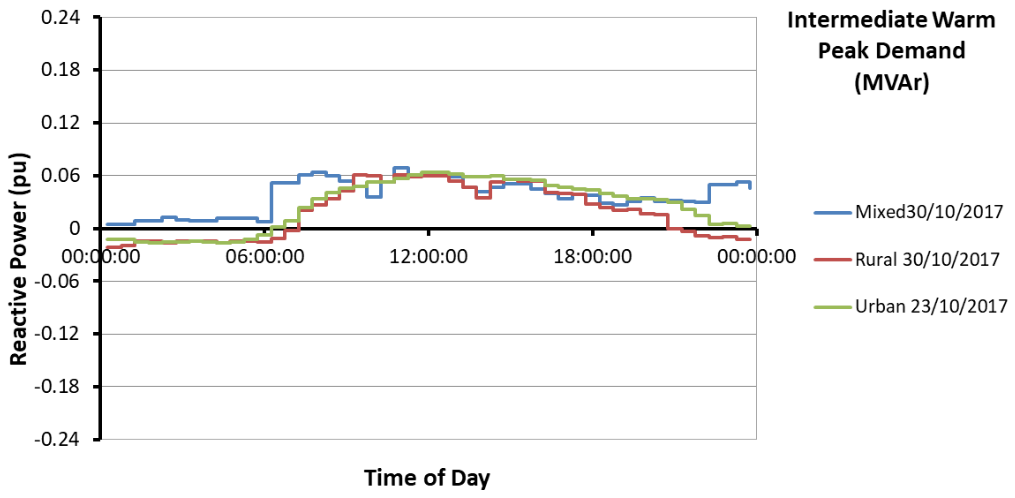

Figure 18: Reactive power underlying demand profiles for the Intermediate Warm Peak Demand day, normalised over the peak real power annual demand (note: reactive power scale is not the same as the active power scale)

Heat Pumps

Heat pumps have generally only been installed on off-gas houses, where an electric back-up is used at times where the heat-pump is not sufficient. Recent developments in hybrid heat pumps, which work with a backup technology (primarily gas) have started to reduce some of the barriers and raise potential for much higher growth in the sector. As well as starting to make it a cost-effective option for an on-gas grid customer, a hybrid system also requires less disruptive change, the higher temperature heat can use existing radiators and the heat pump operates at times it is most efficient (e.g. low electricity prices or moderate heat requirements) with back up sources taking over when it is not. For this reason, one of the developments for this report was to differentiate the growth of electric back-up and gas back-up heat-pumps.

The profiles for heat pumps were derived from the Electricity North West Limited (ENWL) Network Innovation Allowance (NIA) funded study: Managing the Impact of Electrification of Heat, dated March 2016.

The study considered various types of heat pump as follows:

- Lower temperature Air Source Heat Pump (ASHP)
    - Seasonal performance factor of 2.5-3.0
    - Generates flow temperatures of up to 55 degrees C
    - Suitable for well insulated buildings and new builds
- Higher temperature ASHP
    - Seasonal performance factor of 2.3-3.0
    - Generates flow temperatures of up to 80 degrees C
    - Suitable for older dwellings with a moderate thermal demand
- Hybrid ASHP
    - Lower temperature ASHP plus a boiler
    - Switches between fuel sources, based on efficiency/running costs
    - Suitable for older dwellings with larger thermal demand

Ground source heat pumps were not considered in the ENWL study. Due to space requirements for the ground source loop, these are expected to be less prevalent.

The profiles for gas and electric back-up heat pump are shown in Figure 19 and Figure 20.

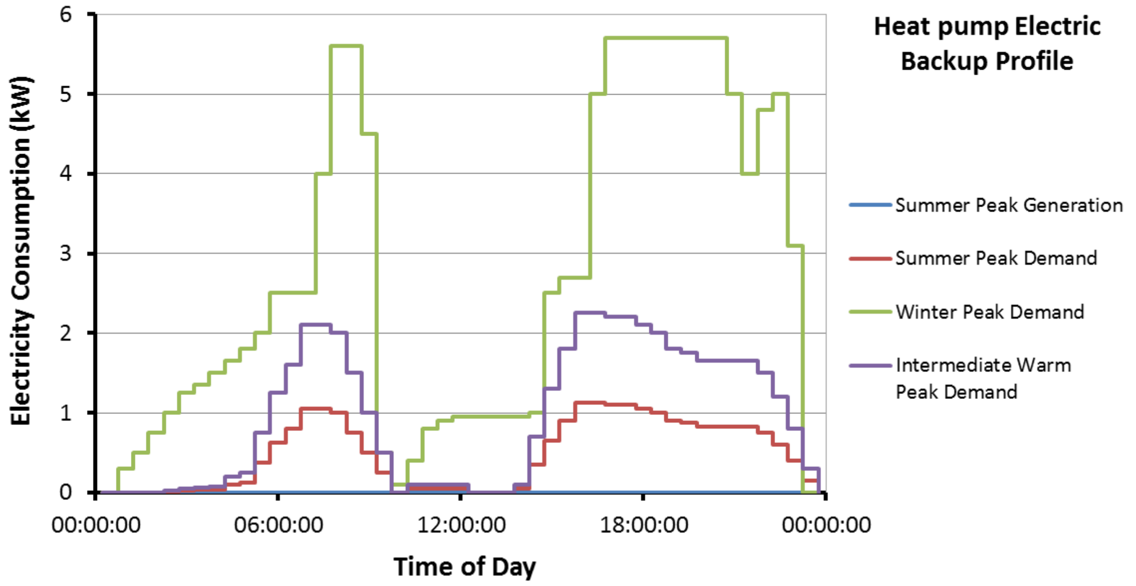

Figure 19: Electric back-up heat pump profile

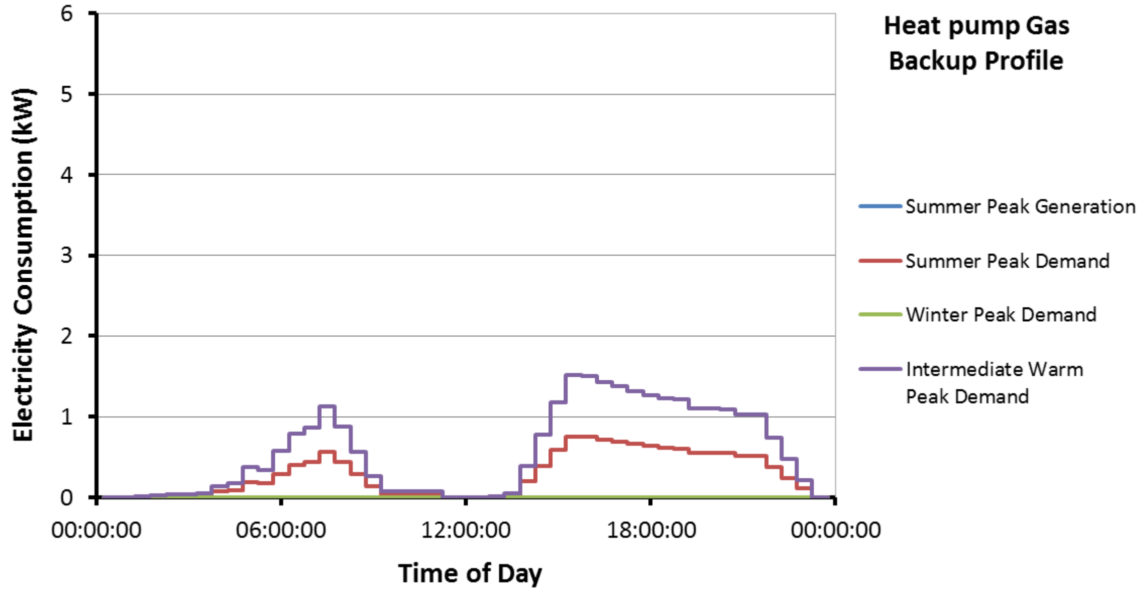

Figure 20: Gas back-up heat pump profile

These profiles highlight the impact an electric back-up has on the network, compared with a gas back-up. The winter peak demand from an electric back-up heat pump is 5.7kW, due to the 3kW electric back-up. The gas back-up heat pump at winter peak demand can switch to entirely gas, meaning there is no demand on the network at times of high demand. The profiles assumed there was no demand in summer from heat pumps during the peak generation studies.

Electric Vehicles

The first round of South Wales Shaping Subtransmission reports forecast the growth of EVs, without differentiating the type of EV. A development in the scenarios for this round was to separate the growth in hybrid and pure electric vehicles.

EV charging profiles were derived from the Electric Vehicles Insight Report of the Customer-Led Network Revolution project. This was based on a trial involving 143 domestic EV owners that took place in 2014. The profiles are shown in Figure 21 and Figure 22.

WPD's is currently hosting the Electric Nation project in partnership with EA, this project is funded by OFGEM, The aim of this project is to determine the impact EVs will have on the network and the effectiveness of demand side management. Whilst there is not currently enough data from the Electric Nation trial to create new profiles, there was sufficient data to back up the Customer-Led Network Revolution profiles used. The Electric Nation project also showed the diversified peak of hybrid vehicles was similar to that of pure electric. For the purposes of these studies we have assumed the same profile for the hybrid and pure electric vehicles; this will be reviewed again, once more information is available from the Electric Nation project.

The daily profile of weekday charging load averaged across all participants exhibits a significant evening peak of 0.9kW per EV at around 21:00. The daytime profile is consistent with the EVs being used primarily as commuting vehicles, where the evening peak correlates with household occupancy as commuters return home and plug-in to charge their EVs. The evening peak begins to drop after 22:00, indicating that some vehicles are fully charged by this time. A large seasonal variation in EV consumption was found, with the January peak charger demand of 0.9kW, steadily reducing to 0.45kW by June. This is likely to be due to additional lighting and heating requirements as well as reduced battery performance in colder weather.

The Regen report considers two different charging profiles, derived from the FES report, dated July 2017. The FES report assumed that a TOUT will be applied for the Two Degrees and Slow Progression scenarios from 2020, while uninhibited charging was assumed for the Consumer Power and Steady State scenarios up to 2032. The TOUT results in a two-hour delay in peak demand, but no reduction in total energy consumption.

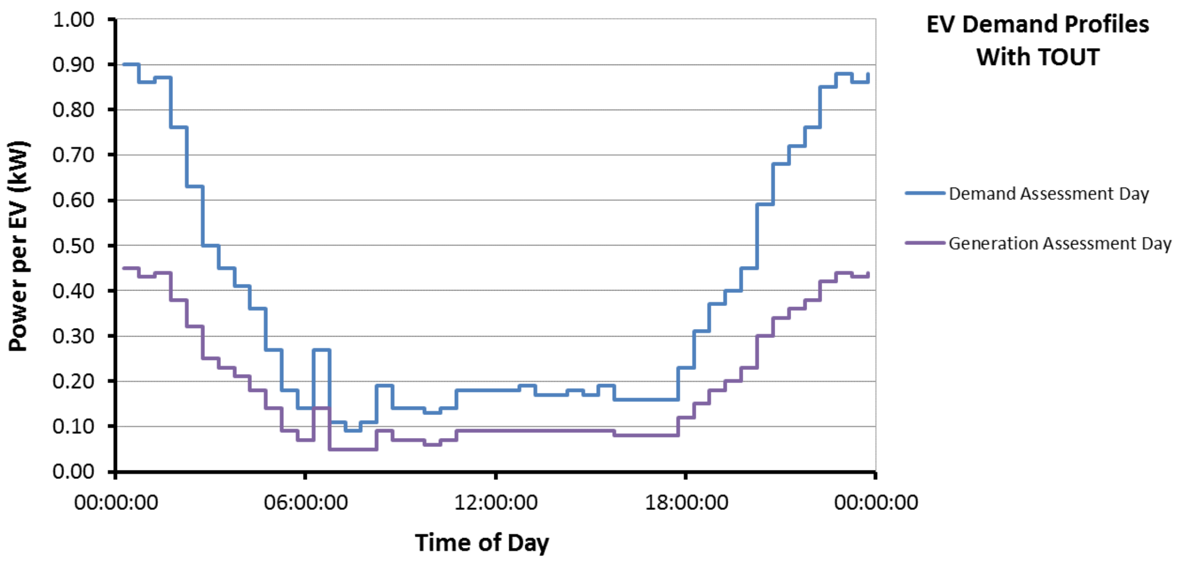

Figure 21: EV profiles with TOUT

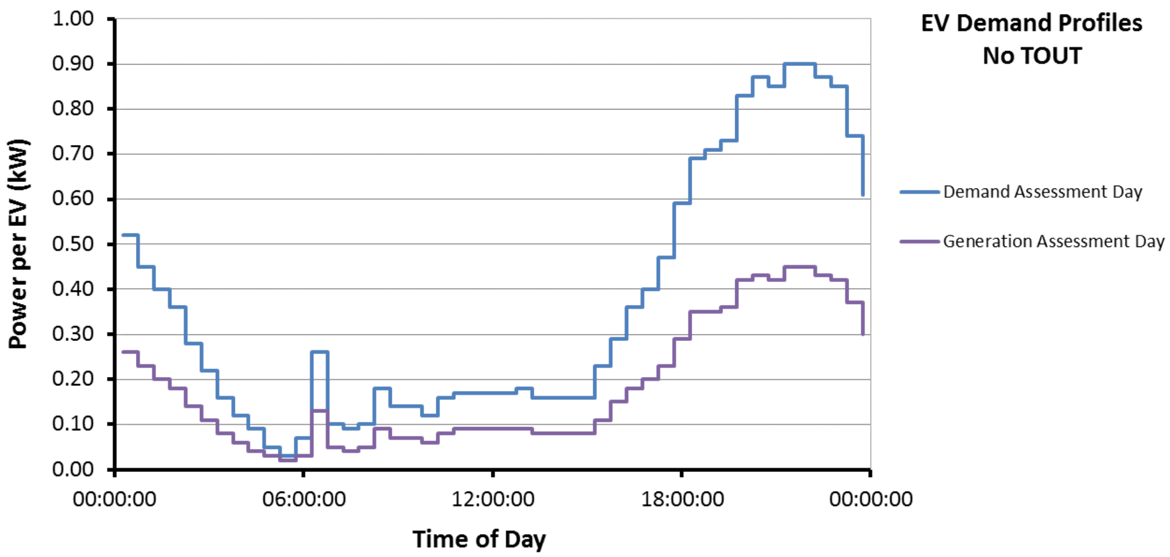

Figure 22: EV profiles without TOUT

Further investigation has shown a reasonable correlation with the EV charging profile produced as part of the My Electric Avenue project.

Air Conditioning

The air conditioning profiles were derived from the Air Conditioning Demand Assessment report as part of the NIA Demand Scenarios project ran by ENWL. As part of the scenario forecasts only domestic air conditioning growth was considered. The daily profile for all of the demand representative days was assumed to be zero. The reasoning for this was that the peak demand representative days in winter, intermediate warm and summer all coincide with a cold day where domestic air conditioning was assumed not to be in use. In the South Wales, the summer peak generation representative day is a solar PV dominated day. As a result, it was assumed that there would be a demand for domestic air conditioning on a warm sunny day. The half hourly profile used for the summer peak generation representative day was taken from the domestic air conditioning load on a peak summer day, for a mid-level of cooling degree days (CDDs).

Conventional Demand Growth

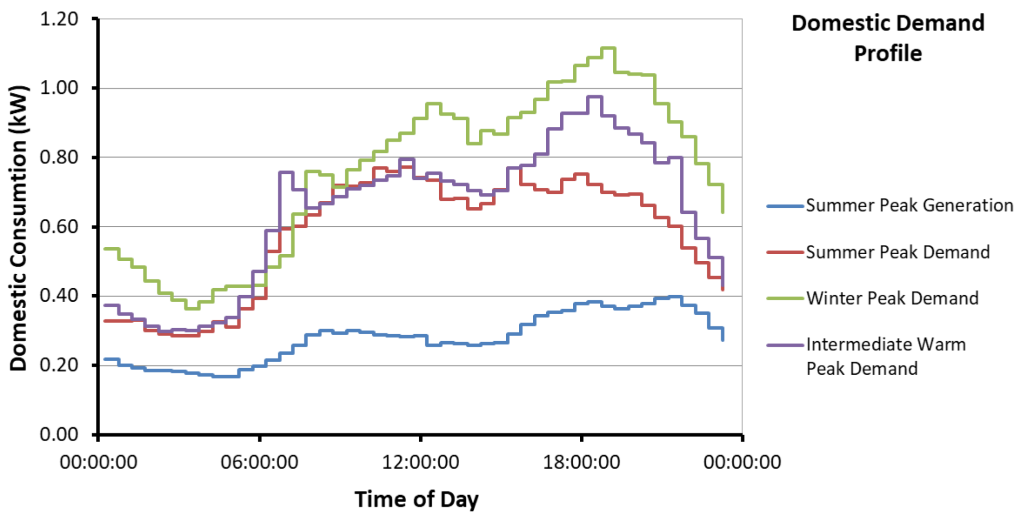

Figure 23: Diversified domestic profile (per house)

The industrial and commercial (I&C) demand growth is measured as a floor space in m^2 expected to be built in the region out to 2032. Regen were provided with a list of fifteen different industrial and commercial demand categories, which were derived from the 'Modelling Demand Profiles in the I&C Sector' innovation project run by Western Power Distribution;

- Factory and warehouse
- Government
- Hospital
- Hotel
- Hypermarket
- Medical
- Office
- Other
- Police
- Restaurant
- Retail
- Shop
- School and college
- Sport and leisure
- University

The fifteen demand categories each have an associated scaling factor to relate the energy consumption in kWh from the development size in m^2. The methodology used for the demand profiles was the same as was used in the West Midlands Shaping Subtransmission study, where aggregated and anonymised half hourly customer metering data was used to obtain a separate profile for each representative day and industrial/commercial demand category. These individual profiles were scaled around the peak half hour of energy consumption as derived from the output of the innovation project. Each individual development in the Regen forecast was assigned a profile and overlaid onto the network model.

132 kV Demand Customers

The South Wales network supplies a number of large demand customers with 66 kV or 132 kV connections or dedicated grid transformers (GTs) at WPD BSPs. Such customers often do not have a regular daily or seasonal demand profile. As a result, the assumed profile for these 132 kV customers is:

- Peak Demand days (Summer, Intermediate Warm and Winter): continuous demand at agreed supply capacity, and
- Summer Peak Generation day: zero demand.

Generation Profiles

Solar PV

Real power output data from all Solar PV generation sites in the South Wales licence area was collected and aggregated by each half hour for 2017/18. Only PV sites with an installed capacity greater than or equal to 1 MW were considered. The PV generator data sample comprised 90 sites, with an installed capacity of 532 MW. The geographical spread of solar PV sites in the data sample is shown Figure 24.

The generation output profiles are for a 24 hour period and consist of 48 data points (48 half hourly readings). A generation profile was created for each of the four representative days and only generation data from the respective representative day and season was considered. Once the generation meter data had been aggregated together, an actual days' worth (48 half hourly readings) of data was selected. The data for each generation profile was selected in the following way:

- **Winter Peak Demand:** Considers data in the months between December and February. The peak power output was found for each day and the day with minimum peak power output was selected.
- **Summer Peak Demand:** Considers data in the months between June and August. The peak power output was found for each day and the day with minimum peak power output was selected.
- **Summer Peak Generation:** Considers data in the months between June and August. The peak power output was found for each day and the day with Maximum peak power output was selected.
- **Intermediate Warm Peak Demand:** Considers data in the months of May, September and October. The peak power output was found for each day and the day with minimum peak power output was selected.

Figure 25 through Figure 26 show the PV generation profiles that were imposed on the network models.

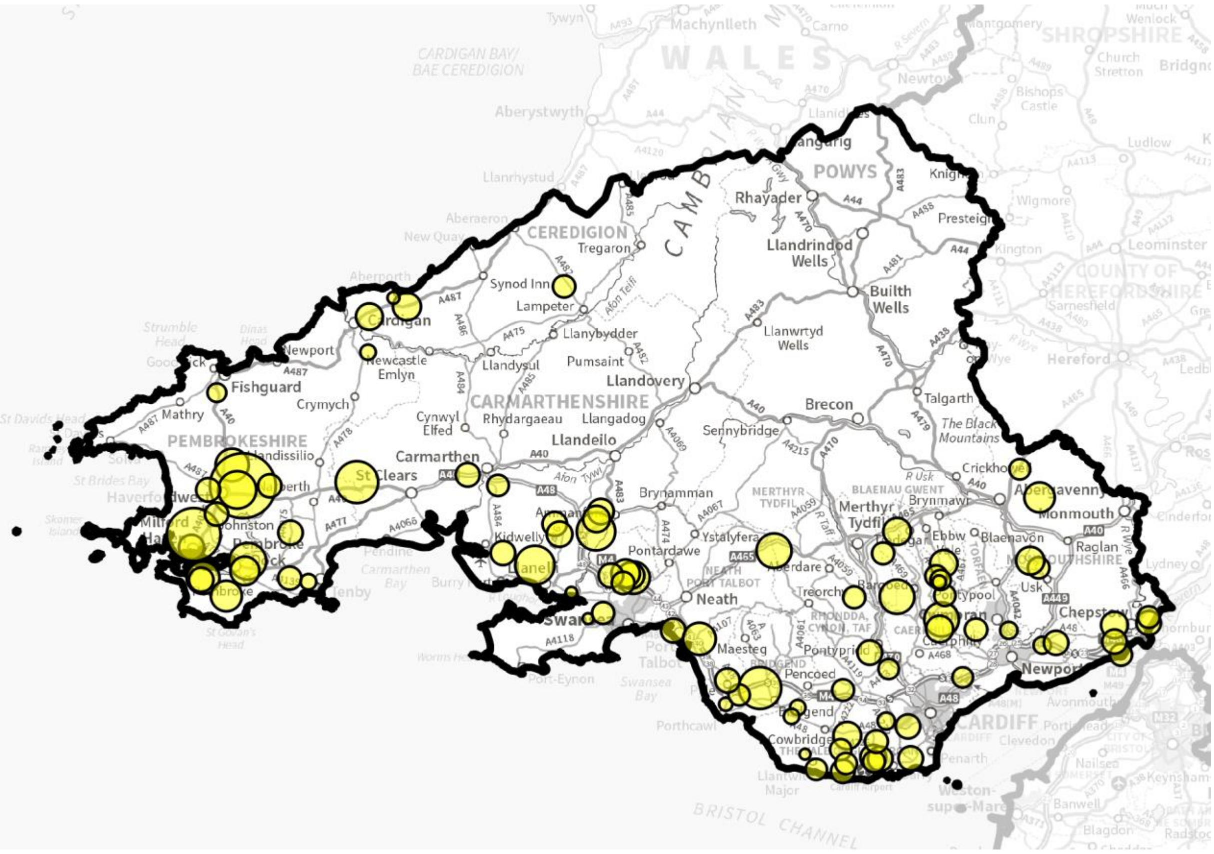

Figure 24: Map of Solar PV sites contributing to generation profiles; symbol area proportional to installed capacity [MW]

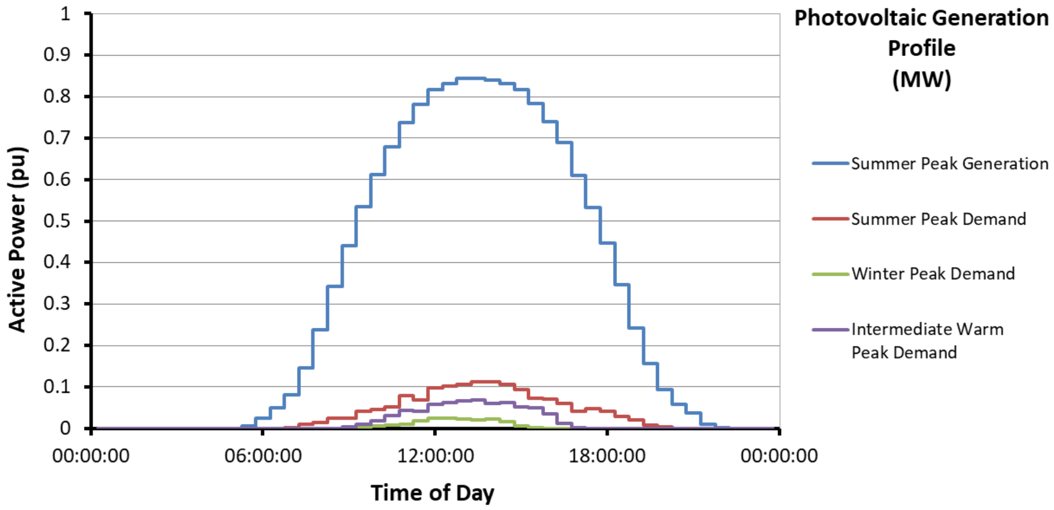

Figure 25: Normalised PV generation profile for each representative day

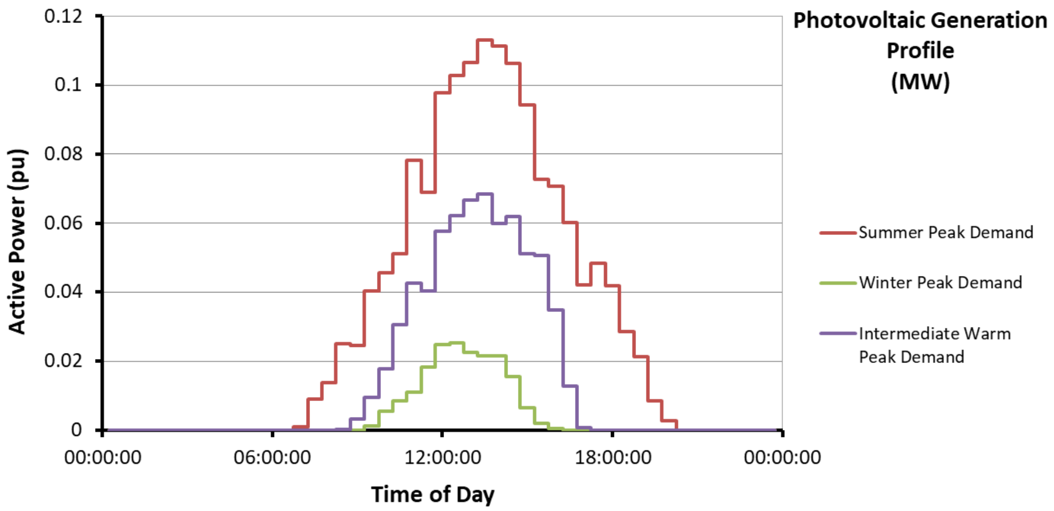

Figure 26: Detailed view of normalised PV generation profiles used for the Summer Peak, Intermediate Warm Peak and Winter Peak demand representative days

Onshore Wind

A similar process used for the PV generation profiles was used to create the Onshore Wind profiles. The wind generator data sample comprised 26 sites, with an installed capacity of 435 MW. The generation output profiles are for a 24 hour period and consist of 48 data points (48 half hourly readings). A generation profile was created for each of the four representative days and only generation data from the respective representative day and season was considered. Once the generation meter data had been aggregated together, an actual days' worth (48 half hourly readings) of data was selected. The data for each generation profile was selected in the following way:

- **Winter Peak Demand:** Considers data in the months between December and February. The peak power output was found for each day and the day with minimum peak power output was selected.
- **Summer Peak Demand:** Considers data in the months between June and August. The peak power output was found for each day and the day with minimum peak power output was selected.

- **Summer Peak Generation:** Considers data in the months between June and August. The peak power output was found for each day and the day with Maximum peak power output was selected.
- **Intermediate Warm Peak Demand:** Considers data in the months May, September and October. The peak power output was found for each day and the day with minimum peak power output was selected.

Figure 28 through Figure 29 show the Wind generation profiles that were imposed on the network models.

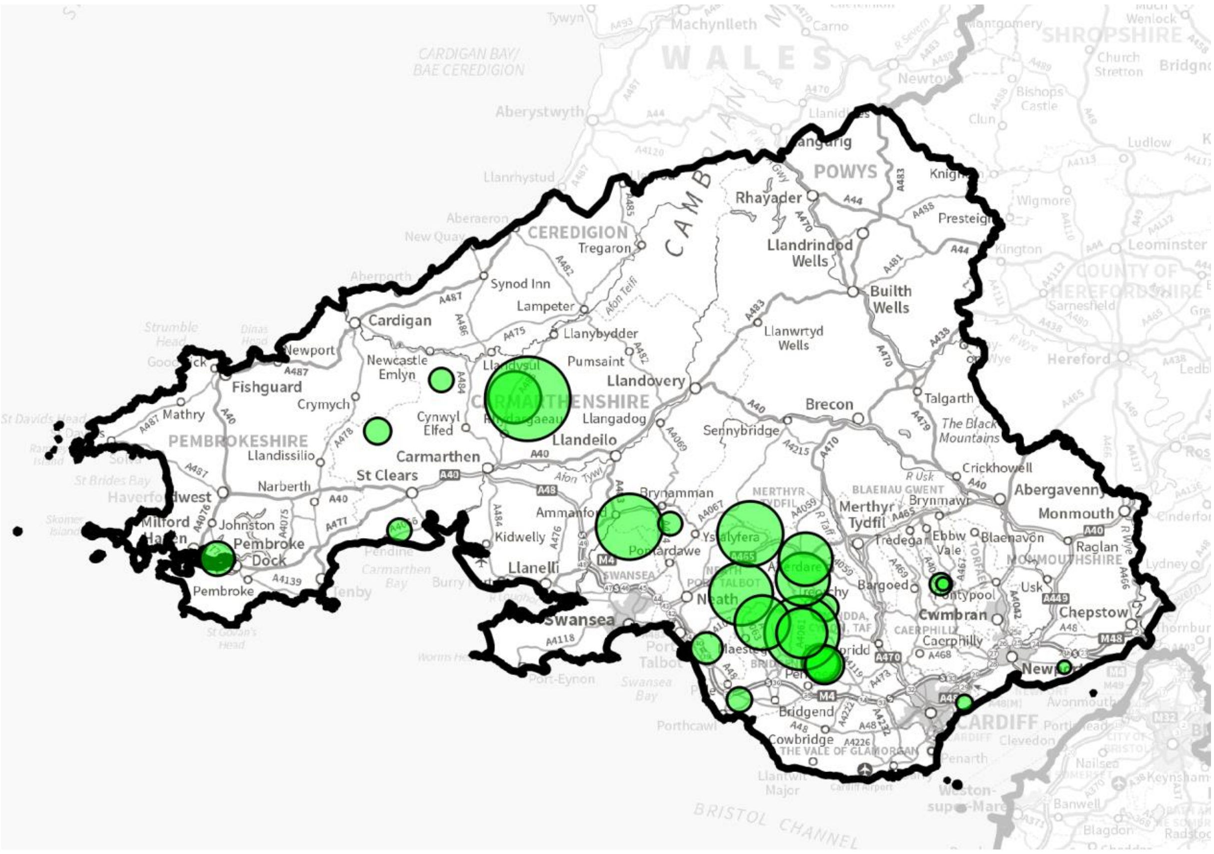

Figure 27: Map of Onshore Wind sites contributing to generation profiles; symbol area proportional to installed capacity [MW]

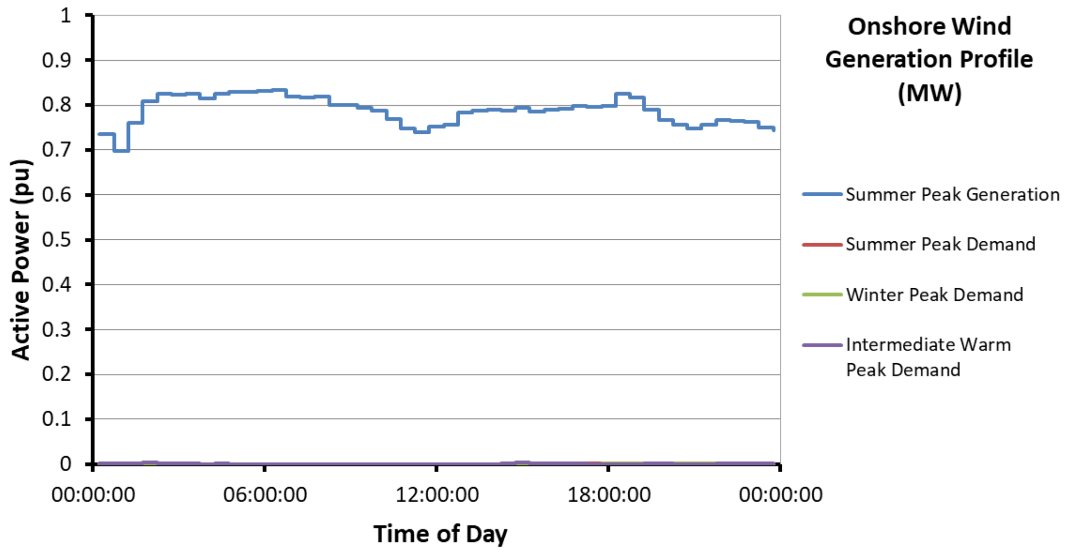

Figure 28: Normalised Onshore Wind generation profile used for each representative day. Note that due to the scale, the profiles for the demand days are shown near zero.

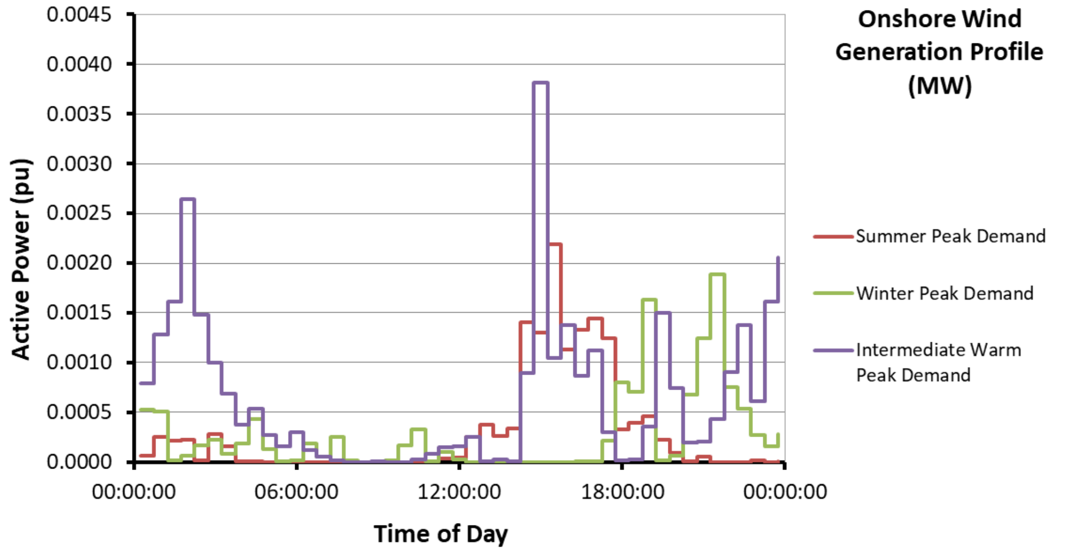

Figure 29: Detailed view of normalised Onshore Wind generation profiles used for the Summer Peak, Intermediate Warm Peak and Winter Peak demand representative days

Other Generation

The remaining DG types modelled were:

- Anaerobic Digestion
- Deep Geothermal
- Floating wind and wave energy
- Energy from waste
- Hydropower
- Non-renewable Distributed Generation – including diesel and gas

Insufficient data was available to derive profiles from measured flows for these technologies. In the case of infrequently-dispatched non-intermittent generation, measured flows may not reflect the potential network impact. Instead, a flat (continuous output) profile was assumed for each representative day, representing the realistic behaviour that would have the worst impact upon the network. These were assumed as follows.

- Summer Peak Generation day: continuous export at agreed supply capacity, and
- Peak Demand days (Summer, Intermediate Warm and Winter): zero export.

Storage Profiles

WPD has been working with Regen to develop an approach to model the growth and operation of storage. As part of this modelling work, a consultation paper was developed and issued aiming to validate some of the key assumptions used to model energy storage. The results from the consultation paper have been published and can be found on our website at:

www.westernpower.co.uk/energystorage

The consultation paper proposed different energy storage business models and asked for feedback on the behaviour of energy storage in each of these business models. One noteworthy response to the consultation was that customers expressed a desire to be able to 'stack' different business models and revenue streams. Respondents also identified a preference not to commit to a specific operating mode, as the evolving nature of procurement of balancing services by the GBSO in the future may change some of the proposed operating modes.

The consultation responses demonstrated that energy storage customers prefer flexibility to operate energy storage without a specific operating profile. As a result, the profile assumptions used in this study are:

- Peak Demand days (Summer, Intermediate Warm and Winter): continuous demand at agreed import capacity, and
- Summer Peak Generation day: continuous generation at agreed export capacity.

This unconstrained mode of operation is onerous for networks. In some cases, it may trigger major reinforcements that would prove unnecessary with relatively minor changes in the behaviour of energy storage connections. The energy storage profiles will be reviewed in future studies, with the expansion of the suite of representative days to assess the energy curtailment impact of measures such as ANM and DSR.

6 – Results Overview

Results are given by year, GSP and network area within GSP. The scenarios to which particular results apply are identified with the following logos beside section headings:

CP Consumer Power	TD Two Degrees
SS Steady State	SP Slow Progression

The severity of a particular network deficiency often varies between scenarios. Where this variation is material, it is described in the text.

Where a network deficiency is identified, potential reinforcements or mitigations are identified in bold.

Note that under intact conditions, ONAN ratings have been assigned to transformers fitted with forced cooling. This ensures that transformers are not prematurely aged by prolonged high loading. More detail on the ratings assigned to transformers is given in Chapter 11 – Definitions and References.

Demand results at a glance

Table 5: Summary of demand-driven network deficiencies by year, scenario and GSP group

GSP Group	2022				2027			
Pembroke	SS	SP	CP	TD	SS	SP	CP	TD
Swansea North	SS	SP	CP	TD	SS *	SP *	CP *	TD *
Pyle	SS	SP	CP	TD			CP	TD
Margam								
Upper Boat	SS	SP	CP	TD			CP	TD
Aberthaw and Cardiff East	SS	SP	CP	TD	SS	SP	CP	TD
Uskmouth	SS	SP	CP	TD	SS *	SP *	CP *	TD *
Rassau	SS	SP	CP	TD	SS *	SP *	CP *	TD *

* Swansea North, Uskmouth and Rassau GSPs were not studied in detail against the 2027 scenarios due to the sheer scale of growth in the 2022 scenarios.

Generation results at a glance

Table 6: Summary of generation-driven network deficiencies by year, scenario and GSP group

GSP Group	2022				2027			
Pembroke	SS	SP	CP	TD				TD
Swansea North	SS	SP	CP	TD	SS *	SP *	CP *	TD *
Pyle	SS	SP	CP	TD			CP	TD
Margam								TD
Upper Boat				TD				
Aberthaw and Cardiff East	SS	SP	CP	TD	SS	SP	CP	TD
Uskmouth	SS	SP	CP	TD	SS *	SP *	CP *	TD *
Rassau	SS	SP	CP	TD	SS *	SP *	CP *	TD *

* Swansea North, Uskmouth and Rassau GSPs were not studied in detail against the 2027 scenarios due to the sheer scale of growth in the 2022 scenarios.

Assessing Network Access Requirements

There are two broad classes of network outage:

- **Fault outages:** when a component of the network fails, it is detected by protection relays which open the circuit breakers enclosing the failed component. This de-energises the network between those circuit breakers, so clearing the fault. By their nature, fault outages cannot be predicted so may be expected to happen at any time.
- **Arranged outages:** each component of the network needs to be accessed for periodic or condition-driven inspection, maintenance and replacement. Similarly, access may be required for reinforcement or to make new connections. The minimum zone to access any particular component is usually defined by the isolators enclosing the component. The scheduling of arranged outages is flexible to some extent, so can take advantage of seasonal variation in network loading.

Since any component of the network could fail, it is necessary to assess the impact of each credible fault outage on the network. Since each component of the network will need to be accessed eventually, it is necessary to assess the impact of each credible arranged outage on the network. These are both types of *First Circuit Outage (FCO)*.

Combining these two requirements, it is also possible that a network component could fail during access to another network component. It is therefore also necessary to assess the impact of each credible fault outage during each credible arranged outage. Each combination is a *Second Circuit Outage (SCO)*.

Case Study: Three-circuit Group

Some areas of network are operated with three (or more) circuits in parallel, feeding a group demand of less than 300 MW. Below that threshold, P2/6 has no requirement for demand to be supplied immediately following a second circuit outage. This does not, however, mean that the possibility of an SCO can be ignored.

Consider the network shown in Figure 30. Each of the circuits A, B and C has a rating of 90 MVA. The three circuits share load evenly. The seasonal peak demand at the 33 kV bar of the BSP is:

- Summer peak demand: 85 MW
- Intermediate warm peak demand: 105 MW
- Winter peak demand: 125 MW

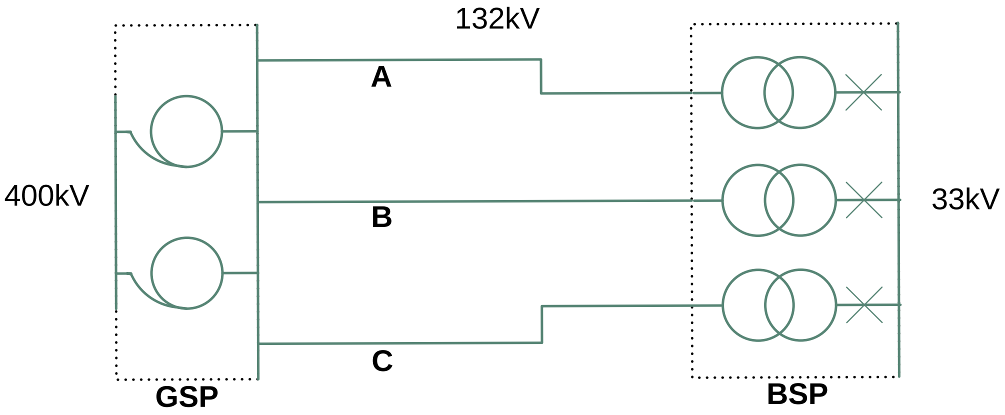

Figure 30: Three-circuit group example network

The group demand is the maximum of the seasonal peak demands, 125 MW. This puts the group into class D of P2/6. This requires that:

1. For a circuit fault from an intact network (FCO fault):
    a. Group demand minus up to 20 MW (automatically disconnected), i.e. 105 MW, is met immediately; and
    b. Group demand is met within three hours.
2. For a circuit fault during an arranged outage (SCO):
    a. Group demand minus 100 MW, i.e. 25 MW, is met within three hours; and
    b. Group demand is met within the time taken to restore the arranged outage.

The FCO of one of the three circuits leaves the prevailing demand of the group fed by the remaining two circuits, total rating 180 MVA. Since the group demand of 125 MW is well within the capability of the circuits, this meets the requirements of P2/6 without compromising network integrity.

The SCO of any two of the three circuits leaves the prevailing demand of the group fed by the remaining circuit, rating 90 MVA. While the remaining circuit is sufficient to supply the demand required by P2/6 (25 MW), the actual impact on the network depends on the prevailing demand:

- In summer, the demand of 85 MW is within the capability of the remaining circuit
- In Intermediate Warn, the demand of 105 MW overloads the remaining circuit
- In winter, the demand of 125 MW overloads the remaining circuit

This overload is unacceptable, so steps should be taken to prevent it. Options include:

1. Only taking the arranged outages of the three circuits in summer.
2. Reinforcing all three circuits so that any one circuit can support the group demand of 125 MW.
3. Splitting the 33 kV bar and downstream network into two sections for the duration of the arranged outage, with each section connected to one of the circuits and a 62.5 MW demand group. If a fault occurs during an arranged outage, half of the demand would be disconnected, but the remaining circuit would not be overloaded.
4. Installing intertripping or overload schemes to detect and trip any circuit that is overloaded.

5. Contracting with any dispatchable generators within the 33 kV network to operate during arranged outages to reduce the net demand of the group.

Several areas of the South Wales subtransmission network exhibit similar network access constraints to this case study. Some of these areas were found to have an access window which is limited to summer. This may be acceptable for some areas, but if large parts of the network have narrow, coincident access windows, that may conflict with scheduling requirements for specialist staff and equipment.

It is recommended that techniques for assessing the sufficiency of available access windows are formalised.

Seasonal ratings

The ratings of most electrical circuits vary with seasonal changes, particularly ambient temperature. Traditionally, distribution networks have only been assessed for ‘edge-case’ conditions, and so some circuits have only had ratings assigned for the season(s) pertinent to those edge-cases.

In order to economically and efficiently facilitate the connection of new types of demand, generation and storage, it is becoming necessary to assess network capacity and utilisation all year round. As we develop new analysis techniques to assess year-round network capability, some limitations in our existing ratings methodologies have been identified.

Overhead line ratings

An NIA project to improve the accuracy of overhead line ratings, *Improved Statistical Ratings for Distribution Overhead Lines*, is approaching completion. It is intended that the results of this project are used to revise the ENA standard for overhead line ratings, ER P27. The project identified that some of the traditional seasons used for ratings do not align well with seasonal changes in network loading and ambient temperature. For example, assessment of autumn peak demand against an autumn rating compares a demand that is likely to be driven by cold weather in late November against a rating that is constrained by warm weather in September. To mitigate this effect, the project proposes new seasonal definitions, shown in Table 7. These seasons have been chosen to limit the variation in ambient temperature-related demand behavior during any one season.

Table 7: Changing seasons for overhead line ratings

<table>
<tr><th>Month</th><th>Old season (WPD’s ST:SD8A/2)</th><th>New season (proposed P27/1)</th></tr>
<tr><td>January</td><td rowspan="2">Winter</td><td rowspan="2">Winter</td></tr>
<tr><td>February</td></tr>
<tr><td>March</td><td rowspan="2">Spring</td><td rowspan="2">Intermediate Cool</td></tr>
<tr><td>April</td></tr>
<tr><td>May</td><td rowspan="4">Summer</td><td>Intermediate Warm</td></tr>
<tr><td>June</td><td rowspan="3">Summer</td></tr>
<tr><td>July</td></tr>
<tr><td>August</td></tr>
<tr><td>September</td><td rowspan="3">Autumn</td><td rowspan="2">Intermediate Warm</td></tr>
<tr><td>October</td></tr>
<tr><td>November</td><td>Intermediate Cool</td></tr>
<tr><td>December</td><td>Winter</td><td>Winter</td></tr>
</table>

For this project, the assessed seasons have been aligned with the proposed P27/1, and draft overhead line ratings to the proposed P27/1 methodology have been used.

Transformer ratings

WPD's transformer ratings standard includes ratings for summer and winter, but not for intermediate seasons. In order to assess transformers for the Intermediate Warm Peak Demand representative day, it was necessary to estimate Intermediate Warm transformer ratings. Summer emergency ratings were used as a proxy to Intermediate Warm cyclic ratings in the studies.

It is recommended that the new seasons used in the proposed revision to ER P27 are also used to recalculate a wider suite of transformer ratings. The calculation of cyclic ratings should take into account changing load profiles.

7 – Baseline Results

Pembroke GSP

Figure 31: Areas fed from Pembroke GSP

Pembroke-Swansea North parallel

Pembroke GSP and Swansea North GSP are run independently at 132 kV, with the A-route circuit offering interconnection between the two GSPs. For an arranged outage of an SGT at Pembroke, this interconnecting circuit (between Haverfordwest 405 and Carmarthen 805) is switched in to parallel Swansea North and Pembroke at 132 kV. The circuit breaker at Haverfordwest is fitted with overload protection, which is intended to operate when the circuit loading is above 500A (DT, 3 seconds), a condition which could happen for a double SGT outage SCO condition.

In the baseline studies the group demand of Pembroke GSP is 186 MW, which falls into Class D of P2/6. For a summer peak demand case the demand of the group does not fall below 127 MW. This is largely due to the high amount of industrial customers which are modelled at full import capacity for all half hours of all peak demand representative days. As a result, for the SCO combination which results in a double SGT loss at Pembroke, the overload trip would operate for all half hours of all peak demand representative days and result in the loss of the entire Pembroke group. The overload trip will not operate if the group demand of the Pembroke network does not exceed 107 MW.

It is recommended that further study is undertaken to determine the available access window is for the arranged outage of an SGT at Pembroke. If the group demand does not fall below 107 MW in the available access window, the overload trip scheme will always operate and effectively leaves Pembroke at single circuit risk for the arranged outage.

132 kV Circuit Overloads

The Milford Haven, Golden Hill and Haverfordwest BSP group is run in parallel at 33 kV with 5 grid transformers in the group fed from Pembroke GSP. There are two transformers at each of Golden Hill and Haverfordwest, another transformer is connected onto the 8 corner mesh at Milford Haven. The group is fed via three 132 kV circuits:

- The AW-route from Pembroke 305 to Milford Haven 603, teed onto the RR-route (Waterston Gulf GT1),
- The CW-route from Pembroke 105 to Golden Hill GT1, teed onto the EE-route (Milford Haven 803),
- A cable circuit from Pembroke 205 to Golden Hill GT2, also teed onto the EE-route (Milford Haven 203)

CW-route overloads

For an arranged outage of the Main 2 busbar at Golden Hill followed by a circuit fault of the AW/RR-route circuit, the group is fed from the one remaining circuit in service (CW-route). For a summer peak generation case, this would overload the CW-route up to 112%.

The CW-route is currently 175mm² ACSR (Lynx) profiled for 75°C operation.

It is recommended that operational measures are taken to prevent this overload.

AW/RR-route overloads

For an arranged outage of the cable circuit between Pembroke and Golden Hill GT2 followed by the circuit fault of the CW/EE-route between Pembroke-Golden Hill GT1-Milford Haven, the group is fed from the one remaining circuit in service (AW/RR-routes). This SCO combination would overload the AW and RR-routes for a summer peak generation case, up to 106% (AW-route) and 102% (RR-route).

The limiting sections of the AW-route are the overhead trident sections, which for these studies are being studied as 250mm² AAC (Cockroach) profiled for 60°C operation, with a summer rating of 139 MVA. It had previously been surveyed for reprofiling based on the assumption that these sections were 250mm² AAAC (Sycamore). It is recommended that work is done to determine what the cable is on the AW-route, and whether it can be reprofiled for 75°C operation. If it is reprofiled to 75°C operation, this would remove the overloads in the baseline studies.

The RR-route is currently 175mm² ACSR (Lynx) profiled for 75°C operation.

It is recommended that operational measures are taken to prevent these overloads.

Cable Circuit from Pembroke to Golden Hill GT2

For an arranged outage of the AW/RR-routes between Pembroke and Milford Haven followed by the circuit fault of the CW/EE-route between Pembroke and Golden Hill, the group is fed from the one remaining cable circuit in service between Pembroke and Golden Hill. This SCO combination would overload the circuit for a summer peak generation case up to 109%.

It is recommended that operational measures are taken to prevent this overload.

Swansea North GSP

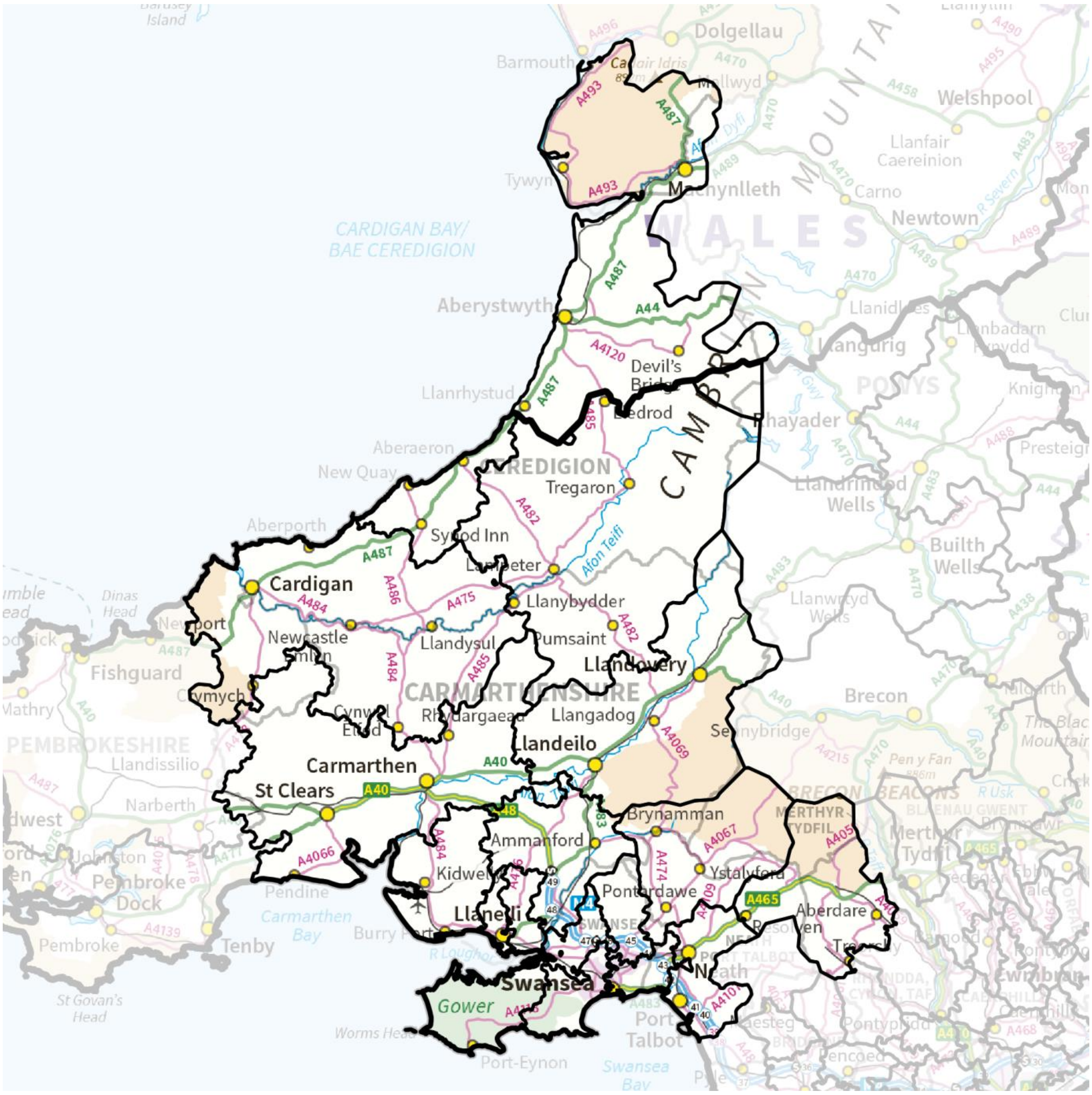

Figure 32: Areas fed from Swansea North GSP

P18 Assessment

The 132 kV group consisting of Ammanford BSP, Ystradgynlais BSP and Hirwaun BSP is fed via 2 132 kV circuits on the PP/C/D-routes from Swansea North, which is held normally open on line breakers 305 and 405 at Hirwaun BSP, with no 132 kV bussing between the two circuits. There are also two 132 kV connected wind farm on the southern side of the C-route and D-routes. The two circuit breakers (405 and 605) at Ystradgynlais and two normally open circuit breakers at Hirwaun (305 and 405) are functional switches, therefore are not capable of operating for the isolation of faults. This makes 6 different sites in the group – from a P18 perspective:

- The Swansea North-Ammanford GT1-Travellers Rest GT1-Hirwaun GT2 circuit is compliant with P18 restriction A (*"The normal operating procedure or protective gear operation for making dead any 132 kV circuit shall not require the opening of more than seven circuit-breakers. These circuit-breakers shall not be located on more than four different sites")* as for a fault, 4 circuit breakers must be opened at 4 different sites.
- The Swansea North-Ammanford GT2-Bettws WF-Travellers Rest GT2-Maesgwyn WF-Hirwaun GT1 circuit exceeds the limits recommended in P18 restriction A (*"The normal operating procedure or protective gear operation for making dead any 132 kV circuit shall not require the opening of more than seven circuit-breakers. These circuit-breakers shall not be located on more than four different sites")* as for a fault, 6 circuit breakers must be opened at 6 different sites.
- Both circuits from Swansea North to Ammanford, Travellers Rest and Hirwaun are compliant with P18 restriction C (*"No item of equipment shall have isolating facilities on more than four different sites"*) as a maximum of 4 different sites are required to achieve isolation of this circuit.

Swansea North SGT Capacity

At Swansea North GSP, there is a 400 kV double busbar that supplies three 240 MVA 400/132 kV SGTs (SGT5, 6 and 7). On a separate 400 kV circuit, there is a 400/275 kV SGT4A, with feeds a further two 275/132 kV SGTs (SGT3 and 4B). The five 132 kV connected SGTs supply a 132 kV double busbar arrangement. This 132 kV board runs with a vertical split, with SGT5 and SGT6 connected to the Main 1 and Reserve 1 bars and SGT3 and SGT7 connected to the Main 2 and Reserve 2 bars. SGT4B is run on hot standby, with an auto-close scheme in place to operate for the loss of SGT7. For an arranged outage of an SGT, the site is modelled with the remaining three SGTs running in parallel.

In the baseline studies, the group demand of Swansea North GSP is 525 MW, with the group normally supplied via three 240 MVA SGTs and one 180 MVA transformer. For a fault which results in the loss of an SGT at Swansea North, the site is left with three SGTs supplying two sections of 132 kV bar. This fault would overload the remaining SGT in service supplying one of the two 132 kV bars, up to 104% for a winter peak demand case.

The overload can be alleviated by either switching in SGT4B (depending on the fault which occurs) or closing circuit breakers 120/160. This would be reliant on control room intervention to complete the action.

For the arranged outage of an SGT, the 120 and 160 circuit breakers are closed to run the site off three SGTs in parallel. When this arranged outage is followed by an SGT fault this leaves two SGTs in service. For this SCO combination, the remaining two SGTs in service would overload up to 118% for an intermediate warm peak demand case; however if one of the remaining SGTs in service is the smaller SGT3, this would overload up to 123% for an intermediate warm peak demand case.

This overload does not occur for summer peak demand case; although it is recommended that the adequacy of the available access window is assessed. SGT4B can also be switched in post fault to alleviate the overloads.

Other SGT overloads

For an arranged outage of Cilfynydd 305 circuit towards Swansea North Main 2 400 kV busbar, followed by a circuit fault of the Pembroke 205-Swansea North 505 circuit, this results in a poor load share between SGT3 (fed from Pembroke at 400 kV) and SGT7 (fed from the Swansea North 400 kV double busbar). As a result, SGT3 would overload up to 105% in summer and 117% for an intermediate warm peak demand cases. This overload would also occur up to 115% for a summer peak generation case.

For the arranged outage, if SGT4B is switched in instead of SGT7 this would improve the load share between the two SGTs feeding the Main 2 and Reserve 2 132 kV bars.

Hirwaun BSP

Hirwaun BSP has two 22.5/45 MVA grid transformers and is fed from Swansea North via the D-route 132 kV circuits. The D-route circuit connected to GT1 at Hirwaun also has Maesgwyn 132 kV wind farm connected to it. For a summer peak generation case, when Maesgwyn wind farm is exporting the load share between the grid transformers at Hirwaun is unequal. Under intact network conditions, GT2 at Hirwaun would operate into the forced cooling rating for 13 half hour periods on the summer peak generation case, as shown by Figure 33 below.

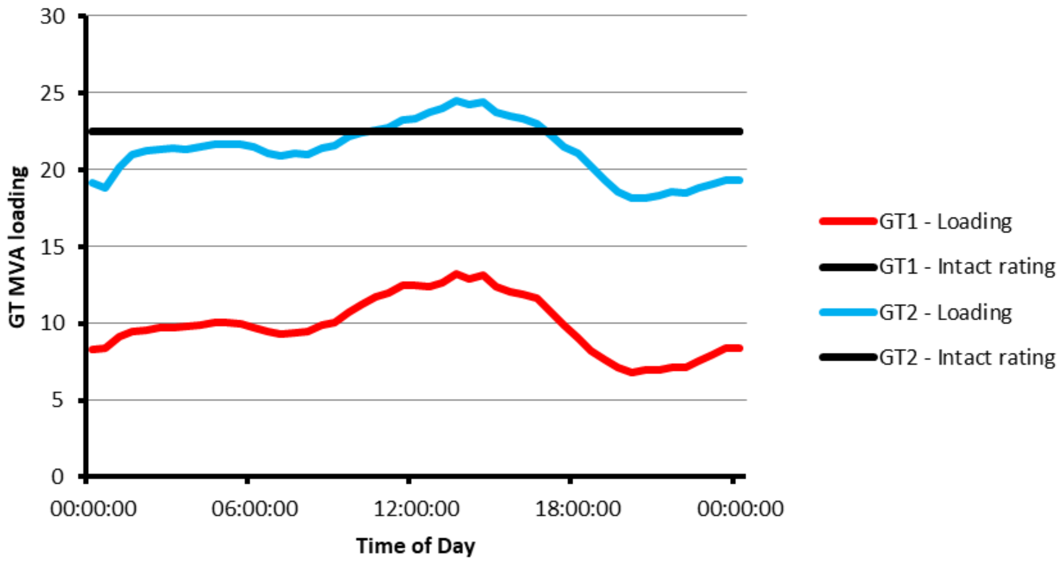

Figure 33: MVA loading on Hirwaun grid transformers for a summer peak generation representative day, baseline study

132 kV circuit issues

A-route

For an arranged outage of the circuit between Swansea North-Carmarthen-Rhos (which is carried on numerous 132 kV circuits), the normally open A-route circuit between Carmarthen and Haverfordwest is switched in to provide support to the Carmarthenshire network from Pembroke. When this arranged outage is followed by a circuit fault between Carmarthen and Llanelli, both of the 132 kV infeeds from Swansea North to Carmarthen are lost and the group is entirely fed via Pembroke at 132 kV. The group encompasses Carmarthen, Rhos, Llanarth, Lampeter, Aberystwyth and Rhydlydan BSPs, as Ammanford BSP is split from the group for the arranged outage. For this SCO combination, the A-route circuit would overload up to 115% for an intermediate warm peak demand case.

This overload does not occur for summer peak demand case; although it is recommended that the adequacy of the available access window is assessed.

Voltage issues

A busbar fault of the Main 2 busbar at Swansea North for a summer peak generation case would result in high volts at 132 kV above 1.1 per unit at Aberystwyth, Rhydlydan and along the CC-route from Rhydlydan to Lampeter. This is in spite of the overvoltage trip operation to disconnect Cefn Croes wind farm.

For an arranged outage of Main 2 busbar at Llanelli, the normally open A-route circuit between Carmarthen and Haverfordwest is switched in to provide support to the Carmarthenshire network from Pembroke. When this arranged outage is followed by a circuit fault of the Swansea North-Carmarthen GT2-Rhos circuit (which is carried on numerous 132 kV circuits), the entire group is supplied at 132 kV via Pembroke and via the 33 kV interconnection with Ammanford BSP. This SCO combination would cause high volts at 132 kV above 1.1 per unit across Rhos, Llanarth, Lampeter, Aberystwyth and Rhydlydan for a summer peak generation case. This is in spite of Blaengwen wind farm being switched out for the arranged outage and the overvoltage trip operation to disconnect Cefn Croes wind farm following the second circuit fault.

For an arranged outage to maintain isolator 603 at Swansea North, the normally open A-route circuit between Carmarthen and Haverfordwest is switched in to provide support to the Carmarthenshire network from Pembroke. For this arranged outage, GT2 at Carmarthen is fed via the 132 kV mesh at Rhos BSP. When this arranged outage is followed by a circuit fault between Swansea North and Llanelli, both of the 132 kV infeeds from Swansea North to Carmarthen are lost and the group is entirely fed via Pembroke at 132 kV. The group encompasses Carmarthen, Rhos, Llanarth, Lampeter, Aberystwyth and Rhydlydan BSPs for a summer peak generation case, as Ammanford BSP is split from the group for the arranged outage. This SCO combination would cause high volts above 1.1 per unit across Rhos, Llanarth, Lampeter, Aberystwyth, and Rhydlydan and along the numerous 132 kV circuits from Carmarthen to Swansea North and Llanelli. This is in spite of Blaengwen wind farm being switched out for the arranged outage and the overvoltage trip operation to disconnect Cefn Croes wind farm following the second circuit fault.

It is recommended that a detailed study of voltage performance in the Carmarthenshire and West Wales area is carried out. This should include study into the AVC settings at Pembroke GSP and Aberystwyth and Rhydlydan BSPs to ascertain if measures can be taken to prevent 132 kV overvoltages.

Carmarthenshire and West Wales

The 132 kV circuits from Swansea North into the area north of the GSP (encompassing the B, C, CC, H, V, W, W23 and XY routes) provide supplies to Llanelli, Carmarthen, Rhos, Lampeter and Llanarth BSPs and also supply the SP Manweb network in the Aberystwyth area. In addition, there are three 132 kV connected wind farms in the area; Blaengwen and Brechfa West wind farm, which is geographically close but is supplied on a separate 132 kV circuit; also Cefn Croes which is in the SP Manweb area of network. Carmarthen, Rhos, Lampeter and Llanarth BSPs are run in parallel at 33 kV; this group also contains Ammanford BSP which is also supplied from Swansea North. This 33 kV group contains seven grid transformers across 5 different sites.

With no pre-emptive action taken for arranged outages, this area would be heavily reliant on control engineer intervention to resolve overloading or cascade failure following a second circuit fault. An example of this is for an arranged outage to maintain the Main 2 busbar at Carmarthen, followed by the circuit fault between Swansea North-Carmarthen GT2-Rhos. This SCO combination removes all sources of 132 kV infeed into the Carmarthen group (as a result of the arranged outage the A-route interconnector is not available). This leaves the entire Carmarthenshire group supplied via the two grid transformers at Ammanford and the long 33 kV interconnecting circuits, which would result in very low volts and back-energised grid transformers to supply the SP Manweb areas.

Whilst it is recognised that aggregating demand and generation at the 33 kV bars of BSPs in these studies may exacerbate some contingencies, for these studies a variety of 33 kV splits have been modelled. These 33 kV splits are intended to run the BSPs in smaller independent groups, where any SCO combination does not result in grid transformer overloads or the 132 kV network being back energised by a 132/33 kV grid transformer.

Aberystwyth and Rhydlydan BSP

A pair of 132 kV circuits to the North of Rhos BSP supplies four separate single transformer BSPs; Llanarth and Lampeter in WPD's South Wales area, also Aberystwyth and Rhydlydan BSPs in SP Manweb's licence area. In these studies the grid transformers at Aberystwyth and Rhydlydan are modelled as 45 MVA fixed rating and the BSPs are run in parallel at 33 kV. There is also the Cefn Croes 132 kV connected wind farm which is teed onto the Rhos-Lampeter-Rhydlydan circuit. In these studies, the output of this wind farm is constrained down to zero for an arranged outage which results in 'any abnormal running of the Rhos 132 kV ring'. There is also an overvoltage trip modelled, where the 132 kV circuit breaker at Cefn Croes will operate if the measured voltage is above 1.1 per unit.

In the baseline studies, there is 83 MW of generation connected to the 33 kV bars at Aberystwyth and Rhydlydan, which run in parallel at 33 kV. At the time of summer peak generation, the net export of the group is 64 MW. For an arranged outage or fault of the grid transformer at Rhydlydan, this leaves the entire group exporting via the grid transformer at Aberystwyth. For the FCO this would overload GT2 at Aberystwyth up to 138% for a summer peak generation case.

Similarly, for an arranged outage or fault of GT2 at Aberystwyth this leaves the entire group exporting via the grid transformer at Rhydlydan. In addition, for the arranged outage the 132 kV connected Cefn Croes wind farm is not switched out. The FCO would overload GT1 at Rhydlydan up to 138% for a summer peak generation case. The CC-route circuit between Rhydlydan-Lampeter tee-Rhos would also overload for this FCO up to 111% (Rhydlydan to Lampeter tee) and 104% (Lampeter tee to Rhos)

It is recommended that the Aberystwyth and Rhydlydan directional overcurrent (DOC) settings are obtained in addition to any intertripping schemes at 33 kV for the SP Manweb operated area fed from Swansea North.

Pyle GSP

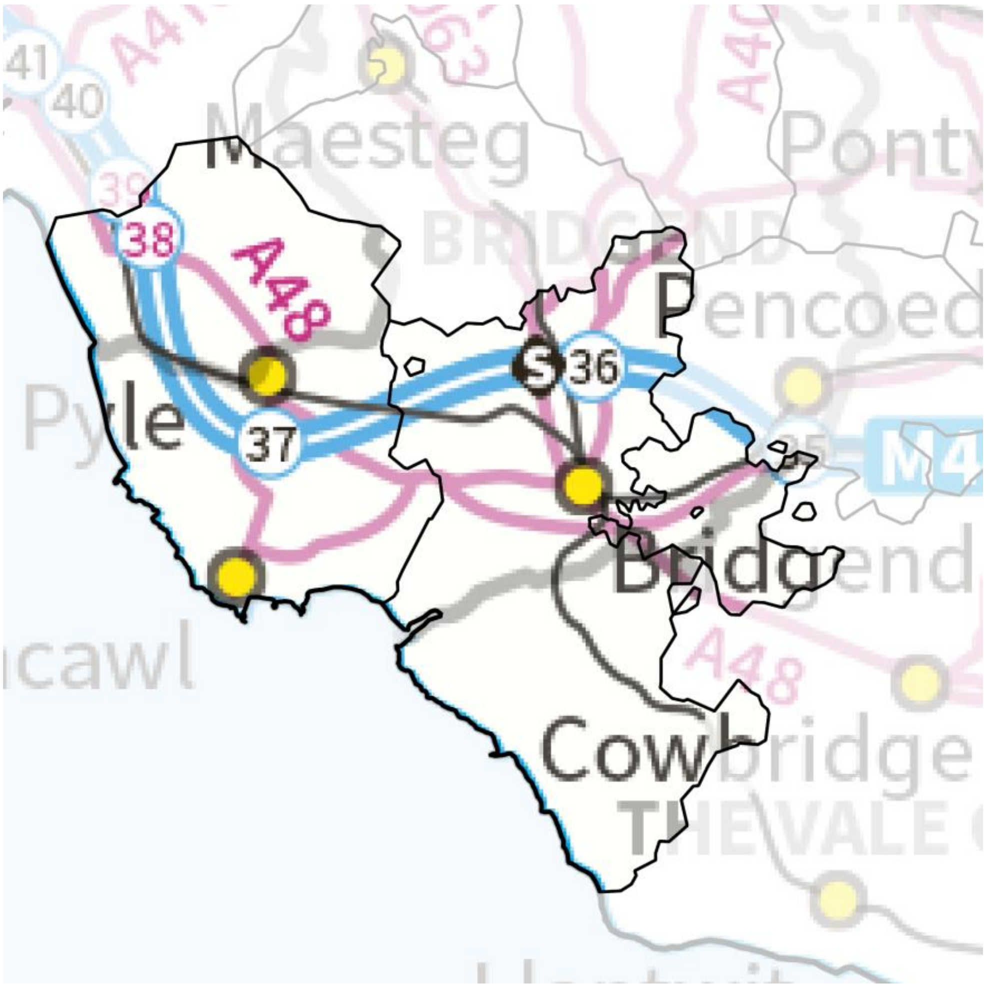

Figure 34: Areas fed from Pyle GSP

Pyle GSP contains two 275/132 kV SGTs and provides normally open interconnection with Swansea North and Upper Boat GSPs.

Pyle GSP also supplies the 66 kV networks associated with Margam GSP under abnormal conditions. Potential overloads of Pyle SGT1 under these conditions are described in the Margam GSP Baseline results.

P18 Compliance

The 132 kV group consisting of Bridgend BSP, Fords Bridgend BSP and Waterton Industrial BSP is fed via 2 132 kV circuits on the U-route from Pyle, which is held normally open on line breakers 105 and 205 at Pencoed BSP, with no 132 kV bussing between the two circuits. This makes 5 different sites in the group – from a P18 perspective:

- Both circuits into the group are compliant for P18 restriction A (*"The normal operating procedure or protective gear operation for making dead any 132 kV circuit shall not require the opening of more than seven circuit-breakers. These circuit-breakers shall not be located on more than four different sites")* as both circuits require circuit breakers to be opened at 4 different sites.
- The Pyle 605-Bridgend 203 and Bridgend 403-Waterton GT2-Fords Bridgend GT2-Pencoed 205 circuits are compliant for P18 restriction C (*"No item of equipment shall have isolating facilities on more than four different sites"*) as for an arranged outage these are treated as

two distinct circuits. A maximum of 4 different sites are required to achieve isolation of this circuit.

- The Pyle 505-Bridgend GT1-Waterton GT1-Fords Bridgend GT1-Pencoed 105 circuit exceeds the limits recommended in P18 restriction C (*"No item of equipment shall have isolating facilities on more than four different sites"*) as five different sites are required to achieve isolation of this circuit.

GT overloads: Pyle 132 kV split node

For an arranged outage of circuit breaker 220 at Pyle this splits the 132 kV bar into two sections, SGT1 supplies the Main 1 and Main 2 busbars and SGT2 supplies the Main 3 busbar. The 132 kV network is remotely coupled via the 11 kV bars at BOC Margam, the 11 kV bars at Waterton Industrial and the 33 kV bar at Bridgend. If the arranged outage is followed by a fault of SGT1 at Pyle, the network supplied from SGT1 is fed via back-energising the GTs at BOC Margam, Waterton Industrial and Bridgend. This SCO combination would overload GT2 at BOC Margam for an intermediate warm peak demand case. This SCO combinations would also overload GT1 and GT2 for a summer peak generation representative day.

Currently, no actions are taken for the arranged outage to mitigate the further loss of an SGT. It is recommended that the 11 kV running arrangement at BOC Margam is studied in detail. If the BOC Margam 11 kV bus sections were to run split, this SCO combination would overload GT2 at Bridgend as the next lowest impedance path to supply the Main 1 and Main 2 busbars at Pyle. In these studies for the arranged outage of Pyle 220, the line breaker 405 between Pyle and Swansea North is closed to run Pyle and Swansea North in parallel. Detailed protection studies should be undertaken to determine if this is a credible running arrangement.

Pyle to Upper Boat transfers

For an arranged outage which results in the loss of an SGT at Pyle, these studies have modelled a transfer of Bridgend BSP, Fords Bridgend BSP and Waterton Industrial onto Upper Boat GSP via the normally open circuit breakers at Pencoed BSP. Likewise, for an arranged outage that leaves Pontyclun and Pencoed BSPs at single circuit risk, Pontyclun and Pencoed are currently transferred onto Pyle GSP. The Upper Boat baseline studies also showed a number of Upper Boat 132 kV busbar arranged outages that leave the network susceptible to the next fault splitting the Upper Boat busbar, causing thermal and voltage issues. More details can be found in the Upper Boat section of the report. This transfer results in a ladder network comprising of two 132 kV circuits which are loose-coupled via the 11 kV and 33 kV bars at several BSPs.

The thermal overloads as a result of the transfer from Pyle to Upper Boat are discussed in the Upper Boat results section of this report.

Transfers into Pyle

For an arranged outage whereby Pontyclun and Pencoed are transferred onto Pyle followed by a fault on the U-route circuit, the fault is cleared on the HV side of the grid transformers at Bridgend, Waterton and Fords Bridgend. As the circuit breakers 105 and 205 at Pencoed are functional switches, the fault zone will be extended to clear at the circuit breaker on the LV side of the grid transformer at Pencoed and the corresponding line breaker towards Pontyclun. The resultant network contains Bridgend, Waterton Industrial, Fords Bridgend and Pencoed fed radially with one grid transformer in service at each BSP. Pontyclun is fed from the remaining healthy circuit but also with the other grid transformer energised at 132 kV up to the open point at Talbot Green and the open circuit breaker (as a result of the fault) at Pencoed. This SCO combination causes high volts on the back-energised grid transformer and 132 kV network fed from Pontyclun for all representative days.

Margam GSP

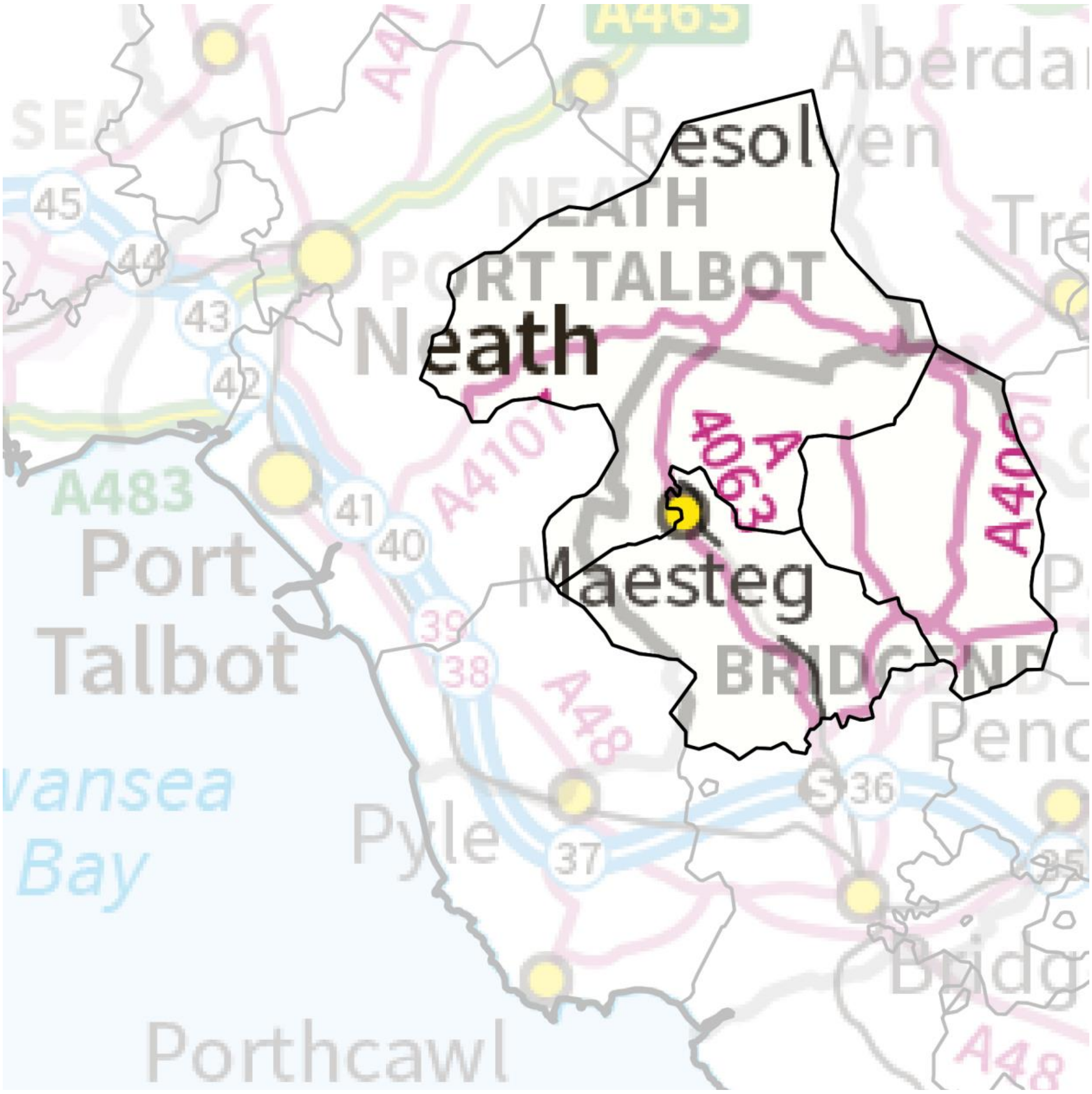

Figure 35: Area supplied by Margam GSP. Supplies are also provided to Port Talbot Steelworks.

The Margam complex of substations supplies the adjacent Port Talbot Steelworks, three primary substations and two 66 kV wind farms in the Llynfi Valley. It comprises four substations:

- Margam GSP has two 275/66 kV 180 MVA SGTs, connected to Grange 66 kV bar. The GSP is supplied at 275 kV by one circuit from Swansea North via Baglan Bay and one circuit from Pyle GSP.
- Grange has a three-section 66 kV single busbar with:
  - Two transformer incomers from Margam GSP
  - Two circuits to the Llynfi Valley
  - Ten exit points towards the Port Talbot Steelworks private network
  - Two interconnectors to Cefn Gwrgan
- Margam BSP has two 132/66 kV 45 MVA GTs, connected to Cefn Gwrgan 66 kV bar. The BSP is supplied at 132 kV by two circuits from Pyle GSP.

- Cefn Gwrgan has a three-section 66 kV single busbar with:
  - Two transformer incomers from Margam BSP
  - Nine exit points towards the Port Talbot Steelworks private network
  - Two interconnectors to Grange

The group demand is 146 MW. Because this is dominated by industrial demand, the seasonal maximum demand remains high all year round.

The group also has around 238 MW of generation connected, including 108 MW of wind generation in the Llynfi Valley

The normal running arrangement is:

- Both SGTs at Margam GSP on load
- Both GTs at Margam BSP off load
- Cefn Gwrgan supplied via the interconnectors from Grange

Group infeed

For any arranged outage of an SGT or transmission circuit which leaves Margam GSP supplying Grange via a single circuit:

- One SGT at Margam GSP is taken off load (if not already off load as part of the outage); the remaining SGT is left on load
- Both Margam BSP GTs are brought on load. These GTs are operated on fixed tap, so voltage control is solely provided by the remaining SGT at Margam GSP.

This couples Margam GSP and Pyle GSP via WPD's 66 kV and 132 kV networks. This running arrangement is intended to prevent interruption to supplies in the event of the subsequent fault loss of the remaining SGT at Margam GSP.

Margam GSP SGTs and 66 kV interplants to Grange

Although each SGT at Margam GSP has a nameplate rating of 180 MVA, National Grid's 66 kV interplant circuits to Grange are currently modelled with ratings that significantly limit allowable loading of each SGT:

- The 66 kV overhead interplant from Margam GSP SGT1 to Grange 1T0 is modelled with a rating of around 100 MVA, depending on season
- The 66 kV cable interplant from Margam GSP SGT2 to Grange 2T0 is modelled with a rating of around 120 MVA, depending on season

These ratings are exceeded for various FCO and SCO conditions, even though loading is below the rating of the SGT in most cases.

It is recommended that the ratings and impedances of the 66 kV interplant circuits between Margam GSP and Grange are confirmed with National Grid, and the results of these studies reassessed as necessary.

It has been assumed for this project that both interplants will be confirmed capable of 180 MVA by 2022.

Margam BSP GTs and 66 kV interplants to Cefn Gwrgan

An arranged outage that takes one SGT off-load followed by the fault loss of the remaining SGT would leave the group load supplied by the two GTs. At peak demand, regardless of season, this would heavily overload both GTs and their associated 66 kV interplant cables to Cefn Gwrgan. For example, at summer peak demand the arranged outage of the 275 kV circuit between Margam GSP and Pyle GSP followed by the fault loss of the 275 kV circuit between Baglan Bay and Margam GSP would result in the following overloads:

- Margam BSP GT1: 147% of assigned 49 MVA summer cyclic rating
- 66 kV interplant from Margam BSP GT1 to Cefn Gwrgan 1T0: 140% of 52 MVA summer rating
- Margam BSP GT2: 142% of assigned 49 MVA summer cyclic rating
- 66 kV interplant from Margam BSP GT2 to Cefn Gwrgan 2T0: 134% of 52 MVA summer rating

These overloads could be prevented by not operating Margam BSP in parallel with Margam GSP. This would interrupt supplies for the SCO loss of both Margam GSP SGTs, leaving Margam BSP available to restore part of the group load.

It is recommended that a detailed study of demand security and network integrity in the Margam network is undertaken. If it remains necessary to operate Margam BSP in parallel with Margam GSP to avoid interruption to supplies under SCO, reinforcement or load management schemes should be used to prevent overloads.

It has been assumed for this project that in future the Margam BSP GTs will only be brought on load following the SCO loss of both SGT infeeds.

DOC Protection

Each GT at Margam BSP is fitted with DOC protection. This protection is intended to detect and clear 132 kV circuit faults back-fed via the Cefn Gwrgan 66 kV bar. To ensure that 132 kV faults are reliably detected, the protection is set for a primary current of 300A at 66 kV flowing towards the 132 kV terminals of the GT: below the rating of the GT. This gives a stable reserve power flow limit of approximately 27 MVA on each 45 MVA GT.

Under summer peak generation conditions, an arranged outage that takes one SGT off-load followed by the fault loss of the remaining SGT would result in reverse power flow through each GT of 47 MW, marginally overloading each GT (102% of 45 MVA rating). This loading would operate the DOC protection of both GTs, interrupting supplies to Port Talbot Steelworks and the Llynfi Valley.

A ‘load-blinded’ DOC relay is available which can distinguish between load current and fault current. Consideration should be given to replacing the existing DOC protection on Margam BSP GT1 and GT2 with ‘load-blinded’ schemes. Although DOC protection is primarily intended to clear faults, it is sometimes also relied upon as a form of overload protection. If ‘load-blinded’ DOC is to be fitted, the role of the existing DOC protection in preventing overloads should be considered, and appropriate alternative measures taken.

An arranged outage of the 275 kV circuit between Margam GSP and Pyle GSP leaves Margam GSP supplied at 275 kV from Swansea North via Baglan Bay. Running Margam GSP in parallel with Margam BSP at 66 kV creates a couple across National Grid’s transmission network, affecting load share between Pyle GSP and Margam GSP. Under peak generation conditions, this is likely to operate the DOC protection of the GTs at Margam BSP.

This DOC operation is heavily dependent on the loading and configuration of National Grid’s network. If it remains necessary to operate Margam BSP in parallel with Margam GSP, it is recommended that this outage is studied in more detail in cooperation with National Grid.

As described above, it has been assumed for this project that in future the Margam BSP GTs will only be brought on load following the SCO loss of both SGT infeeds. This would prevent the studied DOC operations.

Interconnectors between Cefn Gwrgan and Grange

There are two 66 kV interconnectors between Cefn Gwrgan and Grange:

- Interconnector A is composed of 0.35 square inch (approximately 226mm²) copper and 350mm² aluminium cable, rated at around 50 MVA depending on season
- Interconnector B is composed of 260mm² copper cable, rated at around 60 MVA depending on season.

FCO overload

The fault loss of interconnector B from intact leaves Cefn Gwrgan supplied by interconnector A. At peak demand, this would overload interconnector A to as much as 108% of rating, depending on the season.

This overload could be alleviated by overlaying interconnector A with 300mm² copper EPR cable. It is recommended that a detailed assessment is made of the distribution of load between Cefn Gwrgan and Grange. To enable this assessment, it is also recommended that:

- **A more detailed network model is built in cooperation with Port Talbot Steelworks**
- **Directional monitoring is fitted to all WPD circuit breakers at Grange and Cefn Gwrgan**

If it can be confirmed that the maximum load at Cefn Gwrgan is below the rating of interconnector A, it may be possible to avoid reinforcement.

It has been assumed for this project that interconnector A will be overlaid with 300mm² copper EPR cable before 2022.

Pyle GSP SGT1 overload

For the arranged outage of either interconnector between Grange and Cefn Gwrgan, an alternative running arrangement is used to avoid overloading the remaining interconnector:

- Both GTs at Margam BSP are brought on load
- Port Talbot Steelworks splits their private network between Grange and Cefn Gwrgan
- The remaining interconnector is opened to split Grange and Cefn Gwrgan

This leaves Cefn Gwrgan fed from Margam BSP and, in turn, Pyle GSP.

Pyle GSP has two SGTs: SGT1 (180 MVA) and SGT2 (240 MVA). At peak demand, the fault loss of SGT2 in this running arrangement overloads SGT1 to between 112% (summer) and 121% (winter) of nameplate rating.

If interconnector A is reinforced or confirmed sufficiently rated as recommended above, the transfer of Cefn Gwrgan load onto Pyle GSP would become unnecessary. This would avoid the overload of Pyle SGT1. It has been assumed for this project that interconnector A would be reinforced and the alternative running arrangement discontinued before 2022.

Alternatively, National Grid may be able to determine short-term ratings for Pyle SGT1 which allow loading to be managed by post-fault transfers. If that is not possible, the studied overloads could be alleviated by:

- **Replacing SGT1 with a 240 MVA unit; or**

- **Transferring some demand from Pyle GSP to Upper Boat GSP for the duration of the arranged outage. This would make Margam, Pyle and Upper Boat GSPs more interdependent, potentially hindering outage coordination.**

Transmission network couple

A 275 kV arranged outage between Margam GSP and Pyle GSP leaves Margam GSP supplied from Swansea North via Baglan Bay. Running in parallel with Margam BSP at 66 kV creates a couple across National Grid's transmission network, affecting load share between Pyle GSP and Margam GSP. Depending on load conditions, Margam BSP goes into reverse power flow.

The fault loss of either interconnector between Cefn Gwrgan and Grange leaves the remaining interconnector supplying the load at Cefn Gwrgan and part of the load of the Pyle 132 kV network. At peak demand, this overloads the remaining interconnector, e.g.:

- For summer peak demand, the fault loss of interconnector B would overload interconnector A to 139% of rating
- For winter peak demand, the fault loss of interconnector A would overload interconnector B to 110% of rating

Although the studied overloads could be alleviated by overlaying each interconnector with 630mm² copper EPR cable, the magnitude of the overloads is heavily dependent on the loading and configuration of National Grid's network. If it remains necessary to operate Margam BSP in parallel with Margam GSP, it is recommended that these outages are studied in more detail in cooperation with National Grid.

Llynfi Valley

The Llynfi Valley 66 kV network consists of two transformer-feeders from Grange supplying Llynfi, Ogmore Vale and Caerau Road primary substations. There are two 66 kV wind farms: Ffynnon Oer connected to circuit number 1, and Pant Y Wal connected to circuit number 2.

A second 66 kV network in the Llynfi Valley fed from Pyle BSP supplies two further 66 kV wind farms. There is currently no connection between the two 66 kV networks in the Llynfi Valley.

Voltage at Pant Y Wal Wind Farm

Under peak generation conditions, the voltage rise from Grange to Pant Y Wal 66 kV is approximately 3%. Both SGTs at Margam GSP are modelled with automatic voltage control (AVC) set to 101.8% ±1.55%. Margam BSP is modelled as operating on fixed tap.

Under some studied conditions, the controlled nodes of the SGTs sit at the upper end of the AVC bandwidth. This results in a voltage at Pant Y Wal 66 kV bar of 106.37%, marginally above the 106% design limit.

It is recommended that the AVC settings at Margam GSP and Margam BSP are confirmed, and the reactive behaviour of demands and generators in the Llynfi Valley assessed. A detailed study of voltage performance in the Llynfi Valley should be carried out. If necessary, measures should be taken to prevent overvoltage, such as:

- **Revising AVC settings at Margam GSP and/or Margam BSP**
- **Review generators in the Llynfi Valley power factor settings**

It has been assumed for this project that the AVC set-points at Margam GSP will be reduced by 0.8%.

Loading on Grange/Llynfi 66 kV number 2 circuit

There are various SCO combinations which reduce the demand on the Grange/Llynfi 66 kV number 2 circuit (Grange 4L5 to Llynfi 4L3) without disconnecting Pant Y Wal wind farm, e.g.:

- The arranged outage of Llynfi T1, followed by
- The fault outage of Ogmore Vale T2

Under peak generation conditions, these outage combinations would overload the Grange/Llynfi 66 kV number 2 circuit (Grange 4L5 to Llynfi 4L3) to 100.3% of summer rating.

The 66 kV circuits from Grange to Llynfi have recently been surveyed for reprofiling from 50°C to 75°C; the results of these surveys are expected shortly. It is recommended that any necessary works are undertaken to reprofile the Grange/Llynfi 66 kV number 2 circuit for a temperature that enables a rating to alleviate the studied overloads.

It has been assumed for this project that the Grange/Llynfi 66 kV number 2 circuit will be reprofiled for operation at 65°C before 2022.

Pant Y Wal intertrip

The 66 kV circuits to the Llynfi Valley are connected to two separate sections of the Grange 66 kV busbar. A fault outage of either section of busbar would leave the Llynfi Valley supplied by the circuit connected to the remaining healthy busbar, but the other circuit would remain back-energised via the 66/11 kV transformers at Llynfi, Caerau Road and Ogmore Vale. The 66 kV wind farm on the back-energised circuit would also remain in service, unless it serendipitously disconnects itself in response to the transient disturbance of the fault.

An intertripping scheme opens Caerau Road 3L5 if Grange 1L5 is opened for any reason, including the fault outage of Grange 66 kV busbar Main 1. This disconnects Ffynnon Oer Wind Farm, preventing overvoltage and overloads.

An intertripping scheme opens Pant Y Wal 1H0 if Grange 4L5 trips for a circuit fault. The scheme is not triggered by the fault outage of Grange 66 kV busbar Main 2; for that fault Pant Y Wal Wind Farm is left in service on the back-energised circuits. Under peak generation conditions, this overloads:

- Grange/Llynfi 66 kV circuit number 1 (Grange 1L5 to Llynfi 66 kV Main 1): 151% of summer rating
- Ogmore Vale T1: 123% of assigned 12 MVA summer continuous rating
- Ogmore Vale T2: 140% of assigned 12 MVA summer continuous rating

It is recommended that the intertripping scheme from Grange 4L5 to Pant Y Wal 1H0 is extended to operate if Grange 4L5 is opened for any reason.

It has been assumed for this project that this modification will be made before 2022.

Upper Boat GSP

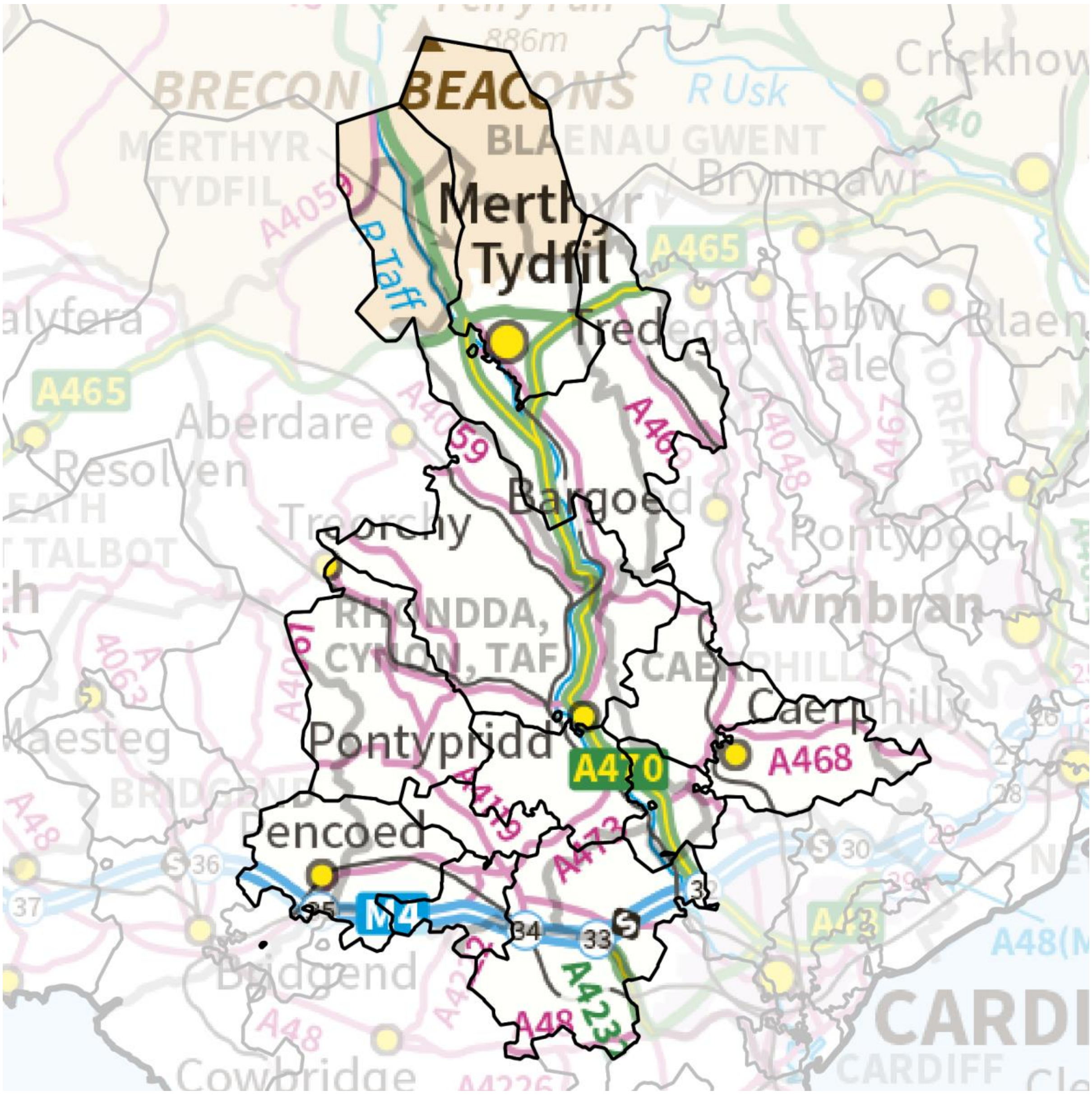

Figure 36: Areas fed from Upper Boat GSP

Upper Boat is an unconventional network supplied by two 275/132 kV and two 275/33 kV SGTs. The 132 kV and 33 kV networks are remotely coupled by a small GT at Mountain Ash. The 132 kV busbar at Upper Boat is arranged as a ring of 12 section breakers, without line or transformer-incomer breakers. The group demand is 263 MW, of which 116 MW is in the 33 kV network.

132 kV Busbar splits

The existing configuration at Upper Boat 132 kV busbar leaves the network susceptible to various SCO conditions that split the132 kV busbar. This split can be problematic for combinations where there is a part of the busbar without a direct SGT infeed from either an Upper Boat 275/132 kV SGT or Aberthaw SGT3.

For any arranged outage that takes an Upper Boat SGT out of service, the Aberthaw busbars can be reselected and the normally open Aberthaw to Upper Boat 132 kV interconnector can be closed to provide an additional infeed into group. To be able to close the interconnector, the Aberthaw busbars need reselecting so SGT3 is on a separate bar which just supplies the Upper Boat network.

There are a number of SCO combinations where putting the Aberthaw interconnector into service does not help resolve the possible 132 kV busbar split. This is because of where the infeeds into the Upper Boat 132 kV bar are connected. The SGTs are connected to Main 3 and Main 7 and the Aberthaw interconnector is connected to Main 1. The majority of the problematic conditions are where there is not a direct GSP infeed to busbars 8 to 12. One example of an SCO condition that would result in an unacceptable 132 kV busbar split is the arranged outage of Main 1 followed by the fault of:

- Upper Boat Main 4, SGT4 and associated transmission circuits; or
- Upper Boat Main 9 and the circuit towards Talbot Green GT2

Figure 37 shows the Upper Boat Main 1 arranged outage as described above. Figure 38 shows the configuration of the Upper Boat 132 kV network if a fault was to occur on SGT4 whilst Main 1 was out of service. For this particular example, if no control action is taken for the arranged outage, it leaves Upper Boat Main 12 to Main 8 without a direct 132 kV infeed. This leaves all of Dowlais, Merthyr East, Mountain Ash and a 132 kV generator supplied via:

- The 33 kV interconnection at Mountain Ash, which is in turn supplied via the Upper Boat 275/33 kV SGTs; and
- Loose coupled through the 11 kV at Talbot Green, Pontyclun and Pencoed, as one side of this double circuit is supplied via the side of the Upper Boat split with a direct 132 kV infeed.

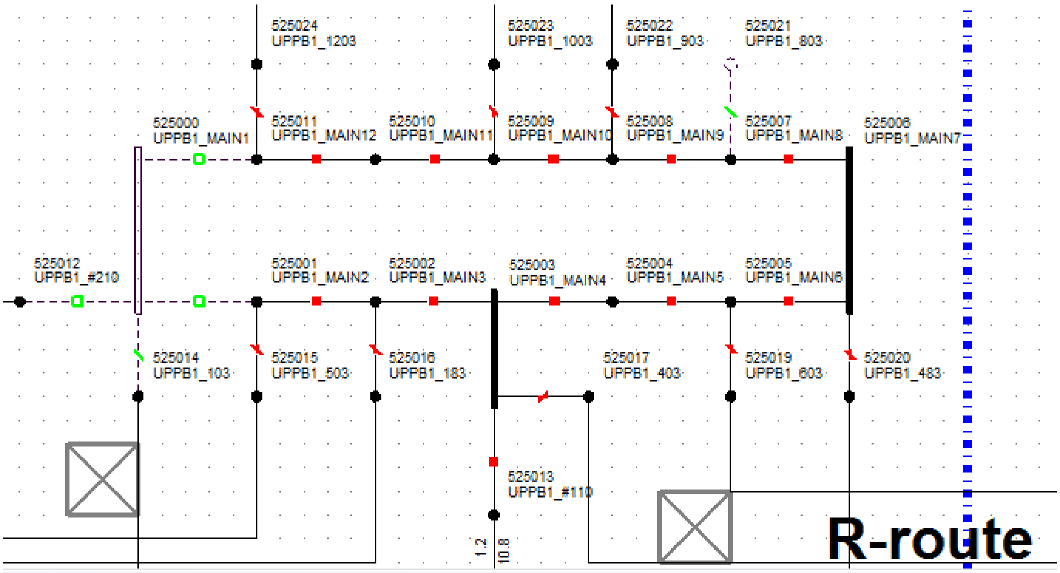

Figure 37: Upper Boat 132 kV Main 1 arranged outage

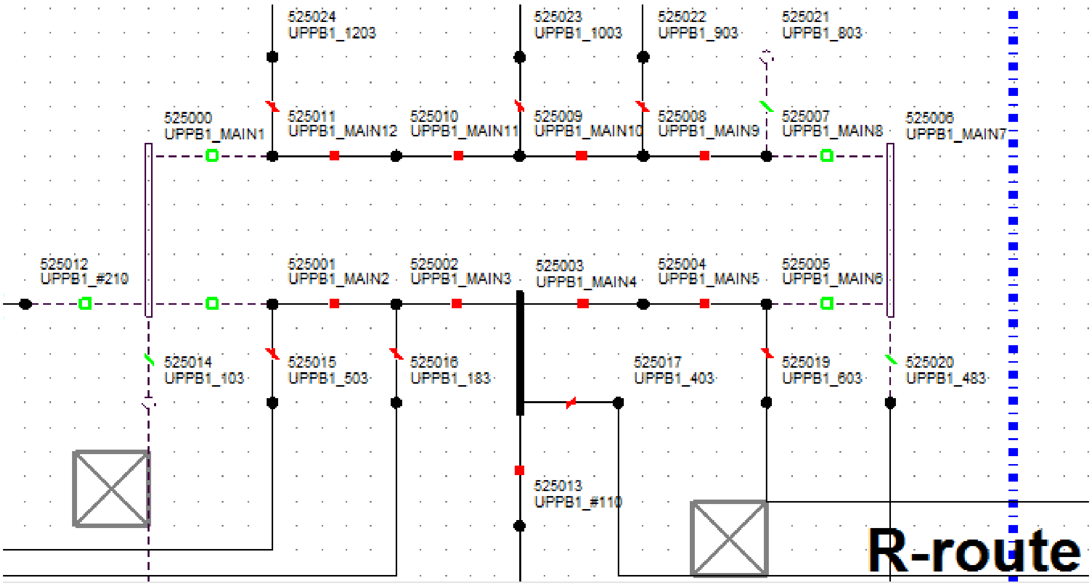

Figure 38: Main 1 arranged outage followed by SGT4 (Main 7) fault

The 33 kV interconnection between Upper Boat and Mountain Ash is regularly broken during outages to mitigate the Mountain Ash loose couple. The loose couples at Talbot Green, Pontyclun and Pencoed are not normally mitigated.

There are also splits which leave the R-route coupled across the Upper Boat bar split via a loose couple at Nantgarw, Upper Boat and Energlyn BSPs. A similar approach can be used to ensure no overloads are seen.

The results from this analysis show that not all 132 kV busbar splits at Upper Boat cause overloads or voltage exceedances for all half hours within the representative days studied. DOC settings were also added to see if they would consistently operate to stop the 132 kV back-energisation via the LV bars. The results showed that the DOC does not always operate, as it depends on the prevailing demand and generation conditions. The DOC operation stopped the majority of the thermal overloads but where the demand was insufficient to operate the DOC, voltage exceedance on the 132 kV network were identified.

It is recommended that when taking any arranged outage that leaves the Upper Boat 132 kV busbar susceptible to a fault that will split the busbar, careful consideration is given as to what mitigation is required. This may include any combination of:

- **Breaking loose couples at 11 kV;**
- **Checking protection is in place that will operate to avoid unacceptable network conditions;**
- **Transferring Pencoed and Pontyclun BSPs onto Pyle GSP to avoid loose couples;**
- **Supplying Talbot Green BSP via a single 132 kV circuit to avoid loose couples;**
- **Closing normally open 132 kV circuit with Aberthaw GSP; and**
- **Splitting Upper Boat and Mountain Ash at 33 kV**

For the purposes of these studies all of the above recommendations were implemented as deemed appropriate to show that the Upper Boat network can be operated without causing any thermal or voltage exceedances. Considerations will need to be given to the risk at the point the outage is taken. Saturating Pyle and Aberthaw may not be the best approach if appropriate protection was implemented so no credible fault that can split the Upper Boat 132 kV busbar would cause any unacceptable network issues.

Pyle to Upper Boat transfers

For an arranged outage which results in the loss of an SGT at Pyle, these studies have modelled a transfer of Bridgend BSP, Fords Bridgend BSP and Waterton Industrial onto Upper Boat GSP via the normally open circuit breakers at Pencoed BSP. Likewise, for an arranged outage that leaves Pontyclun and Pencoed BSPs at single circuit risk, Pontyclun and Pencoed are currently transferred onto Pyle GSP. The Upper Boat baseline studies have shown a number of Upper Boat 132 kV busbar arranged outages that leave the network susceptible to the next fault splitting the Upper Boat busbar, causing thermal and voltage issues. This transfer results in a ladder network comprising of two 132 kV circuits which are loose-coupled via the 11 kV and 33 kV bars at several BSPs.

Transfers into Upper Boat

An arranged outage whereby Bridgend, Fords Bridgend and Waterton are transferred onto Upper Boat, followed by a fault on either side of the UE-route from Upper Boat GSP towards Talbot Green would overload the remaining in-service cable section between Talbot Green and Pontyclun up to 104% for an intermediate warm peak demand case.

It is recommended that the adequacy of the access window is assessed with respect to transferring Bridgend, Fords Bridgend and Waterton Industrial onto Upper Boat GSP for an arranged outage.

Upper Boat/ Mountain Ash Group

For an arranged outage of Mountain Ash GT2, followed by the fault of either Upper Boat SGT2 or SGT3, the entire Upper Boat/Mountain Ash 33 kV group is supplied via the remaining in-service SGT. This overloads the remaining Upper Boat SGT to as much as 122% for winter peak demand and 111% for the intermediate warm peak demand study.

The access window should be assessed to determine if a summer access window is sufficient. If a longer access window is required then short-term ratings of the SGTs should be confirmed with National Grid. Alternatively, available 33 kV transfers should be assessed to determine if they are sufficient to reduce the loading within ratings.

Dowlais BSP

Dowlais BSP is supplied by two 22.5/45 MVA transformers via the DD-route double circuit from Upper Boat GSP. Under intact network conditions for the maximum summer generation case, both transformers are at 126% of their ONAN rating. This is predominately caused by two large generation sites connected at 33 kV.

Both generator sites are constrained off for any arranged outage that leaves the BSP supplied via a single transformer. Intertrips are installed to both generators to stop the overload for any credible fault that will lose the direct infeed to one of the GTs.

The intact overload is within the forced continuous OFAF rating, but may cause increased aging on both transformers if a high persistence of generation was seen at Dowlais.

Aberthaw and Cardiff East GSPs

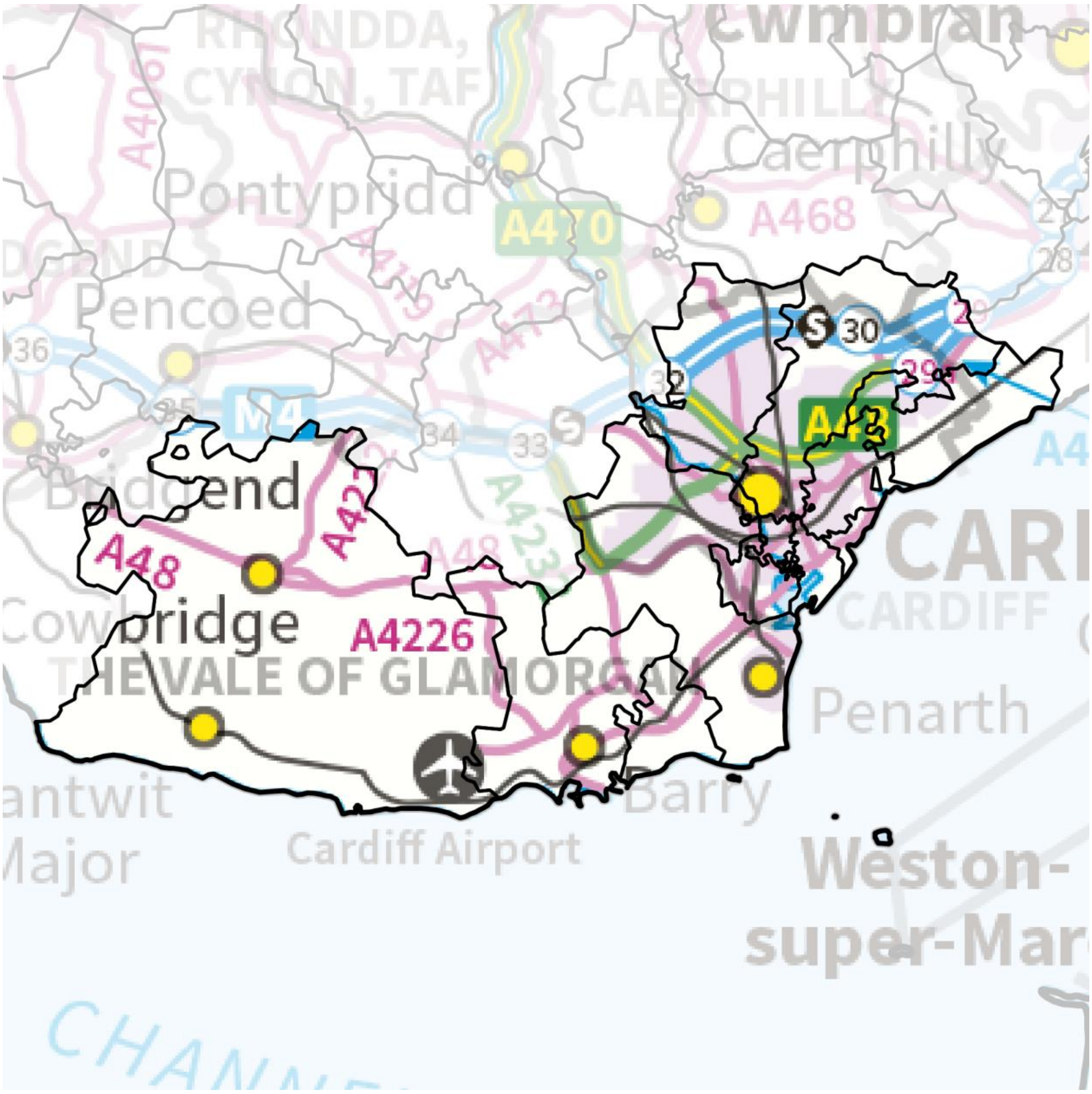

Figure 39: Area supplied by Aberthaw and Cardiff East GSPs.

Aberthaw and Cardiff East GSPs supply the city of Cardiff and part of the surrounding area:

- Aberthaw GSP has three 275/132 kV SGTs, supplied by a 275 kV bar with five incoming circuits:
    - SGT1: 180 MVA
    - SGT2: 180 MVA
    - SGT3: 240 MVA
- Cardiff East GSP has two 275/132 kV SGTs, supplied by two incoming 275 kV circuits:
    - SGT2: 240 MVA
    - SGT3: 240 MVA

The two GSPs operate in parallel via three interconnecting circuits through the Cardiff 132 kV network.

The group demand is 433 MW. This does not include power station auxiliary demand drawn at Aberthaw 132 kV bar, which is not currently modelled by Western Power Distribution.

Group infeed

To manage conflicting fault level and load flow constraints, the normal running arrangement has:

- All three SGTs on load at Aberthaw, with the 132 kV bar split into three sections: each section supplied by one SGT and supplying one 132 kV circuit into the Cardiff interconnected network.
- One SGT on load and one SGT off load at Cardiff East, with the 132 kV bar solid.

Outage management

To avoid depleting group infeed during arranged outages, various interventions are made.

For the arranged outage of either SGT at Cardiff East, the remaining SGT at Cardiff East is brought on load.

For the arranged outage of any of:

- An SGT at Aberthaw,
- A section of busbar at Aberthaw 132 kV,
- A bus section breaker or busbar Main 2 at Cardiff East 132 kV, or
- A 132 kV circuit interconnecting Aberthaw and Cardiff East,

An alternative running arrangement is adopted:

- Both SGTs on load at Cardiff East, with the 132 kV bar solid unless splitting it forms part of the arranged outage.
- Two SGTs on load at Aberthaw, with the 132 kV bar split into two sections: each section supplied by one SGT, and supplying at least one of the remaining 132 kV circuits into the Cardiff interconnected network.

Load-share and transmission through-flow

WPD’s Cardiff East/Aberthaw 132 kV network is coupled across National Grid’s 275 kV and 400 kV transmission network. Load share between Cardiff East GSP and Aberthaw GSP can alter drastically depending upon the loading and configuration of the transmission network. In turn, this affects the loading of WPD’s 132 kV and 33 kV circuits between Cardiff East GSP and Aberthaw GSP.

Fault outages of the Aberthaw/Pyle/Cardiff East 275 kV circuit when Cardiff East SGT3 is on load are of particular concern, since they leave Aberthaw and Cardiff East supplied by remote parts of the transmission network. The dispatched output of Aberthaw B Power Station (connected to the 275 kV bar at Aberthaw GSP) also has a major impact on flows through the 132 kV network.

All of the studied examples below are dependent upon network modelling limitations which are beyond scope of this project. General recommendations and reinforcement options are given at the end of this section.

Through-flow for 275 kV outages between Aberthaw and Cardiff East

The simultaneous outage of:

- The Aberthaw/Pyle/Cardiff East 275 kV circuit; and
- Either or both parts of the Aberthaw/Tremorfa/Uskmouth/Whitson 275 kV circuit:
    - Aberthaw/Tremorfa; or

  - Tremorfa/Uskmouth/Whitson.

Leaves Cardiff East and Aberthaw GSPs supplied by relatively weakly connected parts of the transmission network. For a peak generation case, Cardiff East SGT3 would overload to 137% of its 240 MVA rating due to real power flow from Aberthaw towards Cardiff East.

The 132 kV circuits between Aberthaw and Cardiff East are also heavily loaded under these conditions. In particular, the circuit between Sully tee and Grangetown BSP (via Cardiff West mesh corner 4) is loaded to 89% of summer rating.

Aberthaw 275 kV busbar Main 2 fault

The fault loss of Aberthaw 275 kV busbar Main 2 splits Aberthaw 275 kV into three nodes and disconnects Aberthaw SGT3. Combined with the three-way split of the Aberthaw 132 kV bar, this causes poor load share triggering the following overloads:

- At peak demand, regardless of season, the 132 kV BB-route circuit from Aberthaw 305 to Sully tee would overload to 101% of seasonal rating
- For a winter peak demand case, Aberthaw SGT1 would overload to 109% of 180 MVA nameplate rating

Reprofiling the existing 400mm² ACSR (Zebra) conductors of the 14km overhead section of the 132 kV circuit from Aberthaw 305 to Sully tee for operation at 65°C would resolve the studied overload of that circuit.

If National Grid can provide details of mitigating measures such as 275 kV or 132 kV auto-close schemes, modelling these might confirm that 132 kV reinforcement is not required.

Aberthaw SGT overloads: Upper Boat transfer

For arranged outages depleting SGT infeed to Upper Boat 132 kV, Aberthaw SGT3 is transferred into the Upper Boat 132 kV network. The Aberthaw/Cardiff East 132 kV network is configured into a similar running arrangement to the alternative running arrangement described above. The Aberthaw 132 kV reserve bar is used to connect Aberthaw SGT3 to Upper Boat via the normally open circuit from Aberthaw 605 to Upper Boat 103.

At winter or intermediate warm peak demand, the subsequent fault loss of the Aberthaw/Pyle/Cardiff East 275 kV circuit would overload Aberthaw SGT2 up to 112% of 180 MVA nameplate rating. For comparison, Cardiff East SGT3 is only loaded to around 19% of 240 MVA nameplate rating. No overload occurs for a summer peak demand case.

If National Grid can provide details of mitigating measures such as 132 kV auto-close schemes, these should be modelled.

Aberthaw SGT overloads: 132 kV busbar section 1 SCO

For an arranged outage including Aberthaw 132 kV Main 1 or Reserve 1, the network is reconfigured into the alternative running arrangement described above. For most arranged outages, this leaves Aberthaw SGT1 feeding two interconnecting circuits, and Aberthaw SGT2 feeding one interconnecting circuit: Aberthaw 405 to Barry mesh corner 1.

For a winter or intermediate warm peak demand case, the subsequent fault loss of the 132 kV circuit Aberthaw 405 to Barry mesh corner 1 would overload Aberthaw SGT1 up to 112% of 180 MVA nameplate rating. No overload occurs for a summer peak demand case.

If National Grid can provide details of mitigating measures such as 132 kV auto-close schemes, these should be modelled.

Aberthaw SGT overloads: Cardiff East 132 kV split node

For the arranged outage of bus section breaker or busbar Main 2 at Cardiff East 132 kV, the Cardiff East 132 kV bar is split into two nodes. To mitigate this, the network is reconfigured into the alternative running arrangement described above.

For a winter or intermediate warm peak demand case, the subsequent fault loss of Aberthaw SGT1 would overload Aberthaw SGT2 up to 113% of 180 MVA nameplate rating. For comparison, neither SGT at Cardiff East is loaded beyond 50% of 240 MVA nameplate rating. No overload occurs for a summer peak demand case.

Modelling recommendations and potential reinforcements

It is recommended that the effect of transmission network loading and outages on this interconnected network are assessed in further detail with National Grid.

To accurately analyse this network, it will be necessary to improve the network model in areas including:

- **Connectivity between transmission circuits east of the Welsh/English border**
- **Placement and monitoring of swing bus(es)**
- **Impedance and settings of 275 kV quadrature boosters at Whitson**
- **Coincident output of transmission-connected and distribution-connected generation**
- **Outage management and load management scheme behaviour on the transmission network**

If through-flow and/or load-share driven overloads are confirmed, options for preventing or resolving overloads include:

- **Permanently splitting the 132 kV network between Aberthaw and Cardiff East, which would require extensive 132 kV reinforcement**
- **Commissioning plant that can control power flow such as quadrature boosters, series reactors, HVDC links or FACTS devices**
- **Constraining transmission-connected and/or distribution-connected generators**
- **Commissioning overload protection to trip circuit breakers and split the 132 kV network between Aberthaw and Cardiff East if overloads occur**
- **Commissioning an operational tripping scheme (OTS) to automatically and immediately split the 132 kV parallel between Aberthaw and Cardiff East in the event of any transmission network outage which would trigger overloads.**

BSP 132 kV section and coupler breaker arranged outages

Several BSPs in the Cardiff area are looped in to the 132 kV circuits between Aberthaw and Cardiff East. In each case, the arranged outage to access the 132 kV section or coupler breaker leaves the substation with two 132 kV nodes: one fed from Aberthaw GSP, and one fed from Cardiff East GSP.

One of these arranged outages followed by a fault in the area could lead to:

- An area of network (including other BSPs) solely supplied via the 33 kV or 11 kV bar of the BSP (with risk of tap-changer runaway and/or GT thermal overload); or
- Through-flow driven overloads of the GTs and 33 kV or 11 kV bar of the BSPs;

To avoid those consequences in these studies, it was assumed that the following pre-emptive switching would be applied under arranged outage:

132 kV breaker being accessed	Pre-emptive switching actions
Cardiff West 120	Offload Cardiff West GT1
Cardiff South 120	Offload Cardiff South GT1
Grangetown 120	Offload Grangetown GT1
Rover Way 120	Offload Rover Way GT1
Sully 120	Offload Sully GT1
Barry 120	Offload Barry GT2
Cardiff Central 130	Select all bays to the same busbar

It is recommended that these operational measures are applied where outage planning network studies confirm that they are necessary.

Cardiff East BSP and Cardiff North BSP 132/33 kV GT capacity

Cardiff East BSP and Cardiff North BSP operate in parallel at 33 kV. This network has a group demand of 122 MW, and is supplied by:

- Cardiff East GT2, 132/33 kV 60/90 MVA
- Cardiff East GT4, 132/33 kV 60/90 MVA
- Cardiff North GT2, 132/33 kV 45/90 MVA

Cardiff East also has two 132/11 kV GTs supplying a separate 11 kV network.

At winter peak demand, the SCO of both 132/33 kV GTs at Cardiff East would overload Cardiff North GT2 to 102% of its assigned 117 MVA winter cyclic rating. No overload occurs for a summer or intermediate warm peak demand case.

It is recommended that the adequacy of the available access window for the GTs is assessed. If it is not long enough, alternative 33 kV running arrangements, load management schemes, flexibility services and reinforcement should be considered as means to extend it.

Barry BSP and East Aberthaw BSP GT capacity

Barry BSP and East Aberthaw BSP operate in parallel at 33 kV. This network has a group demand of 59 MW, and is supplied by:

- Barry GT1, 132/33 kV 30/60 MVA
- Barry GT2, 132/33 kV 30/60 MVA
- East Aberthaw GT2, 132/33 kV 22.5/45 MVA

The SCO of both GTs at Barry would overload East Aberthaw GT2 to:

- 109% of estimated 51 MVA intermediate warm cyclic rating at intermediate warm peak demand
- 106% of assigned 58 MVA winter cyclic rating at winter peak demand

No overload occurs for a summer peak demand case.

It is recommended that the adequacy of the available access window for the GTs is assessed. If it is not long enough, alternative 33 kV running arrangements, load management schemes, flexibility services and reinforcement should be considered as means to extend it.

Uskmouth GSP

Figure 40: Areas fed from Uskmouth GSP

Uskmouth GSP has three 275/132 kV 240 MVA SGTs supplying:

1. WPD's network in the city of Newport and the surrounding area, with a group demand of 263 MW; and
2. Uskmouth B power station.

To manage fault level constraints, the 132 kV bar is normally operated in two sections with an SGT supplying each section. The third SGT is on hot-standby, able to close onto either section for the loss of the SGT normally supplying that section.

Uskmouth GSP also has two 275/33 kV SGTs supplying the adjacent steelworks.

The 132 kV network includes Llantarnam BSP, which in turn supplies 66 kV network with a group demand of 24 MW.

Uskmouth Reactor

The arranged outage of Uskmouth isolator 184 takes SGT 1 and Uskmouth Main 1 busbar out of service. Under these conditions all bays are selected to the Reserve 1 busbar and breaker 480A is closed to bring SGT4 into service on Reserve 1. The subsequent fault of SGT4 leaves all circuits fed from Reserve 1 supplied via the remaining SGT infeed via the series reactor. This overloads the reactor to as much as 102% for the winter peak demand representative day.

Details of the 132 kV running arrangements and auto-close schemes at Uskmouth should be confirmed with National Grid. The access window should be assessed to determine if a summer and an intermediate warm access window is sufficient.

Pontypool North

Pontypool North BSP is normally supplied by one 132/11 kV transformer fed from Uskmouth GSP and one 66/11 kV transformer fed from Llantarnam BSP, which is in turn fed from Uskmouth GSP. Any SCO condition that takes both 132/66 kV infeeds into Llantarnam out of service leaves Rogerstone 66/11 kV Primary supplied via the 11 kV busbar at Pontypool North. Depending on the arranged outage at Llantarnam, the entire Llantarnam 132/11 kV demand can also be supplied via the Pontypool North 11 kV bar for some SCO conditions.

This condition overloads the Pontypool Transformers up to 145% on GT2 (132/11 kV) and 187% for T1 (66/11 kV) for the winter peak demand representative day. Under lower levels of demand these studies showed the DOC at Pontypool North will not always operate. Where the DOC does not operate, voltage exceedances are seen at Rogerstone 66 kV.

The studies indicated that there are no overloads on the Llantarnam 132/66 kV transformer that is back-energising the 132 kV to supply the Llantarnam 11 kV demand. The voltage does go outside of limits for a number of the representative day half hours; due to a 30/60 MVA 132/66 kV transformer supplying the 11 kV demand, DOC does not operate for all representative days studied.

It is recommended that when one of the 132 kV infeeds to the Llantarnam 66 kV busbar is out of service, Pontypool North 11 kV bar should be split or the 66/11 kV transformer taken off load to mitigate this issue. For the purposes of these studies, Pontypool North 1T0 is opened for any arranged outage which leaves Llantarnam BSP at single circuit risk.

Llantarnam 11 kV

Any arranged outage of either Llantarnam 132/66 kV GT followed by the fault of the 132 kV circuit supplying the other 132/66 kV GT leaves the entire 66 kV network supplied via the 11 kV bar at Llantarnam. This assumes Pontypool North has been split away as recommended for the arranged outage of either infeed into Llantarnam.

It is recommended that for the arranged outage of either 132/66 kV GT at Llantarnam the appropriate 132/11 kV LV breaker is opened to leave the 132/11 and 132/66 supplied via different circuits. This removes the risk of the 66 kV demand being supplied via the 11 kV and has the operational benefit that the entire Llantarnam load is not lost for a single fault credible fault.

Rassau GSP

Rassau GSP has two 400/132 kV 240 MVA SGTs supplying a large area in the east of South Wales. The group demand is 228 MW.

The 132 kV network includes Abergavenny and Panteg BSPs, which in turn supply a large rural 66 kV network with a group demand of 90 MW.

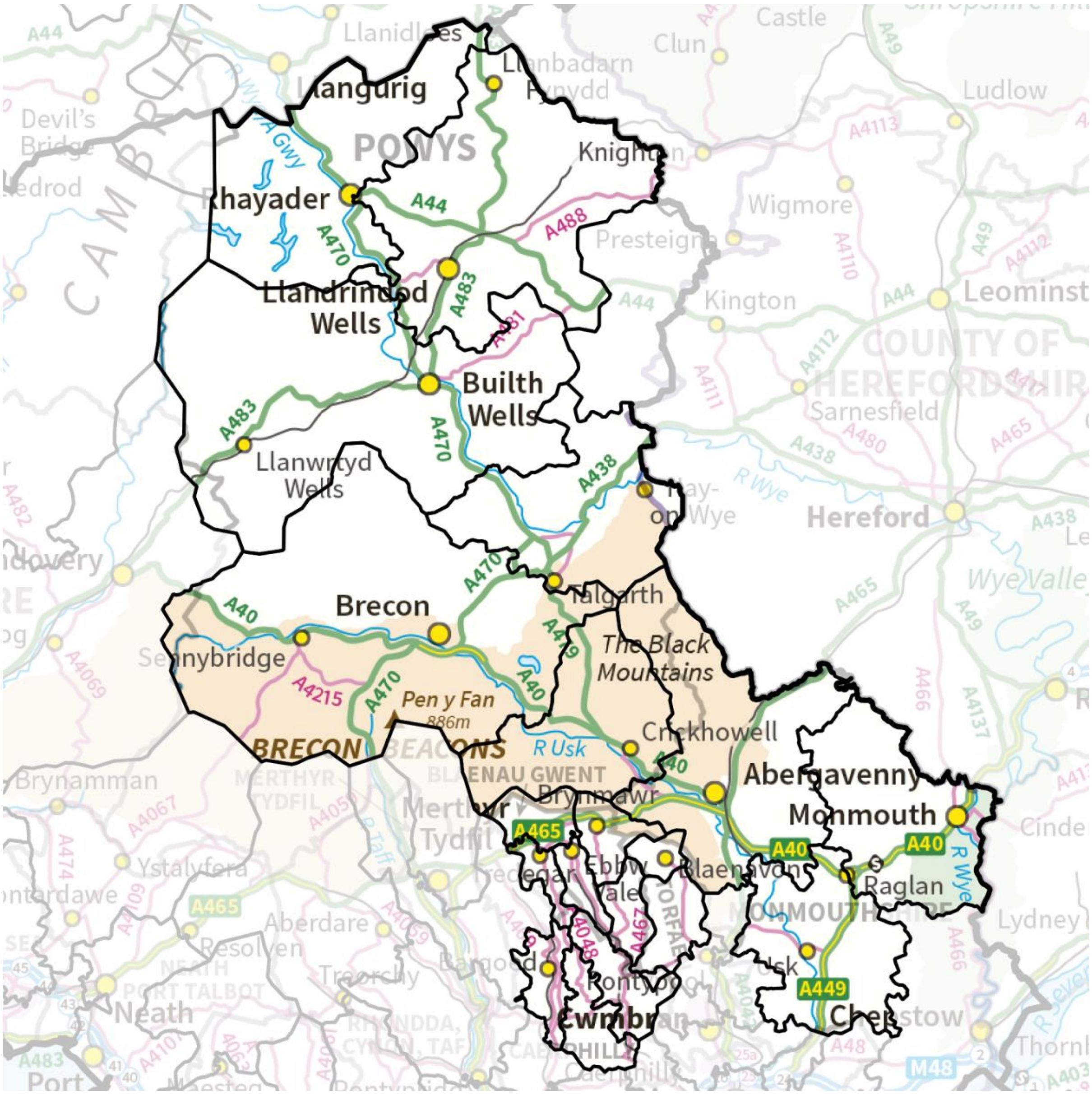

Figure 41: Areas fed from Rassau GSP

Ebbw Vale BSP

Ebbw Vale (132/33 kV) and Ebbw Vale Central (132/11 kV) are fed out of Rassau GSP at 132 kV via the double circuit AA-route. Ebbw Vale 33 kV and Ebbw Vale Central 11 kV are both supplied by two transformers. One side of AA-route feeds Ebbw Vale Main 2A which has Ebbw Vale GT1A (132/11 kV) and GT1B (132/11 kV) double banked. The other 132 kV circuit has both transformers on adjacent mesh corners, connected by a motorised isolator. The double circuit continues to Crumlin and Pengam with a functional switch on both outgoing circuits from Ebbw Vale.

The arranged outage of Ebbw Vale GT2B (132/33 kV) followed by the fault of the circuit supplying GT GT1A and GT1B leaves all of the Ebbw Vale 33 kV demand supplied via GT3A (132/11 kV) at Ebbw Vale Central. This assumes the fault of the AA-route is cleared on the HV transformer breaker of GT1A and GT1B, which leaves the 132 kV busbar that supplies both the 132/33 kV and the 132/11 kV in-service. The Ebbw Vale 132 kV SCO combination is shown in Figure 42.

This does not occur for the arranged outage of Transformer 1B, as 2B and 3A have their own HV breaker and are not double banked.

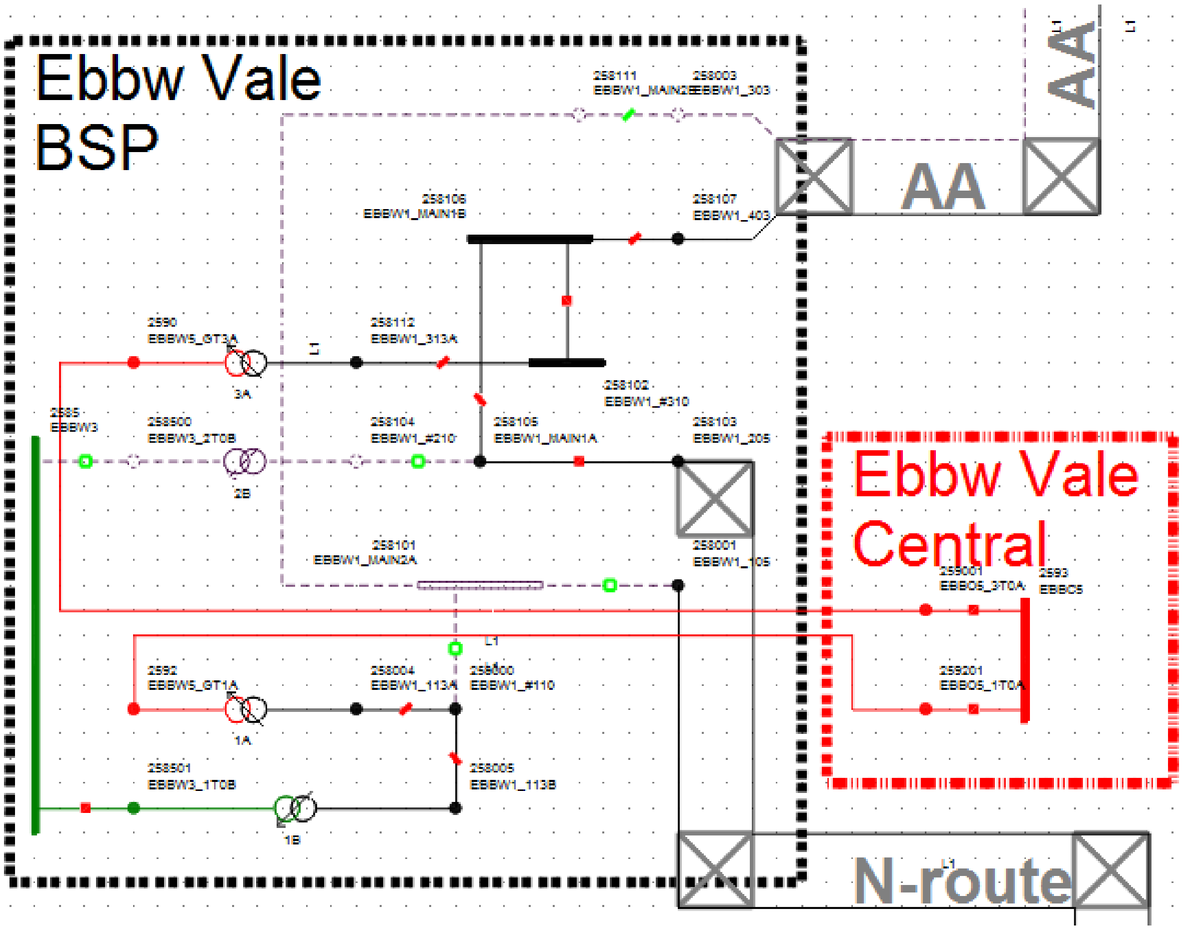

Figure 42: Ebbw Vale 132 kV running arrangement

The loading on Ebbw Vale Central 3A for the summer maximum generation peak are causing non-convergence. Running the outage combination manually shows an overload in excess of 150% of rating. The loading for the demand cases are as much as 70%.

The DOC setting on Ebbw Vale Central is currently set to 600A with no load blinding element. As the maximum generation day is not converging due to loading it is not possible to check if the DOC will operate. The DOC does operate for the peak of all demand days, but when demand drops below ~60% of winter peak demand the DOC is shown to not operate. In this situation it does not overload the transformer, but does mean the 33 kV is being supplied via the 11 kV Ebbw Vale Central busbar. This is shown to cause voltage exceedances within the model on the 132 kV and 33 kV Ebbw Vales busbars.

It is recommended that for the arranged outage of Ebbw Vale transformer 2B, the 11 kV bus section at Ebbw Vale central or a transformer LV breaker is opened to mitigate the fault that leaves the network in the condition described above. Alternatively, an intertrip could be installed from Ebbw Vale circuit breaker 110 to the transformer LV breakers of GT1A and GT1B.

Crumlin BSP

Crumlin BSP is normally fed via the same double circuit out of Rassau GSP as Ebbw Vale BSP. Each side of the double circuit goes to a separate 132 kV busbar; with no 120 coupling breaker. Each busbar feeds a 132/33 kV transformer and a 132/11 kV transformer. The arranged outage of either 132/33 kV transformer followed by the fault of the circuit supplying the other 132/33 kV transformer leaves all of the 33 kV demand supplied via the Crumlin 11 kV busbar.

This SCO condition overloads the 132/11 kV transformer that is supplying all the 11 kV and 33 kV demand to as much as 142% for winter peak demand and 127% for summer peak demand. During times of lower demand this loading reduces within the summer abnormal cyclic rating.

Both of the 132/11 kV transformers have a DOC setting of 800 A. The 132/11 kV transformer with reverse power flow has the DOC operates for some half hours within the demand representative days, but does not operate when the demand is lower. These results show that the DOC cannot be relied up on to stop this condition occurring. There are half hours where the loading is not enough to trigger the DOC on the transformer with reverse power flow, but is high enough to overload the transformer supplying all the 33 kV and 11 kV demand. There is also a voltage performance issue where the 132 kV busbar is back-energised via the 11 kV busbar.

The same condition can be seen where the 11 kV is supplied via the 33 kV busbar. This does not cause any overloads for any representative days and it does not trigger the DOC, but it was shown to cause voltage exceedances.

It is recommended that for the arranged outage of any transformer at Crumlin the appropriate 11 kV or 33 kV bus section or LV transformer breaker is opened to ensure this back-energisation does not occur.

Rassau P18 Assessment

The AA-route double circuit fed out of Rassau GSP feeds Rassau West, Ebbw Vale, Pengam and Crumlin BSPs. Ebbw Vale currently has two line breakers (105 and 205) which face towards the double circuit that normal feed Crumlin and Pengam BSPs. These breakers are currently operated as switching isolators and not regarded as circuit-breakers for the purpose of a P18 restriction A assessment.

The Engineering Recommendation “P18 – Complexity of 132 kV circuits” sets out the normal limits of complexity for 132 kV circuit design. The Engineering recommendation states that these limits should be regarded as being in general the limits of good planning.

P18 restriction A states *“The normal operating procedure or protective gear operation for making dead any 132 kV circuit shall not require the opening of more than seven circuit-breakers. These circuit-breakers shall not be located on more than four different sites”.* At present, the fault of either side of AA-route is isolated at 5 locations.

It is recommended that when future work is undertaken on this part of the network it is brought in-line with the P18 Engineering Recommendations.

Mid Wales 66 kV Baseline

Abergavenny BSP

Abergavenny GT1 Overload

The Mid-Wales 66 kV network is normally supplied by two 132/66 kV transformers at Abergavenny and one 132/66 kV transformer at Panteg.

The arranged outage of Panteg GT followed by the fault of the larger 45/90 MVA Abergavenny GT2 leaves the smaller 30/60 MVA Abergavenny GT1 overloaded to as much as 115% for winter and intermediate warm peak demand studies.

It is recommended that prior to taking any arranged outage that takes Panteg GT3 out of service; the prevailing demand of the 66 kV network is assessed to determine if it is within the

rating of Abergavenny GT1. If the demand is likely to exceed the Abergavenny GT1 rating then the Southern ring can be transferred onto Uskmouth by opening Abergavenny 4L5, opening Monmouth 1L5 and closing Panteg 5L5.

Abergavenny to Monmouth Circuit

As described above, the arranged outage of Panteg GT3 leaves the southern 66 kV ring supplied entirely from Abergavenny if no additional control actions are taken. The subsequent fault of the Abergavenny to Blaenavon BSP circuit leaves the southern 66 kV ring supplied by the Abergavenny to Monmouth circuit. This overloads the Abergavenny to Monmouth circuit to as much as 121% for winter peak demand and 111% for the intermediate warm peak demand case.

It is recommended that when taking the arranged outage of Panteg GT 3 careful consideration is given to the prevailing demand and generation on the southern 66 kV ring to ensure described overload will not occur. If studies indicate a potential overload on the Abergavenny to Monmouth circuit, the Southern ring can be transferred onto Uskmouth by opening Abergavenny 4L5, opening Monmouth 1L5 and closing Panteg 5L5.

Builth Wells Primary

Busbar Fault

The Builth Wells Main 1 Busbar normally feeds Rhayader T1, Bryn Titli Wind Farm and Llandrindod Wells T1. The circuit going north from Builth Wells Main 2 Busbar only feeds Llandrindod Wells T2 under normal running.

The Builth Wells Main 1 busbar fault overloads the Llandrindod Wells T2 transformer to as much as 164% for the peak generation demand study, 126% for the winter peak demand representative day, 110% for the intermediate warm peak demand study and 102% for the summer peak demand study.

The overload for the generation representative day is predominately caused by the output of Bryn Titli Wind Farm exporting via the Llandrindod Wells 11 kV bar; hence the significant overload seen on Llandrindod Wells T2 at times the generator is exporting. The demand overloads are caused by all of the Llandrindod Wells and Rhayader demand being supplied via Llandrindod Wells T2.

It is recommended that the existing intertripping installed north of Builth Wells is reviewed to check it covers Builth Wells Main 1 busbar fault and is sufficient to remove all overloads identified. Direct intertripping to generators and operation of Loss of Mains as a result of any intertripping should be confirmed.

Bus Section Outage

Builth Wells is supplied at 66 kV from Abergavenny BSP. It has two busbars with a 1S0 section breaker run normally closed. There are two 66 kV circuits that supply Llandrindod Wells BSP, Rhayader BSP and Bryn Titli Wind Farm.

The arranged outage of the 1S0 section breaker at Builth Wells leaves the network susceptible to the fault of either circuit out of Abergavenny supplying the northern ring. The fault of the circuit from Abergavenny 2L5 to Crickhowell and Brecon leaves all of Brecon supplied via the Builth Wells and Llandrindod Wells 11 kV busbars, assuming no mitigation is taken for the arranged outage of Builth Wells 1S0. The thermal overload on the Builth Wells T2 is as much as 177% for the winter peak demand case, 134% for the intermediate warm demand case and 114% for the summer peak demand case. The Llandrindod Wells T2 transformer is also overloaded to 195% for the winter peak demand case, 159% for the intermediate warm demand case and 146% for the summer peak demand case.

The fault of the Abergavenny 1L5 circuit to Glasbury and Crickhowell overloads Builth Wells T1 up to 112% for the winter peak demand case only. This condition is not as onerous because the peak demand at Glasbury is only 6.6 MW compared with 13 MW at Brecon.

Closing the Llandrindod Wells 1S0 breaker so there is a direct 66 kV infeed to Brecon/Glasbury removes all the thermal overloads described above but the voltage on the 66 kV bar at Brecon is as low as 0.78 p.u.

It is recommended for the arranged outage of the Builth Wells 1S0 section breaker, the 11 kV busbar is split or a transformer is offloaded at Builth Wells and Llandrindod Wells.

Llandrindod Wells/Rhayader Group

The fault of the Builth Wells to Rhayader and Llandrindod Wells T1 circuit leaves all of the Rhayader and Llandrindod Wells 11 kV demand supplied via Llandrindod Wells T2. This first circuit fault overloads T2 for all demand representative days studied to as much as 134% for winter peak demand. The arranged outage of the Glasbury or Brecon Main 1 busbars followed by the Builth Wells to Rhayader circuit increase the overload up to 147% for the winter peak demand case and 120% for the intermediate warm peak demand case.

There are a number of SCO conditions that leaves Llandrindod Wells T1 supplying all of the Rhayader and Llandrindod Wells demand. This overloads T1 for all the demand representative days to as much 135% for winter peak demand down to 102% for summer peak demand.

Any SCO condition that causes the loss of both Llandrindod Wells Transformers leaves the entire Llandrindod Wells and Rhayader demand supplied by Rhayader T1 if the 11 kV is not split for the arranged outage. This overloads T1 up to as much as 232% for winter peak demand and 142% for summer peak demand. The voltage at the Llandrindod Wells 11 kV bar is reduced to 0.65 p.u.; this is likely overstated due to the way the 11 kV demand is lumped at the Primary busbars

It is recommended that the existing intertripping on the northern part of the 66 kV ring around Llandrindod Wells and Rhayader is reviewed to ensure there are sufficient intertrips and operational measures in place to mitigate the overloads identified.

If the intertipping is shown to be insufficient to resolve all overloads, one of the following could be implemented:

1. **Revise existing intertripping schemes and add additional intertrips and operation measures where necessary**
2. **Splitting the Rhayader and Llandrindod Wells 11 kV under normal running; this would leave Rhayader at single circuit risk, but would remain fully P2/6 compliance and reduces the risk of a single fault overloading assets**
3. **Replace the Rhayader and both Llandrindod Wells transformers with 12/24 MVA CER units**
4. **An additional circuit and transformer into the group**
5. **It may be possible to run the Llandrindod Wells 1S0 closed and install a 66 kV circuit breaker at Llandrindod Wells on the circuit towards Rhayader and Builth Wells; this would mean a single fault could not take two transformers out of service. A detailed assessment would be required to ensure this running arrangement was credible.**

Northern 66 kV Low Voltages

Abergavenny Busbar

The fault of either Abergavenny 66 kV busbar causes voltages on the northern 66 kV ring as low as 0.86 p.u. for all peak demand representative days. The lowest voltages are seen at 66 kV near Rhayader and Glasbury or Brecon depending on which busbar faults.

All 66/11 kV transformers are still controlling the voltage of the 11 kV bar within their defined bandwidths with taps available. The only customer who is not receiving a voltage within the statutory limits is Bryn Titli Windfarm, which is seeing a voltage of 0.88 p.u. for the fault of either Abergavenny 66 kV busbar. Their connection agreement currently states a voltage down to 0.86 p.u. is acceptable.

There is currently no scheme that will automatically close Crickhowell 1S0 for the fault of either Abergavenny busbar. A manual control action to close Crickhowell 1S0 resolves all voltage exceedances for all representative days studied.

Abergavenny to Glasbury or Brecon Outage

The fault of either 66 kV circuit from Abergavenny 66 kV to Crickhowell and Brecon or Glasbury causes low volts at Builth Wells and north 66 kV network to as low as 0.9 p.u. Low volts are also seen at either Brecon or Glasbury depending on which fault occurs.

The same low volt issues are also seen for any arranged outage that means Brecon of Glasbury does not have a direct 66 kV infeed via Crickhowell of Abergavenny.

An arranged outage of Brecon to Crickhowell, or any combination that means it is fed via Builth Wells causes low for all demand representative days with volts as low as 0.86 for winter peak demand.

An arranged outage of Glasbury to Crickhowell, or any combination that means it is fed via Builth Wells causes low for all demand representative days with volts as low as 0.86 for winter peak demand.

Closing Crickhowell 1SO for some of the arranged outages where possible helps increase the voltage but it is still outside of statutory limits for all demand representative days.

It is recommended that reactive compensation is installed at Builth Wells, Brecon and/or Glasbury to support network voltage in winter. Ideally this should be installed in at least two independent units arranged so that the FCO triggering the need for compensation does not make the compensation unavailable.

WPD are currently in the process of installing 3 x 2.2 MVAr capacitors on the 11 kV at Glasbury. Baseline studies with this reactive compensation added have shown it improves the voltage on the northern 66 kV ring for the outage condition described.

Southern 66 kV Low Voltage

The arranged outage of the Abergavenny to Blaenavon circuit followed by any fault that causes the loss of Panteg GT3 leaves Blaenavon and Abersychan supplied via the southern ring from the Abergavenny Main 1 busbar. Low voltages are seen for all demand representative days with voltages as low as 0.84 p.u. in the winter peak demand study and 0.90 p.u. in the summer peak demand representative day.

The arranged outage of Abergavenny 3L5 followed by any fault that takes Panteg GT3 out of service is showing voltages of 0.93 p.u. for the winter peak demand representative day only.

It is recommended that the prevailing demand and generation is considered when splitting the southern 66 kV ring to ensure no subsequent fault will cause unacceptable low volts. If the subsequent fault shows low volts then Panteg GT3 can be moved onto Uskmouth by closing 120 and opening 3L5. The Southern Ring can then be split from Abergavenny, so the fault of Panteg GT3 causes a lost load that can be safely restored within the requirements stated in P2/6.

8 – 2022 Results

Pembroke GSP

Network changes modelled

For the 2022 studies, the AW-route was assumed to be 250mm² AAC (Cockroach) profiled for 75 degree operation. In addition, a new 132 kV connected generator at Texaco BSP was connected at the existing point of connection. As in the baseline studies, for a GT outage at Haverfordwest, the 33 kV parallel group is split to run Haverfordwest independently from Milford Haven and Golden Hill.

Pembroke SGT Capacity

SS SP CP TD

In the 2022 studies the group demand (at winter peak) of Pembroke exceeds 240 MW under all scenarios. In particular, under a Two Degrees scenario, the winter peak group demand of Pembroke GSP increases to approximately 290 MW. As a result, a first circuit outage (arranged or fault) of an SGT at Pembroke would overload the remaining SGT in service up to as much as 118% for summer, 123% for intermediate warm and 132% for a winter peak demand case under all scenarios.

It is recommended that detailed study is undertaken to ascertain the true group demand for each of the peak demand representative days. It is acknowledged that these studies model industrial customers at full import continuously and do not take into account additional on-site generation installed, which can increase the pre-fault SGT loadings.

It is also recommended that a discussion with National Grid is had to determine if these overloads are within the short-term ratings of the Pembroke SGTs or if any operational mitigation is in place to manage these overloads, such as transferring Haverfordwest onto Swansea North for an arranged outage of an SGT.

132 kV Circuit Overloads

CW/EE-route overloads

SS SP CP TD

The overloads described in the baseline results are exacerbated under all scenarios in the 2022 studies. The SCO combination would overload the CW-route up to between 130% and 170% for a summer peak demand case and up to between 145% and 182% for an intermediate warm peak demand case. The overload would also occur up to between 103% and 114% for a summer peak generation case.

This SCO combination would also overload the EE-route between Golden Hill GT1 and Milford Haven under all scenarios for all peak demand representative days. Under a the highest growth Two Degrees scenario, the EE-route circuit would overload up to 143% in summer and 154% for an intermediate warm peak demand case.

AW/RR-route overloads

SS SP CP TD

Despite the AW-route being reprofiled for 75 degree operation, the SCO combination whereby the Milford Haven, Haverfordwest and Golden Hill group is supplied via the AW/RR-route would overload the AW-route up to between 103% and 130% in summer peak demand case and up to between 114% and 141% for an intermediate warm peak demand case under all scenarios.

This SCO combination would also overload the RR-route section of this circuit from Milford Haven under all scenarios for all peak demand representative days. Under the highest growth Two Degrees scenario, the RR-route circuit would overload up to 164% in summer and 169% for an intermediate warm peak demand case. The overload would also occur up to 103% for a summer peak generation case; albeit only under a Two Degrees scenario.

Cable Circuit from Pembroke to Golden Hill GT2

SS SP CP TD

The overloads described in the baseline results are exacerbated under all scenarios in the 2022 studies. The SCO combination would overload the cable circuit up to between 121% and 160% for a summer peak demand case and up to between 134% and 164% for an intermediate warm peak demand case. The overload would also occur up to between 104% and 110% for a summer peak generation case, albeit only under the Slow Progression, Consumer Power and Two Degrees scenarios.

This SCO combination would also overload the EE-route circuit between Golden Hill GT2 and Milford Haven under all scenarios for all peak demand representative days. Under a the highest growth Two Degrees scenario, the EE-route circuit would overload up to 140% in summer and 144% for an intermediate warm peak demand case.

In addition to the SCO overloads, the cable circuit would also overload for a first circuit outage (arranged or fault) of the AW/RR-route circuit, due to poor load share with the CW-route. These overloads would occur in all peak demand representative days up to 105% in summer, 107% for intermediate warm and 105% for winter; only under the Two Degrees and Consumer Power scenarios.

Pembrokeshire 33 kV parallel group

Milford Haven BSP

SS SP CP TD

In 2022, the winter peak group demand at Milford Haven approaches 60 MW under the Two Degrees scenario. Under intact network conditions, the single GT at Milford Haven operates well into the forced cooling rating of the transformer under all scenarios.

For the second circuit outage loss of both GTs at Golden Hill, the group demand is shared between the single GT1 at Milford Haven and the two GTs at Haverfordwest. This SCO combination would overload GT1 at Milford Haven under all scenarios up to as much as 154% for summer, 147% for intermediate warm and 140% for a winter peak demand case.

Haverfordwest BSP

CP TD

For the SCO combination which results in the loss of GT2 at Golden Hill, GT1 at Milford Haven and GT1 at Haverfordwest, the group demand is shared between GT2 at Haverfordwest and GT1 at Golden Hill. This SCO combination would overload GT2 at Haverfordwest up to as much as 102% in summer, 107% for intermediate warm and 102% for a winter peak demand case under the Two Degrees and Consumer Power scenarios.

Splitting the 33 kV parallel group for an arranged outage of a GT at Golden Hill such that Golden Hill is run independently of Milford Haven and Haverfordwest would alleviate the project overloads.

Proposed 2022 Reinforcement Strategy

To alleviate the projected overloads in 2022, the following reinforcements were modelled:

- A third SGT at Pembroke GSP

- Replacing the existing GT at Milford Haven with a 40/60 MVA unit
- Installing a cable circuit from a new 132 kV bay at Pembroke GSP following the same route as the AW-route and teed onto the RR-route adjacent to the AW/RR-route tee off point.
- Extending the 132 kV ring at Milford Haven to install two new circuit breakers (120 and 1020) and an outgoing circuit 1003 to un-bank the new Pembroke-RR-route circuit from the FF-route circuit to Haverfordwest
- Installing a 230 bus coupler circuit breaker and changes to the running arrangement at Pembroke GSP to run the 132 kV bar in four sections.

This reinforcement strategy provides a fourth 132 kV infeed into Milford Haven from Pembroke. After running 2022 studies with these reinforcements modelled, the overloads on the 132 kV circuits from Pembroke to Milford Haven were largely removed. For a GT outage at Haverfordwest, the 33 kV parallel group is split to run Haverfordwest independently from Milford Haven and Golden Hill. Likewise, for a GT outage at Golden Hill, the 33 kV parallel group is split to run Golden Hill independently from Milford Haven and Haverfordwest to alleviate the GT overload of Haverfordwest GT2.

Results

Pembroke SGT Overloads

SS SP CP TD

With a group demand greater than 240 MW, an arranged outage of an SGT followed by an SGT fault would result in the group being fed from the remaining SGT in service and the A-route interconnection with Swansea North (which is switched in as part of the arranged outage). For this SCO combination, the load share between the A-route and the SGT is poor. The remaining SGT would overload up to as much as 118% for a summer peak demand case under the Two Degrees and Consumer Power scenarios. The overload would also occur up to as much as 129% for an intermediate warm peak demand case under all scenarios.

It is recommended that detailed study is undertaken to ascertain the true group demand for each of the peak demand representative days. It is acknowledged that these studies model industrial customers at full import continuously and do not take into account additional on-site generation installed, which can increase the pre-fault SGT loadings.

It is also recommended that a discussion with National Grid is had to determine if these overloads are within the short-term ratings of the Pembroke SGTs. It should be noted that fault level studies have not been carried out for running two SGTs at Pembroke in parallel with Swansea North GSP via the A-route, and detailed studies should consider this.

RR-route Overloads

SS SP CP TD

For the arranged outage of the cable circuit between Pembroke and Golden Hill, followed by the circuit fault of the proposed circuit from Pembroke-Milford Haven-Waterston, this leaves the group fed via 2 circuits on the CW/EE and AW/RR routes. This SCO combination would overload the RR-route circuit towards Milford Haven, up to as much as 103% for summer and 110% for intermediate warm peak demand cases under the Two Degrees and Consumer Power scenarios.

Similarly for the arranged outage of the cable circuit between Pembroke and Golden Hill, followed by the circuit fault of the AW-RR-route circuit from Pembroke-Milford Haven-Waterston, this leaves the group fed via 2 circuits on the CW/EE and proposed Pembroke-Milford Haven routes. This SCO combination would overload the RR-route circuit towards Milford Haven, up to as much as 161% in summer), 170% for intermediate warm and 167% for a winter peak demand case under all scenarios. The overload would also occur for the summer peak generation case, up to as much as 108% of rating under the Two Degrees and Consumer Power scenarios.

The sections of the RR-route from Milford Haven to the tee-off points with the AW-route and proposed Pembroke circuit are currently 175mm² ACSR conductor. It is recommended that the RR-route is reconductored for the sections between Milford Haven and the tee-off points.

Cable Circuit from Pembroke to Golden Hill Overloads

CP TD

For the SCO combination which results in the loss of both the AW/RR-route and the proposed Pembroke-Milford Haven cable, the group is fed via the two remaining circuits in service via Golden Hill, with an unequal load share. For this SCO combination, the cable circuit between Pembroke and Golden Hill would overload up to as much as 102% for summer and 108% for intermediate warm peak demand cases under the Two Degrees and Consumer Power scenarios.

A summer access window is still available for this overload; it is recommended that thought is given to addressing the poor load share between the cable and the CW-route under this scenario. Potential reinforcements include power flow control devices such as a series reactor at Pembroke.

Alternative reinforcement strategies considered

An alternative reinforcement strategy was considered alleviate the projected overloads in 2022 studies. This also involved a third SGT at Pembroke and replacing the grid transformer at Milford Haven with a 40/60 MVA unit. However instead of installing a fourth 132 kV infeed into Milford Haven from Pembroke, a new cable circuit was installed from a new 132 kV bay at Pembroke GSP to Golden Hill BSP, this is connected onto the EE-route circuit from Golden Hill GT1 to Milford Haven. As part of this reinforcement, GT1 at Golden Hill is un-banked from the EE-route circuit and supplied independently from Pembroke.

Whilst this reinforcement reduced the circuit loadings of the three 132 kV circuits from Pembroke to Milford Haven (as a result of a portion of the Golden Hill demand supplied independently via the CW-route), the majority of the demand growth in the area is centred on the Milford Haven and Haverfordwest BSP areas. As a result, the group demand of the network connected to Milford Haven (including Haverfordwest and three 132 kV connected customers) exceeds 190 MW for a winter peak demand case under a Two Degrees scenario, with demand peaks in excess of 170 MW for the summer and intermediate warm representative days. As a result, any SCO combination which results in the loss of two of the three 132 kV circuits from Pembroke to Milford Haven would overload the remaining circuit in service under all peak demand representative days. This would likely entail reconductoring works on all circuits to increase the circuit rating to be able to support the entire Milford Haven fed group on one circuit.

Due to the large amounts of reinforcement works that would be required to operate this group for the 2022 scenarios using this reinforcement strategy, a fourth circuit into Milford Haven from Pembroke was chosen to continue with 2027 studies.

Swansea North GSP

P18 Assessment

SS SP CP TD

A 132 kV connected wind farm in the pipeline connects under all scenarios on the 132 kV circuit from Swansea North-Ammanford GT1-Travellers Rest GT1-Hirwaun GT2. The connection of this wind farm will result in this circuit exceeding the limits recommended in P18 restriction A (*"The normal operating procedure or protective gear operation for making dead any 132 kV circuit shall not require the opening of more than seven circuit-breakers. These circuit-breakers shall not be located on more than four different sites")* as for a fault, 6 circuit breakers must be opened at 5 different sites.

Swansea North SGT Capacity

SS SP CP TD

Following significant demand growth to 2022, the group demand of Swansea North GSP increases to 715 MW. The baseline running arrangement of four SGTs in service is unchanged in the 2022 studies. The overloads from the baseline studies are exacerbated under all scenarios for the 2022 studies.

First Circuit Outage

Fault

For a fault of the Main 1 busbar at Swansea North, the site is left running with three SGTs in service, SGT3 and SGT7 supplying the Main 2 and Reserve 2 bars, with the remaining SGT6 supplying the Reserve 1 bar. This fault would overload SGT3 up to as much as 117% in summer, 140% for an intermediate warm and 173% for winter peak demand case under all scenarios. This fault would also overload SGT7 up to as much as 110% in summer, 122% for an intermediate warm and 137% for winter peak demand case under all scenarios.

Similarly, for a fault of the Main 2 busbar at Swansea North, this leaves the GSP running with SGT5 and SGT6 supplying the Main 1 and Reserve 1 bars, with the remaining SGT4B supplying the Reserve 2 bar (SGT4B is switched in as part of the auto close scheme for the loss of SGT7). This fault would overload SGT4B (a 180 MVA unit) up to as much as 108% in summer (Two Degrees only), 122% for an intermediate warm (Two Degrees, Consumer Power and Slow Progression) and 128% under all scenarios for a winter peak demand case.

For a fault of SGT5 at Swansea North, the site is left running with three SGTs in service, SGT3 and SGT7 supplying the Main 2 and Reserve 2 bars, with the remaining SGT6 supplying the Main 1 and Reserve 1 bars. This fault would overload SGT6 up to as much as 128% for a winter peak demand case under all scenarios, also up to as much as 113% for an intermediate warm peak demand case under the Two Degrees and Consumer Power scenarios. The overload would also occur on SGT5 for a fault of SGT6.

Similarly, a fault which results in the loss of SGT3 at Swansea North would leave the site running with three SGTs in service, SGT5 and SGT6 supplying the Main 1 and Reserve 1 bars, with the remaining SGT7 supplying the Main 1 and Reserve 1 bars. This fault would overload SGT6 up to as much as 138% for a winter peak demand case under all scenarios, also up to as much as 121% for an intermediate warm peak demand case under the Two Degrees, Consumer Power and Slow Progression scenarios. The overload would also occur for this fault up to 109% for a summer peak demand case under a Two Degrees scenario.

Arranged

For the arranged outage of an SGT at Swansea North, the 132 kV bars are run in parallel with three SGTs in service. For an arranged outage of SGT5 or SGT6, this leaves three SGTs in service – two 240 MVA units and a 180 MVA unit. This arranged outage would overload all of the SGTs in service up to as much as 109% for an intermediate warm peak demand case under a Two Degrees scenario.

For an arranged outage of the Cilfynydd 305 circuit towards Swansea North Main 2 400 kV busbar, this results in a poor load share between SGT3 (fed from Pembroke at 400 kV) and SGT7 (fed from the Swansea North 400 kV double busbar). As a result, SGT3 would overload up to as much as 115% for an intermediate warm peak demand case under all scenarios. This overload would also occur up to 115% for a summer peak demand case for a Two Degrees scenario.

Second Circuit Outage

For an arranged outage of an SGT where three SGTs are run in parallel followed by a fault of another SGT, this leaves the site running off two SGTs with 120 and 160 circuit breakers closed. This SCO combination would overload the remaining two SGTs in service, up to as much as 146% for a summer and 163% for an intermediate warm peak demand case under all scenarios for a 240 MVA unit; also up to 119% for a summer peak generation case under a Two Degrees scenario. When one of the two remaining SGTs in service is the smaller 180 MVA unit, the SCO combination would overload SGT3 up to as much as 161% for a summer and 168% for an intermediate warm peak demand case under all scenarios; also up to as much as 141% for a peak generation case under all scenarios.

Given the scale of the projected demand growth at Swansea North, further SGT capacity will be necessary for the higher growth scenarios in the 2022 studies. The proposed reinforcement strategy outlines a potential solution that considers the other 2022 overloads.

Hirwaun BSP

CP TD

Following demand growth to 2022, the winter peak demand of Hirwaun BSP approaches 80 MW under a Two Degrees scenario. In addition, following generation growth to 2022 the total generation connected to Hirwaun BSP approaches 100 MW under a Two Degrees scenario. As a result, under intact network conditions, both GTs at Hirwaun operate well into the forced cooling rating of the transformer for all peak demand and generation representative days under the Two Degrees and Consumer Power scenarios.

For the first circuit outage (arranged or fault) of a grid transformer at Hirwaun, the remaining GT in service would overload up to as much as 160% for a summer peak generation case under the Two Degrees and Consumer Power scenarios. This FCO would also overload the remaining GT up to as much as 145% in summer, 148% for intermediate warm and 136% for a winter peak demand case under the Two Degrees and Consumer Power scenarios.

A reinforcement scheme has been triggered to replace the grid transformers at Hirwaun BSP with 60/90 MVA units, which should alleviate the projected overloads. Further generation connections at Hirwaun BSP may be required to be managed through flexible connections.

As part of the Upper Boat results section for 2022 studies, it is recommended Hirwaun is not transferred into Upper Boat under any conditions to prevent overloads on the D-route circuits. The Hirwaun transfer is not required for compliance and is only done to improve supply security. If the Hirwaun group demand was to increase above 100 MW, there would be a SCO requirement to resupply demand at the BSP and consideration as to how this would be achieved would be needed.

132 kV circuit issues

A-route overloads

SS SP CP TD

The A-route overloads from the baseline studies are exacerbated under all scenarios, for an arranged outage where the A-route interconnection is switched in to provide support to the Carmarthenshire network. When this arranged outage is followed by a circuit fault between Carmarthen and Llanelli, both of the 132 kV infeeds from Swansea North to Carmarthen are lost and the group is entirely fed via Pembroke at 132 kV. The group encompasses Carmarthen, Rhos, Llanarth, Lampeter, Aberystwyth and Rhydlydan BSPs (as Ammanford BSP is split from the group for the arranged outage). For this SCO combination, the A-route circuit would overload up to as much as 166% for summer and 204% for an intermediate warm peak demand case under all scenarios. This fault would also overload the remaining circuit in service up to as much as 117% for a summer peak generation case under a Two Degrees scenario.

Swansea North to Carmarthen

CP TD

For the first circuit fault which results in the loss of 132 kV infeed from Swansea North GSP to Carmarthen BSP and the wider 132 kV network, this leaves the entire group on one 132 kV circuit. This fault would overload the remaining circuit in service (encompassing the B, C, V, W and XY routes) up to as much as 112% for an intermediate warm (Two Degrees only) and 123% for a winter peak demand case (Two Degrees and Consumer Power). This fault would also overload the remaining circuit in service up to as much as 114% for a summer peak generation case under a Two Degrees scenario.

An arranged outage whereby Ammanford BSP is split from the 33 kV group, followed by a fault of a circuit from Swansea North to Carmarthen would exacerbate the overload of the remaining circuit in service, as the A-route is not switched in to provide support to Carmarthen and the grid transformers at Ammanford do not pick up as much load as for a first circuit fault.

Swansea North to Carmarthen overloads as a result of not being able to use the A-route

SS SP CP TD

For the arranged outage which results in the loss of 132 kV infeed Swansea North GSP to Carmarthen BSP and the wider 132 kV network, the A-route interconnector with Pembroke GSP is switched in to provide support to this area. However there are some arranged outages at Carmarthen where the A-route interconnection cannot be utilised. For these arranged outages, the group is supplied via one 132 kV circuit from Swansea North, which would overload up to as much as 118% for an intermediate warm peak demand case under a Two Degrees scenario. This FCO would also overload the remaining circuit in service up to as much as 127% for a summer peak generation case under a Two Degrees scenario.

When the arranged outage is followed by a fault of GT1 at Rhos, the overloads are exacerbated up to as much as 140% for an intermediate warm peak demand case under all scenarios. This SCO combination would also overload the remaining circuit in service up to as much as 115% for a summer peak demand case under a Two Degrees scenario.

Given the projected demand growth, a third 132 kV infeed into Rhos BSP and the northern part of the wider 33 kV parallel group is necessary. The proposed reinforcement strategy outlines a potential solution that considers the other 2022 overloads.

Carmarthenshire and West Wales

Aberystwyth and Rhydlydan BSP

SS SP CP TD

Aberystwyth and Rhydlydan BSPs are owned by SP Manweb but supplied via two 132 kV circuits from Rhos BSP and run in parallel at 33 kV. In 2022 the group demand of Aberystwyth and Rhydlydan exceeds 50 MW under a Two Degrees scenario. As a result, the first circuit outage (arranged or fault) of one of the grid transformers would overload the remaining GT in service up to as much as 118% for an intermediate warm peak demand case under the Two Degrees and Consumer Power scenarios. This overload would also occur up to as much as 126% for a winter peak demand case under all scenarios, also up to as much as 125% for a summer peak generation case under a Steady State scenario.

The grid transformers at Aberystwyth and Rhydlydan have been modelled as 45 MVA fixed rating GTs. In the latest LTDS for the SP Manweb licence area, it states that the transformer rating is 60 MVA at Aberystwyth and 45 MVA at Rhydlydan. It is recommended that the transformer details are updated.

Carmarthen BSP

SS SP CP TD

Following demand growth to 2022, the winter peak demand of Carmarthen BSP exceeds 65 MW under a Two Degrees scenario. Under intact network conditions both grid transformers operate well into the forced cooling rating of the transformer for a winter and intermediate warm peak demand representative days under the Two Degrees scenario.

For the first circuit outage (arranged or fault) which results in the loss of a grid transformer at Carmarthen, the remaining GT in service would overload up to as much as 117% in winter and 113% for an intermediate warm peak demand case under a Two Degrees scenario. The overload would also occur up to 103% for a summer peak generation case under a Two Degrees scenario.

For an arranged outage of the H-route circuit from Carmarthen to Rhos (which includes GT1 at Rhos), these studies have modelled that the large 33 kV group is split into four smaller 33 kV groups. Ammanford, Llanarth and Lampeter all run independently, with Carmarthen and Rhos BSPs run in parallel at 33 kV. When this arranged outage is followed by a fault of GT1 at Carmarthen, the remaining GT2 in service would overload up to as much as 142% for an intermediate warm peak demand case under the Two Degrees, Consumer Power and Slow Progression scenarios, also up to 113% for a summer peak demand case under a Two Degrees scenario. Under a Two Degrees scenario, the overload would also occur up to 139% for a summer peak generation case.

For an arranged outage of GT2 at Carmarthen, Ammanford BSP is split from the 33 kV group and the remaining 5 GTs run in parallel at 33 kV. When this arranged outage is followed by a fault of GT1 at Rhos, the demand of Rhos, Llanarth, Lampeter and Carmarthen is supplied via the GTs at Carmarthen, Llanarth and Lampeter. This SCO combination would overload Carmarthen GT1 up to as much as 134% for an intermediate warm peak demand case under all scenarios. Under a Two Degrees scenario, the overload would also occur up to 136% for a summer peak generation case.

Llanarth BSP

SS SP CP TD

For an arranged outage of the Main 1 busbar at Carmarthen, the 33 kV group is split into four smaller 33 kV groups. Ammanford, Carmarthen and Lampeter all run independently, with Llanarth and Rhos BSPs run in parallel at 33 kV. When this arranged outage is followed by a fault of Gt1 at Rhos, the demand of Rhos and Llanarth is supplied via the 22.5/45 MVA GT at Llanarth. This SCO combination would overload Llanarth GT1 up to as much as 110% in summer peak demand (Two Degrees and Consumer Power), also up to as much as 153% for intermediate warm peak demand under all scenarios

Lampeter BSP

SP TD

For an arranged outage of the Main 1 busbar at Rhos, the 33 kV group is split into four smaller 33 kV groups. Ammanford, Carmarthen GT2 and Lampeter all run independently, with Llanarth, Carmarthen GT1 and Rhos BSPs run in parallel at 33 kV. As part of these 33 kV splits the demand from Cwmffrwd, Nantgaredig and Llanllwni primary substations is transferred onto Lampeter BSP. This arranged outage would overload Lampeter GT1 up to 109% in summer (Two Degrees only) and up to as much as 130% for an intermediate warm peak demand case under a Two Degrees and Slow Progression scenarios.

This arranged outage would also overload the CC-route circuit between Rhos and Lampeter tee up to as much as 116% for an intermediate warm peak demand case under a Two Degrees scenario.

Rhos BSP

SP CP TD

Following demand growth to 2022, the winter peak demand of Rhos BSP approaches 40 MW under a Two Degrees scenario. Under intact network conditions the grid transformer operates well into the forced cooling rating of the transformer for a winter and intermediate warm peak demand representative days under the Two Degrees and Consumer Power scenarios.

For an arranged outage of the GT2 at Carmarthen, Ammanford BSP is split from the 33 kV group and the remaining 5 GTs run in parallel at 33 kV. When this arranged outage is followed by a fault of GT1 at Carmarthen, the demand of Rhos, Llanarth, Lampeter and Carmarthen is supplied via the GTs at Rhos, Llanarth and Lampeter. This SCO combination would overload Rhos GT1 up to as much as 154% in summer under a Two Degrees and Slow Progression scenario. The overload would also occur up to as much as 210% for an intermediate warm peak demand case under a Two Degrees, Consumer Power and Slow Progression scenario; also up to as much as 144% for a summer peak generation case under a Two Degrees scenario.

Given the scale of the projected demand growth in this complex 33 kV parallel group, it is recommended that this group is split into smaller groups at 33 kV. These works would involve 33 kV reinforcement schemes; detailed studies taking into account the distribution of demand and generation are recommended.

Proposed reinforcement strategy

To alleviate the projected overloads at Swansea North GSP, a reinforcement strategy is proposed that considers the complex nature of the Carmarthenshire and West Wales 132 kV network. Swansea North is already a large GSP with five SGTs, ten outgoing circuits and three local GTs. Given the large geographic area supplied and the distribution of future demand growth, it may be more appropriate to establish a new GSP to transfer load away instead of expanding Swansea North further.

Ferryside GSP, where National Grid's 400 kV circuit from Pembroke to Walham crosses the 132 kV B-route approximately 6km south of Carmarthen BSP was modelled as a potential location for a new GSP. Supplies to Carmarthenshire and West Wales are transferred onto the new GSP via the existing B-route and EE-route circuits. There are six outgoing 132 kV circuits from Ferryside GSP, with three normally open interconnecting circuits with Swansea North GSP and the normally open A-route circuit between Carmarthen and Pembroke also available. A third 132 kV circuit from Ferryside to Rhos BSP is established by connecting the circuits between Brechfa West and Blaengwen wind farms.

In addition to Ferryside GSP, a second GT was installed at Rhos BSP and the large 33 kV parallel group encompassing Carmarthen, Rhos, Llanarth, Lampeter and Ammanford split into three smaller groups. Ammanford is split away from the group and supplied solely from Swansea North, with Carmarthen BSP run independently from Ferryside GSP. The Rhos, Lampeter and Llanarth group is run in parallel at 33 kV.

Detailed network design is required to assess the proposed reinforcement strategy against the projected demand and generation growth, including but not limited to:

- **Intertripping schemes for 132 kV connected generators**
- **Running arrangements for outage management, particularly for transmission network outages**
- **Protection and fault level studies**

Pyle GSP

Network changes modelled

In the 2022 studies, two 66 kV generation connections scheduled to connect under all scenarios were modelled. These were connected via a new 132/66 kV grid transformer at Pyle GSP, with a new 66 kV circuit from Pyle to Llynfi following the WF-route.

Pyle SGT Overloads

SS SP CP TD

Following demand and generation growth to 2022, for a first circuit fault of SGT2 at Pyle GSP, the remaining SGT1 in service (which is a smaller 180 MVA unit) would overload up to as much as 110% for a summer peak generation case under the Two Degrees and Consumer Power scenarios. The overload would also occur up to as much as 116% for summer, 119% for intermediate warm and 124% for a winter peak demand case under all scenarios; albeit there is no summer peak demand overload in the Steady State and Slow Progression scenarios.

As mentioned in the Upper Boat results section of this report, there are arranged outages at Upper Boat GSP whereby Pencoed and Pontyclun BSPs are transferred into the Pyle GSP group by closing the normally open circuit breakers 105 and 205 at Pencoed. Following this transfer, a fault of SGT2 at Pyle would overload the 180 MVA SGT1 up to as much as 138% for a summer peak generation case under all scenarios. The overload would also occur up to as much as 137% for summer and 141% for an intermediate warm peak demand case under all scenarios. Similarly, following the demand transfer of Pencoed and Pontyclun onto Pyle GSP, a fault of SGT1 would overload the remaining 240 MVA SGT2 unit up to as much as 104% for a summer peak generation case under the Two Degrees and Consumer Power scenarios. The overload would also occur up to as much as 103% for summer and 106% for an intermediate warm peak demand case under the Two Degrees and Consumer Power scenarios.

It is recommended that the existing 180 MVA SGT1 at Pyle is replaced with a 240 MVA unit.

Bridgend BSP

SS SP CP TD

Following demand growth to 2022, the winter peak demand of Bridgend BSP exceeds 80 MW under a Two Degrees scenario. Under intact network conditions, both GTs at Bridgend operate well into the forced cooling rating of the transformer under all scenarios for all peak demand representative days.

For the first circuit outage (arranged or fault) of GT2 at Bridgend, the remaining 22.5/45 MVA GT1 in service would overload up to as much as 177% in summer, 172% for intermediate warm and 156% for a winter peak demand case under all scenarios. Likewise, the first circuit outage (arranged or fault) of GT1 at Bridgend would overload the remaining 30/60 MVA GT2 in service up to as much as 130% in summer, 135% for intermediate warm and 122% for a winter peak demand case under all scenarios.

This first circuit outage would also overload the U-route circuit between Pyle and Bridgend GT2 up to as much as 116% in summer, 115% for intermediate warm and 115% for a winter peak demand case under the Consumer Power and Two Degrees scenarios. This circuit is currently limited by a 100m section of 350mm² aluminium underground cable.

It is recommended that both of the grid transformers at Bridgend BSP are replaced with 60/90 MVA units, and the cable section of the U-route to Bridgend GT2 circuit is overlaid to match the rating of the overhead line.

Pyle to Upper Boat transfers

For an arranged outage which results in the loss of an SGT or an outgoing U-route circuit at Pyle, these studies have modelled a transfer of Bridgend BSP, Fords Bridgend BSP and Waterton Industrial onto Upper Boat GSP via the normally open circuit breakers at Pencoed BSP. Likewise, as mentioned in the Upper Boat results section of this report, there are some arranged outages at Upper Boat whereby Pontyclun BSP and Pencoed BSP are transferred onto Pyle GSP. This results in a ladder network comprising of two 132 kV circuits which are loose-coupled via the 11 kV and 33 kV bars at several BSPs.

The thermal overloads as a result of the transfer from Pyle to Upper Boat are discussed in the Upper Boat results section of this report.

Transfers into Pyle

SS SP CP TD

An arranged outage whereby Pontyclun and Pencoed are transferred onto Pyle, followed by a fault on the U-route circuit between Pyle and Bridgend GT1-Fords Bridgend GT1-Waterton GT1 would overload the U-route between Pyle GSP and Bridgend BSP, up to as much as 136% in summer and 138% for an intermediate warm peak demand case under the Consumer Power and Two Degrees scenarios, and up to as much as 104% for an intermediate warm peak demand case under the Slow Progression and Steady State scenarios.

It is recommended that detailed studies are carried out regarding the transfers between Pyle GSP and Upper Boat GSP in future years. The Pyle GSP network is currently operated in excess of the P2/6 compliance requirements in order to minimise customer interruptions. With the scale of demand growth in future years the transfers may not be possible for arranged outages, as second circuit faults can result in overloads on 132 kV circuits and SGT overloads at Pyle. Operating these ladder style networks as a radial network for the arranged outage is possible without affecting the P2/6 compliance of this network.

66 kV generation connections

CP TD

In the 2022 studies, there are two new 66 kV generator connections scheduled to connect in the Llynfi valley area via a new 132/66 kV grid transformer at Pyle GSP. For the arranged outage of the circuit breaker 220 at Pyle, Pyle is run in parallel with Swansea North via the VE-route to provide support to the 132 kV network. If this arranged outage is followed by a fault of SGT1 at Pyle, the 66 kV generation exports along this circuit and would overload the VE-route section from Pyle to Tir John BSP up to 105% for a summer peak generation case under the Consumer Power and Two Degrees scenarios.

It is recommended that these new 66 kV generation connections are constrained off for the arranged outage to alleviate this overload. An alternative conventional reinforcement strategy is to install a 320 circuit breaker at Pyle to enable the Main 1 and Main 3 bars in parallel for an arranged outage to maintain circuit breaker 220.

Margam GSP

As described in the Baseline results, it has been assumed that by 2022:

- Margam BSP will no longer be operated in parallel with Margam GSP, preventing both through-flow issues and SCO overloads. Instead, Margam BSP will be used for partial post-SCO restoration.
- 66 kV interconnector A between Cefn Gwrgan and Grange will be overlaid with 300mm² Copper EPR cable, avoiding the need to transfer Cefn Gwrgan onto Pyle GSP via Margam BSP during interconnector outages.

- AVC settings will be revised at Margam GSP
- Grange/Llynfi 66 kV number 2 circuit will be reprofiled for operation at 65°C
- The Pant Y Wal intertrip will be extended to cover 66 kV busbar faults at Grange

By 2022, group demand is projected to grow from 146 MW in Baseline to:

Scenario	Group demand
TD	153 MW
CP	152 MW
SP	151 MW
SS	151 MW

Although significant generation growth in the Llynfi Valley is projected, all major new generators are planned to connect to the Pyle 66 kV network.

No new reinforcement requirements were identified in the Margam GSP network for 2022.

Upper Boat

Upper Boat/Mountain Ash Group

SS SP CP TD

The Upper Boat 33 kV network is supplied by two 100 MVA 275/33 kV SGTs. It is run normally in parallel with Mountain Ash BSP which is supplied via by a single 30/60 MVA GT from the Upper Boat 132 kV network. This interconnection is broken for any arranged outage that could leave the entire 132 kV Upper Boat network supplied via Mountain Ash for a subsequent fault.

A FCO of either Upper Boat 132/33 kV SGT overloads the remaining SGT to as much as 120% for winter peak demand under Two Degrees and Consumer Power. Intermediate Warm peak demand overloads are as much as 111% and an overload of 102% is seen for summer peak demand under Two Degrees only.

The arranged outage of the Mountain Ash GT leaves the entire 33 kV network supplied via the two SGTs. The subsequent fault of either 132/33 kV SGT overloads the remaining SGT to between 155% and 162% under Two Degrees and Consumer Power for all peak demand days. This overload is reduced to between 137% and 140% under Steady State and Slow Progression for all peak demand days.

The SGT short-term ratings are unlikely to be sufficient to manage this loading. Available 33 kV switchgear ratings prevent the replacement of the 275/33 kV SGTs with larger units.

It is recommended to take this opportunity to rationalise this network and simplify its operation. This can be achieved by:

- **Establishing a second 132/33 kV GT at Mountain Ash (rated at 40/60 MVA) as shown in Figure 43**;
- **Reconfiguring Mynydd Y Bwllfa to provide 132 kV bussing between the two circuits of the D-route as shown in Figure 44. This would put Mountain Ash on a 132 kV ring supplied from Upper Boat GSP, maintaining compliance with Engineering Recommendation P18 (Complexity of 132 kV circuits); and**
- **Carrying out 33 kV reinforcement as necessary to allow Upper Boat and Mountain Ash to be run independently at 33 kV.**

This reinforcement resolves all overloads identified on Mountain Ash and the Upper Boat 33 kV SGTs. To utilise the additional capacity available at Mountain Ash from the installation of the second GT and to reduce the loading on the Upper Boat SGTs within rating, the 33 kV split increases the demand on the Mountain Ash GTs. This increases the loading on the double circuit supplying Mountain Ash to the point where a first circuit fault of one circuit overloads the remaining in-service circuit under all scenarios to as much as 127% (Two Degrees) for an intermediate warm peak demand study.

The Upper Boat 1005 circuit to Mynydd Y Bwllfa (D-route, Y-route and YE-route) and part of the Upper Boat 1205 to Mountain Ash circuit (Y-route and D-route only) are currently 175mm² ACSR (Lynx) @ 50˚C. Reprofiling these circuits for an operating temperature of 75˚C is just sufficient to resolve all overloads under all scenarios. This does requires Mountain Ash to be placed at single circuit risk for some arranged outage that split the Upper Boat 132 kV, as it causes significant flow via the remote couple at Mynydd Y Bwllfa for a subsequent fault.

It is recommended consideration is given to reconductoring these circuits to 300mm² AAAC (Upas) @ 75°C, as the remote couple at Mynydd Y Bwllfa could be better utilised to resolve a number of the Upper Boat 132 kV busbar splits identified in baseline. It will also give the ability to transfer Hirwaun back into Upper Boat for arrange outages on the Swansea North network under certain seasons.

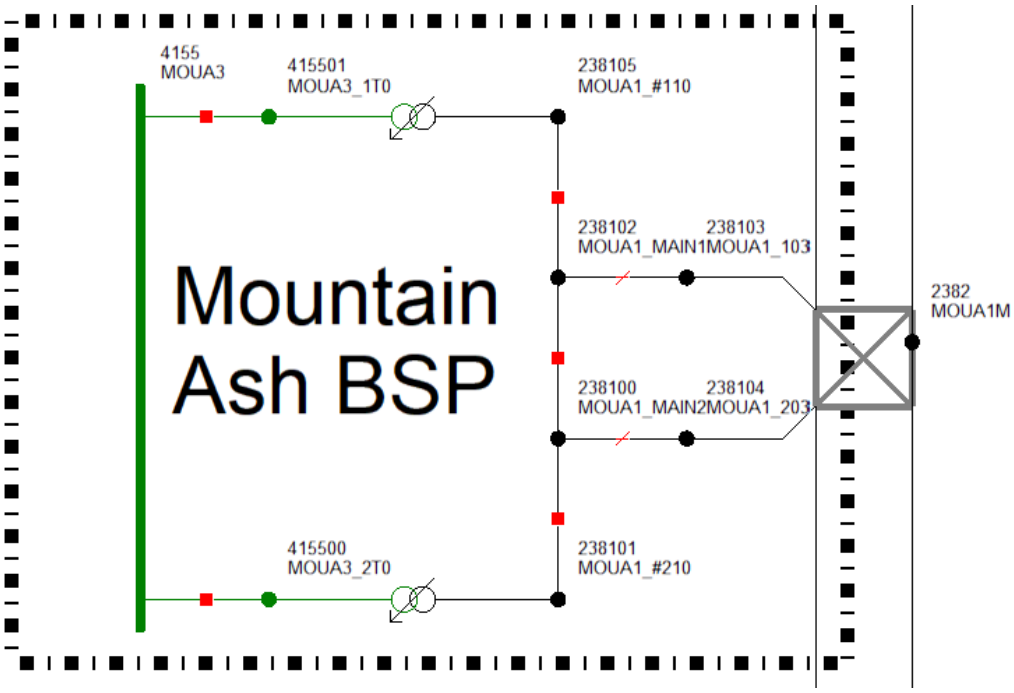

Figure 43: Proposed 132 kV layout for Mountain Ash BSP

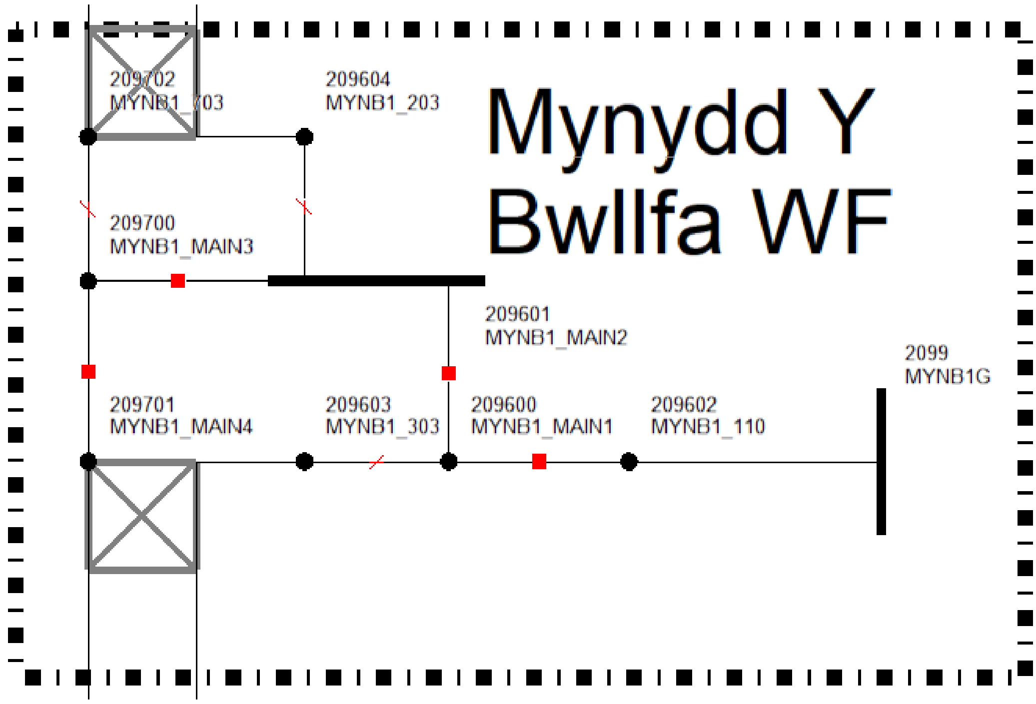

Figure 44: Proposed 132 kV bussing at Mynydd Y Bwllfa

Upper Boat 275/132 kV SGT Capacity

SS SP CP TD

The Upper Boat 132 kV is supplied by two 275/132 kV SGTs. The 132 kV busbar at Upper Boat is arranged as a ring of 12 section breakers, without line or transformer-incomer breakers. There is a normally open 132 kV interconnector. There are no overloads under any intact and credible FCO condition for any demand or generation representative day.

The Pyle GSP is supplied by one 180 MVA SGT and one 240 MVA SGT. There are a number of arranged outages at Pyle GSP where Waterton Industrial BSP, Fords Bridgend BSP and Bridgend BSP are currently (in baseline) transferred onto Upper Boat by closing the Pencoed 105 and 205 normal open points and opening the Pyle 505 and 605. The subsequent fault of either Upper Boat 275/132 kV SGT leaves the remaining SGT overloaded to between 113% and 123% for all demand representative days under Consumer Power and Two Degrees. The Steady State and Slow Progression scenarios have an overload between 101% and 116% for intermediate warm and winter peak demand cases; no overloads are seen for summer peak demand or peak generation.

Although this overload could be alleviated by bringing Aberthaw SGT3 into the Upper Boat 132 kV network, this may not be practical. Bringing Aberthaw SGT3 into group for arranged outages may trigger fault level constraints and would make Pyle GSP dependent upon Aberthaw and Cardiff East GSPs as well as Upper Boat and Swansea North GSPs – this level of interdependence is likely to constrain outage planning so far that reinforcement is triggered anyway. Bringing Aberthaw SGT3 into group post-fault would require short-term ratings for the remaining SGT at Upper Boat while the Cardiff East/Aberthaw 132 kV network was reconfigured to make Aberthaw SGT3 available.

The Pyle outages that in Baseline (current operational procedure) require transfers into Upper Boat should be assessed to determine if a summer access window is sufficient for Slow Progression and Steady State. Under Consumer Power and Two Degrees the Upper boat SGT short-term ratings should be confirmed with National Grid.

If short-term ratings were not sufficient it may be possible to have Aberthaw SGT3 selected to dedicated bars for the duration of the Pyle to Upper Boat transfer. The normal open point could be moved to Upper Boat to make installation of an intertrip to auto-close the Aberthaw interconnector for the loss of either Upper Boat SGTs simpler. It is likely that saturating the capacity at Aberthaw for the entire period of a Pyle outage may not be viable.

Upper Boat to Aberthaw Interconnector

SS SP CP TD

As described above, the Upper Boat 132 kV network is normally supplied by two SGTs. For the arranged outage of either Upper Boat SGT, the 132 kV interconnector is closed to secure against the subsequent fault of the remaining in-service SGT. The current rating of the Aberthaw to Upper Boat 132 kV interconnector is 200 MVA in winter and 190 MVA in summer.

The overloads identified would occur under all scenarios for an intermediate warm or winter peak demand representative day to between 103% (Steady State) and 113% (Consumer Power). An overload of 103% is also seen for summer peak demand under Consumer Power and Two Degrees.

The conditions that overload the 132 kV interconnector can also overload Aberthaw SGT3 to between 103% (Steady State) and 117% (Consumer Power and Two Degrees) of 240 MVA rating.

Where no overload is seen under Steady State and Slow Progression in summer, the access window of Upper Boat SGTs and associated 275 kV outages should be assessed to determine if a summer access window is sufficient. Studies indicate that it is no longer possible to transfer Pencoed and Pontyclun into Pyle under all demand and generation conditions, predominately due to the demand growth at Bridgend. There is sufficient capacity to transfer Pencoed into Pyle under all scenarios without the next fault causing any issues.

Where a summer access window is not sufficient or overloads are seen for summer peak demand, consideration should be given to moving Pencoed into Pyle for the duration of the Upper Boat SGT arranged outage. This will reduce the group demand within the rating of the Aberthaw interconnector.

Preventing the 132 kV interconnector overload should also prevent the Aberthaw SGT3 overload. If it does not, options to resolve the overload include:

- **Determination of short-term ratings by National Grid**
- **Use of the 132 kV capacitor banks at Aberthaw GSP to reduce reactive loading**

Upper Boat to Pencoed Circuits

SS SP CP TD

Under normal running Talbot Green, Pontyclun and Pencoed BSPs are supplied via a double circuit in a ladder configuration from Upper Boat 132 kV. Pencoed has two normally open line breakers that interconnect with Pyle GSP.

For the arranged outage of a Pyle SGT or either side of U-route Waterton Industrial, Fords Bridgend and Bridgend BSPs are transferred onto the Upper Boat 132 kV by closing the Pencoed 105 and 205 normal open points and opening the Pyle 505 and 605.

This causes loading on the double circuit from Upper Boat to Bridgend BSP to as much as 90% (Consumer Power and Two Degrees) and 69% (Steady State and Slow Progression) for all demand cases. The highest loading is seen on the Talbot Green Pontyclun circuit. This circuit only has a summer rating of 83.7 MVA, compared with the Upper boat to Talbot Green circuits that have a summer rating of 147.5 MVA.

The subsequent fault of one of these circuits overloads the remaining circuit to as much as 180% (Consumer Power and Two Degrees) and 144% (Steady State and Slow Progression) for all peak demand cases.

It is recommended that detailed studies are carried out regarding the transfers between Pyle GSP and Upper Boat GSP in future years. The Pyle GSP network is currently operated in excess of the P2/6 compliance requirements in order to minimise customer interruptions. With the scale of demand growth in future years the full transfer onto Upper Boat may not be possible for arranged outages, as second circuit faults can result in significant overloads on 132 kV circuits between Upper Boat and Pencoed. Operating these ladder style networks as a radial network for the arranged outage is possible without affecting the P2/6 compliance of this network. Waterton Industrial BSP and Ford Bridgend BSP can still be transferred onto Upper Boat without causing any next fault issues.

Upper Boat to Hirwaun Circuits

SS SP CP TD

Hirwaun BSP is normally supplied via a double circuit from Swansea North GSP. Hirwaun has two normally open line breakers that are supplied from the Upper Boat network. Where there is an arranged outage that leaves Hirwaun at single circuit risk, the current baseline operating methodology is to transfer Hirwaun into the Upper Boat network. Swansea North and Upper Boat GSPs are only paralleled for the time taken to move Hirwaun into Upper Boat.

In the baseline analysis there is sufficient capacity on the Upper Boat D-route, Y-route, YE-route and SGT capacity for this transfer to be made for all demand and generation cases assessed; this includes resilience to all next credible faults.

In 2022, this transfer significantly overloading the Upper Boat circuits between Hirwaun and Upper Boat GSP for all demand representative days under all scenarios. The transfer of Hirwaun causes overloads between 177% (Two Degrees) and 117% (Steady State), with the highest loading is seen on the D-route between Mountain Ash BSP and the tee onto YE-route. These loadings are increased to between 160% (Two Degrees) and 135% (Steady State) for the subsequent fault of either of the Upper Boat 275/33 kV SGTS, as this means Mountain Ash picks up more of the 33 kV demand, hence increasing the loading on D-route.

These overloads are primarily driven by the significant demand growth forecast at Hirwaun BSP under all scenarios. Hirwaun peak demand in baseline is 39 MW, this doubles to almost 80 MW under Two Degrees and Consumer Power and 56 MW in Steady State and Slow Progression. It is worth noting that in the higher growth scenarios, 14 MW of growth is battery storage, which for the purposes of these studies is assumed as importing at peak demand. Notable demand growth is also seen on Merthyr East; increasing the baseline peak demand of 25 MW to as much as 35 MW under Two Degrees.

An overload is also seen on the D-route between Mynydd Y Bwllfa Wind Farm and the tee for a summer maximum generation case, when Hirwaun is transferred into Upper Boat via Hirwaun 405. This is caused by the combination of the large levels of generation forecast to connect at Hirwaun. This means Hirwaun, Bwllfa wind farm and some of Dowlais generation is exporting via one side of the D-route. This overload only occurs under Two Degrees to as much as 106%.

The demand and generation growth at Hirwaun in 2022 means both GTs need uprating from 22.5/45 MVA units to 60/90 MVA units. More detail can be found in the Swansea North 2022 write-up.

The Hirwaun transfer is not required for compliance and is only done to improve supply security. If the Hirwaun group demand was to increase above 100 MW, there would be a SCO requirement to resupply demand at the BSP and consideration as to how this would be achieved would be needed.

Hirwaun cannot be transferred into Upper Boat under any scenario without causing overloads using the current transfer approach; where both Merthyr East and Dowlais are supplied by both GTs. If both Dowlais and Merthyr East were single legged onto the opposite circuit to Hirwaun, no overloads would occur for summer and the next fault would cause a lost load that could be safely picked up and would remain P2/6 compliant. Before Hirwaun was transferred into the Upper Boat group, the benefits would need assessing against leaving a number of BSPs at next fault risk.

As part of the rationalisation of the Upper Boat 33 kV and Mountain Ash network, a 120 breaker is installed at Mynydd Y Bwllfa WF and circuits are reprofiled to manage the increased demand at Mountain Ash. This is still insufficient to enable Hirwaun to be transferred onto Upper Boat without single legging Dowlais and Merthyr East. If the D-route, Y-route and Ye-route were reconductored to 300mm² AAAC (Upas) @ 75°C Hirwaun could be transferred into group without leaving BSPs at next fault risk.

Merthyr East BSP Capacity

SS SP CP TD

Merthyr East 132/11 kV is supplied by two 15/30 MVA transformers that are normally fed from Upper Boat GSP via the 132 kV DD-route double circuit. Under all scenarios in 2022 both GTs are overloaded for the FCO of the other GT to between 101% (Steady State) and 123% (Two Degrees). There are no SCO conditions that make this overload notable higher.

The Merthyr East GTs are the largest two winding or 132/11 kV transformers that WPD currently install as standard, meaning the transformers cannot be simply replaced with larger two winding units. There are currently limited 132 kV infeeds into the Merthyr East and Dowlais area. The group demand of Merthyr East and Dowlais BSPs grows to 70 MW in 2022 under Two Degrees and Consumer Power. The DD-route double circuit that supplies both BSPs is rated at 100 MVA for summer and 112.5 MVA for winter, so no overloads are seen for any credible outage. At the point where the group demand exceeds 100 MW consideration needs to be given to how P2/6 compliance is maintained.

Dowlais BSP is supplied via two 22.5/45 MVA transformers and has a peak demand of 34.23 MW in 2022 Two Degrees. Dowlais 33 kV currently supplies two large generators connected directly onto the Dowlais 33 kV busbar and 3 primary substations on a ring. Dowlais BSP is located within the Merthyr East ESA and has sufficient capacity to alleviate the identified overloads on the Merthyr East GTs. A significant portion of the forecast demand growth is located geographically close to the Dowlais BSP.

It is recommended that a new 33/11 kV primary substation is established at Dowlais to pick up the office, factory and warehouse developments that are located near to the existing Dowlais BSP. This is sufficient to reduce the loading on the Merthyr East GTs to within rating for all representative days under all scenarios.

Aberthaw and Cardiff East GSPs

By 2022, group demand is projected to grow from 433 MW in Baseline to:

Scenario	Group demand (initial)	Group demand (East Aberthaw projections moderated to 20%)
TD	697 MW	542 MW
CP	697 MW	538 MW
SP	586 MW	501 MW
SS	584 MW	498 MW

Rapid large-scale demand growth in East Aberthaw SS SP CP TD

Under all scenarios, Aberthaw and Cardiff East GSPs are dominated in 2022 by new industrial and commercial demand in the area surrounding Cardiff Airport. This area is currently supplied by East Aberthaw and Barry BSPs, which currently have a combined group demand of 59 MW. By 2022, this is projected to grow to:

Scenario	Group demand (initial)	Group demand (East Aberthaw projections moderated to 20%)
TD	339 MW	117 MW
CP	340 MW	118 MW
SP	225 MW	91 MW
SS	224 MW	91 MW

Most of this demand growth is in the area predominantly supplied by East Aberthaw BSP. As well as the magnitude of the demand peak increasing, it moves from a winter evening peak to a summer afternoon peak.

Reinforcement for demand growth on this scale might entail:

- **One or two additional 240 MVA SGTs at Aberthaw GSP**
- **Replacing 180 MVA SGT1 and SGT2 at Aberthaw GSP with 240 MVA units**
- **Reconductoring and/or reprofiling 132 kV circuits from Aberthaw GSP towards Cardiff**
- **Replacing both 60 MVA GTs at Barry BSP with 90 MVA units**
- **Replacing the single 45 MVA GT at East Aberthaw BSP with two 90 MVA units**
- **One or two new BSPs between East Aberthaw and Barry, each with two 60 MVA or 90 MVA GTs**
- **Extensive 33 kV works to support the new 132 kV configuration and supply the new demand**

Modelling these reinforcements would mask the impact of other demand growth in the Cardiff area. Since demand growth on this scale in three years is relatively unlikely, the demand growth projections for East Aberthaw ESA have been scaled down to 20% of their original value for further studies under all scenarios.

It is recommended that projected large-scale load growth is assessed through a challenge and review process to ensure that the scenarios encompass a broad range of credible futures.

BSP reinforcement despite projection scaling SS SP CP TD

Despite scaling demand growth projections for East Aberthaw ESA to 20% of their original value, group demand still almost doubles under the higher scenarios.

Following this demand growth, the following overloads occur for all peak demand cases:

- East Aberthaw GT2:
  - For the FCO of either GT at Barry, up to 146% of seasonal cyclic rating
  - For the SCO of both GTs at Barry, up to 232% of seasonal cyclic rating
- Barry GT1:
  - For the SCO of East Aberthaw GT2 and Barry GT2, up to 183% of seasonal cyclic rating

- Barry GT2:
  - For the SCO of East Aberthaw GT2 and Barry GT1, up to 184% of seasonal cyclic rating

For this project it has been assumed that these overloads would be resolved by:

- **Replacing East Aberthaw GT2 with a 40/60 MVA (Slow Progression and Steady State) or 60/90 MVA (Consumer Power and Two Degrees) unit;**
- **Installing a second GT at East Aberthaw with the same rating as the replacement GT2, teed into the Aberthaw/Barry 132 kV circuit; and**
- **Splitting the 33 kV network between East Aberthaw BSP and Barry BSP.**

Load-share and transmission through-flow

SS SP CP TD

Exacerbation of issues from Baseline

Under all scenarios, demand and generation growth to 2022 exacerbates the through-flow and load-share issues identified in Baseline. For example:

- At peak generation the peak generation SCO overload of Cardiff East SGT3 reaches 149% of 240 MVA rating
- Demand-driven overloads of Aberthaw SGT1 and SGT2 reach as much as 135% of 180 MVA rating
- Demand-driven overloads the 132 kV BB-route circuit from Aberthaw 305 to Sully tee increase to as much as 111% of seasonal rating, and occur for SGT SCOs as well as 275 kV busbar faults

For this project it has been assumed that Aberthaw SGT1 and SGT2 would be replaced by 240 MVA units by 2022.

New issues

In all scenarios (but with greater severity and scope in Consumer Power and Two Degrees than Steady State and Slow Progression) there are new demand-driven SCO overloads of 132 kV circuits in Cardiff:

- Aberthaw 205 to Cardiff West 103: up to 104% of seasonal rating
- Cardiff Central to Cardiff East: up to 110% of seasonal rating
- Cardiff East to Cardiff North: up to 102% of seasonal rating
- Aberthaw to Barry: up to 111% of seasonal rating
- Sully 205 to Sully Tee: up to 113% of seasonal rating

Additionally, in Two Degrees for a peak generation case the 132 kV cable from Rover Way to Cardiff East is overloaded to 101% of summer rating for the SCO of:

- The 132 kV cable between Cardiff Central and Cardiff East; and
- The Aberthaw/Tremorfa/Uskmouth/Whitson 275 kV circuit.

Modelling recommendations and potential reinforcements

As above, it is recommended that the effect of transmission network loading and outages on this interconnected network are assessed in further detail with National Grid.

If through-flow and/or load-share driven overloads are confirmed, the impact of demand and generation growth both in Cardiff and beyond should be considered when comparing mitigation and reinforcement options.

Even if the studied through-flow and load-share issues are resolved, the projected demand growth would be likely to trigger SGT and 132 kV circuit reinforcement.

Cardiff West BSP and Cardiff Central BSP

132/33 kV GT capacity

SS SP CP TD

Cardiff West BSP and Cardiff West BSP operate in parallel at 33 kV. This network is supplied by:

- Cardiff West GT1, 132/33 kV 45/90 MVA
- Cardiff West GT2, 132/33 kV 45/90 MVA
- Cardiff Central GT2A, 132/33 kV 45/90 MVA

Cardiff Central also has two 132/11 kV GTs supplying an 11 kV customer.

By 2022, group demand of the 33 kV network is projected to grow from 115 MW in Baseline to:

Scenario	Group demand
TD	145 MW
CP	144 MW
SP	134 MW
SS	133 MW

Following this demand growth, the SCO of any two of the three GTs would overload the remaining GT up to 127% of seasonal cyclic rating for all peak demand cases.

For this project it has been assumed that these overloads would be resolved by:

- **Installing a second 90 MVA 132/33 kV GT at Cardiff Central BSP, double banked with 132/11 kV GT1A; and**
- **Splitting the 33 kV network between Cardiff West BSP and Cardiff Central BSP.**

Cardiff East BSP and Cardiff North BSP

132/33 kV GT capacity

SS SP CP TD

In Baseline, the SCO of both 132/33 kV GTs at Cardiff East would overload Cardiff North GT2 for a winter peak demand case.

By 2022, group demand of the 33 kV network is projected to grow from 122 MW in Baseline to:

Scenario	Group demand
TD	129 MW
CP	128 MW
SP	126 MW
SS	126 MW

Following this demand growth, the SCO of any two of the three GTs would overload the remaining GT up to 110% of winter cyclic rating for a winter peak demand case in all scenarios. No overload occurs for a summer or intermediate warm peak demand case.

It is recommended that the adequacy of the available access window for the GTs is assessed. If it is not long enough, alternative 33 kV running arrangements, load management schemes, flexibility services and reinforcement should be considered as means to extend it.

Aberthaw SGT3 overloads for Upper Boat transfer

Following demand growth to 2022, the transfer of Aberthaw SGT3 into Upper Boat 132 kV network followed by the fault loss of the remaining Upper Boat SGT might overload Aberthaw SGT3. This is described in more detail in the Upper Boat 2022 results.

Uskmouth GSP

SGT Capacity

SS SP CP TD

Uskmouth has three 275/132 kV SGTs supplying a three section 132 kV double busbar. SGT1 normally supplies Main 1, which is run split from Main 2 and 4 due to fault level constraints. Main 2 and 4 are normally supplied by SGT2A. SGT4A is a hot-standby SGT with two 132 kV circuit breakers so that it can be quickly and automatically connected to section 1 or section 2 in the event of a fault disconnecting one of the other SGTs.

Any SCO condition that takes two of the three Uskmouth SGTs out of service overloads the remaining SGT between 110% (Steady State) and 119% (Two Degrees) for summer max generation.

It is recommended the short-term reverse power flow ratings of all Uskmouth SGTs are confirmed with National Grid. If the short-term ratings of the SGTs are insufficient to cover the SCO loading, transferring generation out of group into Rassau for the arranged outage should be considered.

Uskmouth GSP Busbar Fault

TD

Uskmouth 132 kV Main 2 and Main 4 are currently run normally interconnected via isolator 224. The fault of Busbar Main 2/4 takes the reactor between Main 4 and Main 1 out of service. This leaves SGT1 supplying section 1 and SGT2 supplying Reserve 2 and 4. Reserve 1 and Reserve 2 are connected via a normally open 169 isolator. This busbar fault leaves all of Magor, Sudbrook and Panteg 132/11 kV BSPs supplied from SGT1. Without the support of the reactor this overloads SGT1 to as much as 106% for a winter peak demand representative day. This overload will only persist for the time taken to reselect the reactor and the P-route 1405 circuit onto reserve 4.

It is recommended the short-term rating of SGT1 is confirmed with National Grid and any operational mitigation for this busbar fault is confirmed.

Llantarnam BSP

SS SP CP TD

These studies have highlighted a poor load share on the Llantarnam 132/11 kV transformers and the 132/66 kV transformers under intact running for all representative days studied. The transformers fed directly from Uskmouth GSP via Q-route are picking up two thirds of the load. This is causing loading to as much as 122% of the ONAN rating on GT2B (132/11 kV) for all demand representative days. No loadings in excess of their seasonal OFAF rating are seen under any scenario.

This poor load share may result in accelerated aging of GT2B and GT2A.

Magor BSP

CP TD

Magor BSP is supplied by two 15/30 MVA transformers that are normally supplied via the double circuit P-route out of Uskmouth GSP. One transformer is teed off either side of the P-route via the P41-route.

The scenarios show a significant demand growth under Two Degrees and Consumer Power at Magor BSP. Most of the demand growth is forecast to be non-domestic, office, factory and warehouse developments. The majority of the demand growth is at Llanwern Village, Celtic Business Park and Gwent Euro Park, which are all located east of Magor. A large portion of these developments are on part of the Llanwern steelworks, which is currently supplied via four SGTs fed from Magor GSP. Steel making stopped at the site in 2001 and only processing from steel made at Port Talbot is undertaken on site. There is currently a £115m regeneration project ongoing which is transforming the former steel-producing part of the steel works into accommodation and commercial premises.

If all of this was to connect into Magor BSP, peak demand increases from 12 MW in baseline to as much as 40 MW under Two Degrees and Consumer Power.

This demand growth causes loadings to as much as 124% of the ONAN rating for intact running for summer and winter peak demand studies. A first circuit fault or arranged outage that leaves Magor supplied via a single transformer overloads the remaining transformer to as much 131%.

For these studies, it has been assumed that a new 132/11 kV BSP will be established near to Llanwern, supplied by twin tees from the 132 kV J-route. The Llanwern Village and Celtic Business Park developments would be supplied from this new BSP. This demand transfer is sufficient to resolve all overloads at Magor BSP and was shown to not cause any additional issues from the connection of the new BSP.

Newport West BSP

CP TD

Under normal running Newport West is supplied from Uskmouth GSP via the R-route double circuit. There are four 132/11 kV 15/30 MVA transformers supplying two 11 kV busbars which are run independently. GT1 and GT2 supply an 11 kV busbar that supplies a variety of domestic and commercial demand. The existing GT3 and GT4 are supplying a single industrial customer, both transformers are currently not heavily utilised and our studies indicated that they do not exceed 24% of their ONAN rating under intact running and 42% under outage conditions. These transformers were primarily installed to resolve power quality issues that the customer were seeing for fault on WPD's network.

The peak demand in in the baseline studies on the GT1 and GT2 bar is 36 MW, this increases to 48 MW under Two Degrees and Consumer Power. The demand growth forecast in the Newport West (GT1 and GT2) 132/11 kV ESA is predominately office, factory and warehouse developments.

This demand increase is sufficient to cause an overload between 112% and 122% for all peak demand representative days.

It is recommended that 12.5 MW is transferred onto the newly established 33/11 kV primary supplied from Newport South to alleviate the overloads seen on Newport West GT1 and GT2.

Newport South BSP

SS SP CP TD

Newport South 132/11 kV is supplied by two 15/30 MVA transformers that are normally fed from Uskmouth GSP via one side of the R-route double circuit and one side of the M-route double circuit. The demand growth forecast in the Newport South 132/11 kV ESA is predominately office, factory and warehouse developments.

Any first circuit arranged or fault outage that leaves the demand at Newport South supplied via a single transformer overloads the remaining transformer up to as much as 165% under Two Degrees and Consumer Power for a summer peak demand case. This overload is reduced to 111% under Steady State and Slow Progression. Loadings up to 165% of ONAN rating are seen on both transformers for intact network running.

Newport South 132/33 kV is supplied by one 30/60 MVA and one 40/60 MVA transformer; both have a winter cyclic rating of 78 MVA. There is sufficient capacity on the 132/33 kV GTs to pick up all of the demand growth forecast within the Newport South 132/11 kV ESA, but insufficient demand to pick up the Newport West demand transfers with the existing GTs.

A 15/30 MVA transformer is the largest two winding transformer WPD currently install as standard for a 132/11 kV transformation, which means the transformers cannot just be replaced with larger units.

It is recommended that a 33/11 kV primary is established in the Newport South 33 kV network to pick up sufficient demand to alleviate the overloads seen on the Newport South and Newport West 132/11 kV GTs. For the purposes of these studies, 20 MW of demand (at time of peak demand) is moved from the Newport South 132/11 kV and 12.5 MW is moved from Newport West 11 kV GT1 and GT2 demand onto the new primary (as described above).

This transfer requires the 30/60 MVA and 40/60 MVA 132/33 kV Newport South transformers to be replaced with larger 60/90 MVA units under Consumer Power and Two Degrees. These transfers increase the group demand of Newport South to 110 MW under Two Degrees and Consumer Power. Newport South is currently supplied by two infeeds as described above, so for any SCO condition where both circuits are out of service, P2/6 requires that 10 MW of demand is restored with 3 hours. Whilst it may be possible to achieve compliance through 33 kV backfeeds, it is recommended that under Two Degrees and Consumer Power a third 132 kV infeed into the group is established. This can be achieved by moving GT4 (132/11 kV) from Main 2 onto a new tee-off from the western/southern R-route circuit. In the model the tee-off was modelled as 50 metres of 300mm² copper XLPE cable.

A graphical representation of this is shown in Figure 45.

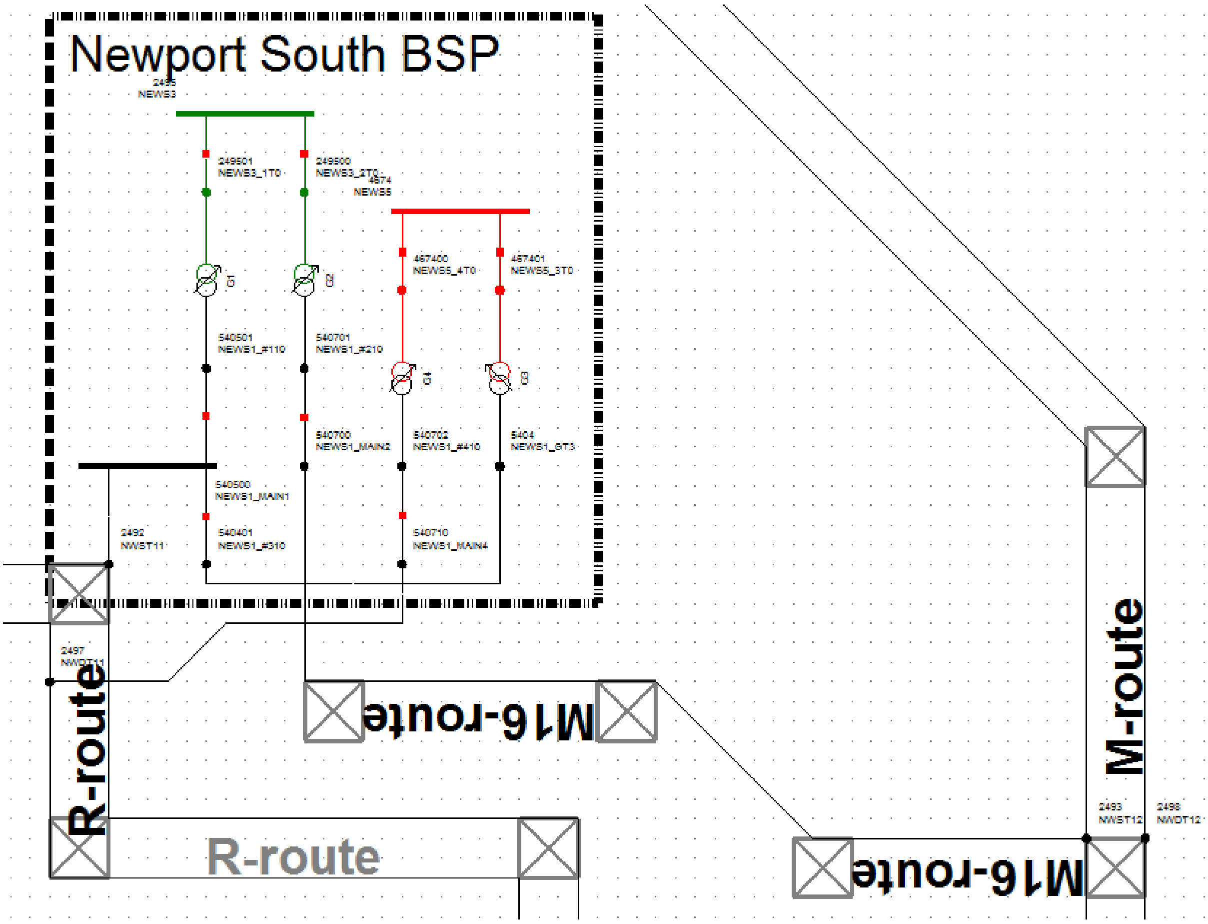

Figure 45: Proposed 132 kV layout and infeeds for Newport South BSP

Panteg 131/11 kV BSP

SS SP CP TD

Panteg 132/11 kV is supplied by two 15/30 MVA transformers that are normally fed from Uskmouth GSP via the J-route 132 kV double circuit. The peak demand in in the baseline studies is 28 MW, this increases to 44 MW under Two Degrees and Consumer Power. The demand growth forecast in the Panteg 132/11 kV ESA is predominately driven by office, factory and warehouse developments.

Both GTs are at 136% of their ONAN rating for intact running. A first circuit outage of one of the transformers leaves the remaining GT overloaded to as much as 146% for summer peak demand under Consumer Power and Two Degrees and 107% for summer peak demand for the lower growth Steady State and Slow Progression.

Cwmbran BSP is located geographically close to Panteg and is supplied by two 15/30 MVA GTs. The group demand in baseline is 18 MW and is only forecast to grow to as much as 20 MW by 2022 under Two Degrees.

A 15/30 MVA transformer is the largest two winding transformer WPD currently install as standard for a 132/11 kV transformation, which means the Panteg 132/11 kV transformers cannot just be replaced with larger units.

It is recommended that sufficient demand is transferred and connected into Cwmbran BSP to alleviate the overloads identified on Panteg BSP. Under the higher growth scenarios approximately 15 MW is transferred onto Cwmbran.

Rassau GSP

The Rassau group demand increases from 220 MW in baseline to between 272 MW (Steady State) and 316 MW (Two Degrees). The significant increase in group demand is predominately driven by office, factory warehouse developments at a number of BSPs and Primaries supplied by Rassau GSP. The group demand goes from a P2/6 Class D group (60-300 MW) to a class E group (300-1500 MW) under Two Degrees and Consumer Power. This requires that:

3. For a circuit fault from an intact network (FCO fault):
    a. Immediately: group demand
4. For a circuit fault during an arranged outage (SCO):
    a. Immediately: All consumers at 2/3 group demand
    b. Within time to restore arranged outage: group demand

In baseline where the Rassau group is P2/6 group D, the SCO requirement for a SCO is:

a. Group demand minus 100 MW, i.e. 25 MW, is met within three hours; and
b. Group demand is met within the time taken to restore the arranged outage.

The Rassau GSP group is currently supplied by two 240 MVA SGTs connected onto a single 132 kV busbar with a bus section run normally closed. The 400 kV is looped into one side of the National Grid circuit between Walham and Cilfynydd GSPs. In baseline, the group is P2/6 compliant as there is sufficient transfer capability with Uskmouth and Upper Boat to pick up the demand within the three hours required by P2/6. In the scenarios where the 2022 group demand exceeds 300 MW it will no longer be P2/6 compliant as the SCO requires immediate resupply (within 60 seconds) for 2/3rd group demand.

The demand growth at Rassau overloads both SGTs to as much as 154% (Two Degrees) for an arranged or fault FCO of the other SGT. Adding an additional 240 MVA SGT at Rassau GSP will give sufficient SGT capacity to supply the group but consideration of how this SGT is connected would be required to ensure the group was P2/6 compliant. The 400 kV at Rassau is currently only looped into one side of the 400 kV double circuit. Adding a third SGT without providing an additional 400 kV infeed will still leave Rassau at SCO risk for the loss of both 400 kV infeeds into the group. The Rassau SGTs are also overload up to 108% for the peak generation case for a SCO condition where the Rassau 120 breaker is out for an arranged outage followed by the fault of Rassau SGT2.

In all scenarios (but with greater severity and scope in Consumer Power and Two Degrees than Steady State and Slow Progression) there are a substantial number of thermal and voltage issues on the Rassau 132 kV and 66 kV networks:

- Both Crumlin 132/11 kV transformers are overloaded for a FCO during all peak demand representative days
- Ebbw Vale BSP overloads to as much as 147% for the summer maximum generation study
- Both Abergavenny GT overload for a FCO due to the demand growth on the northern and southern 66 kV rings
- The northern 66 kV network sees voltages as low as 0.73 p.u. (Two Degrees) for winter peak demand for the fault of either Abergavenny busbar and the fault of either 66 kV circuits from Abergavenny to Brecon/Crickhowell causes similarly low voltages
- The voltage on the Southern ring drops below 0.94 p.u. around Usk for the intermediate warm peak demand
- Both GTs at Builth Wells are overloaded for a fault of the other GT
- Both GTs at Rassau West are overloaded for a fault of the other GT

- Abersychan is overload for all demand representative days under the higher growth scenarios; this is predominately driven by the low voltages seen on this part of the southern 66 kV ring
- Usk BSP is overloaded to as much as 115% for a first circuit fault
- The group demand of Llandrindod Wells and Rhayader increase to as much as 20 MW, so the baseline proposals of uprating the transformers are required under scenarios
- The majority of the 66 kV circuits out of Abergavenny are overloaded for either a first circuit fault an SCO condition where there is no available access window. The overloaded circuits include:
    - Abergavenny to Blaenavon
    - Blaenavon to Abersychan
    - Abersychan to Panteg
    - All circuits between Abergavenny, Crickhowell and Builth Wells
    - Abergavenny to Monmouth
    - Monmouth to Usk
    - Ebbw Vale to Pengam Tee

Demand growth on this scale in three years is relatively unlikely. If this level of demand growth within Rassau GSP was to materialise, major reinforcements beyond the scope and resource of this work would be required to manage this level of growth. It is recommended that projected large-scale load growth is assessed through a challenge and review process to ensure that the scenarios encompass a broad range of credible futures.

Reinforcement for demand growth on this scale might entail:

- **Transferring Ebbw Vale and Crumlin onto Upper Boat and carrying out the necessary SGT and 132 kV circuit reinforcements on the Upper Boat network.**
- **Commissioning a second 132/66 kV GT at Panteg to could enable the 66 kV southern ring to be supplied solely from Panteg. This would require 66 kV switchgear works at Abergavenny to avoid splitting the 66 kV southern ring. Panteg 132/66 kV could then be transferred into Uskmouth to reduce the demand at Rassau.**
- **Additional SGTs at Rassau GSP. This would require 400 kV works to bring the other 400 kV circuit into the GSP to maintain P2/6 compliance. It would also require additional sections on the 132 kV busbar, or conversion to a double busbar.**
- **Further reactive compensation on the northern 66 kV ring.**
- **Uprating transformers where possible to supply the increased group demand. Where the transformers are already the largest available or other constraints prevent transformer replacements consideration should be given to establishing additional BSPs and Primaries as deemed appropriate by a detailed assessment.**

9 – 2027 Results

Pembroke GSP

Network changes modelled

For the 2027 studies the proposed reinforcement strategy was used a basis for the credible future running arrangement. The sections of the RR-route between Milford Haven and the Pembroke tees are modelled as reconductored with 300mm² UPAS profiled for 75 degree operation.

Pembroke SGT Overloads

SS SP CP TD

The overloads seen in the 2022 studies are exacerbated by further demand growth in the Pembroke area out to 2027. The SCO combination which results in the loss of two out of the three SGTs at Pembroke would overload the remaining SGT in service up to as much as 128% for summer and 142% for an intermediate warm peak demand case under all scenarios. The SCO combination would also overload the remaining SGT in service for a summer peak generation case up to 118% under a Two Degrees scenario.

It is recommended that detailed study is undertaken to ascertain the true group demand for each of the peak demand representative days. It is acknowledged that these studies model industrial customers at full import continuously and do not take into account additional on-site generation installed, which can increase the pre-fault SGT loadings.

Whilst this overload could be resolved by commissioning a 4th SGT at Pembroke, it may be more appropriate to manage SGT loading through of use of flexible connections.

Pembrokeshire 33 kV parallel group

Golden Hill BSP

TD

Following generation growth to 2027, under intact network conditions for a summer peak demand case, the grid transformers operate well into the forced cooling rating under a Two Degrees scenario. For an arranged outage of a grid transformer at Golden Hill, the 33 kV parallel group is split and Golden Hill is run independently from Milford Haven and Haverfordwest. This arranged outage would overload the remaining GT in service at Golden Hill up to 138% under a Two Degrees scenario.

Milford Haven BSP

TD

Following generation growth to 2027, under intact network conditions for a summer peak demand case, the grid transformer operates well into the forced cooling rating under a Two Degrees scenario. For the SCO combination which results in the loss of a grid transformer at both Golden Hill and Haverfordwest with the 33 kV group still running in parallel, for a summer peak generation case the net export of the group is fed via GT1 at Milford Haven and a grid transformer at both Haverfordwest and Golden Hill. This SCO combination would overload GT1 at Milford Haven up to 119% (of the 60 MVA rating as per 2022 reinforcements) under a Two Degrees scenario.

Haverfordwest BSP

CP TD

For an arranged outage of a grid transformer at Haverfordwest, the 33 kV parallel group is split and Haverfordwest is run independently from Milford Haven and Golden Hill. For this arranged outage on a summer peak demand case, the remaining GT in service at Haverfordwest would overload up to

118% under a Two Degrees scenario. The overload would also occur for this arranged outage up to 102% for summer and108% for an intermediate warm peak demand case under the Two Degrees and Consumer Power scenarios. This overload is exacerbated when the arranged outage is followed by a fault of GT1 at Milford Haven, as this results in the remaining GT at Haverfordwest supplying all of the Haverfordwest and Milford Haven demand. This SCO combination would overload the remaining GT at Haverfordwest up to as much as 107% for summer and 113% for an intermediate warm peak demand case under the Two Degrees and Consumer Power scenarios.

Under the high growth scenarios, it is recommended that a second grid transformer at Milford Haven is commissioned and detailed studies (also 33 kV reinforcement as necessary) are carried out to be able to run Haverfordwest, Milford Haven and Golden Hill independently.

132 kV Circuit Overloads

AW-route overloads

CP TD

An arranged outage of the proposed circuit from Pembroke to Milford Haven, followed by a fault of the cable circuit between Pembroke and Golden Hill would leave the group supplied via the CW/EE-route and the AW/RR-route circuits. This SCO combination would overload the AW-route up to 112% for an intermediate warm peak demand case under the Two Degrees and Consumer Power scenarios, and up to 131% for a summer peak generation case under a Two Degrees scenario.

RR-route overloads

TD

The SCO combination which results in the loss of the AW-route and the cable circuit between Pembroke and Golden Hill would also overload the RR-route section of the new circuit from Pembroke to Milford Haven up to 106% for a summer peak generation case under a Two Degrees scenario.

Cable Circuit from Pembroke to Golden Hill overloads

CP TD

For an arranged outage of GT1 at Golden Hill, the 33 kV parallel group is split and Golden Hill is run independently from Haverfordwest and Milford Haven. Following generation growth to 2027, this arranged outage would overload the cable circuit between Pembroke and Golden Hill up to 107% for a summer peak generation case under a Two Degrees scenario.

For the SCO combination which results in the loss of both the AW/RR-route and the proposed Pembroke-Milford Haven cable, the group is fed via the two remaining circuits in service via Golden Hill. Under this scenario, the load share between the CW-route and the cable circuit between Pembroke and Golden Hill is unequal. For this SCO combination, the cable circuit between Pembroke and Golden Hill would overload up to as much as 118% for summer and 125% for an intermediate warm peak demand cases and up to as much as 148% for a summer peak generation case under the Two Degrees and Consumer Power scenarios.

This SCO combination would also overload the EE-route between Golden Hill GT2 and Milford Haven up to 106% for a summer peak generation case under a Two Degrees scenario.

Under the high growth scenarios, it is recommended that poor load share between the CW-route and cable circuit is addressed. Generation growth in the area could be managed through flexible connections to allow an access window to take arranged outages.

Pyle GSP

Network changes modelled

For the 2027 studies SGT1 at Pyle was replaced with a 240 MVA unit to match the existing SGT2. In addition, both grid transformers at Bridgend BSP were replaced with 60/90 MVA units. The short length of 132 kV cable from Pyle GSP towards Bridgend GT2 circuit was overlaid with a 630mm² XLPE cable to match the rating of the overhead sections of the circuit.

Pyle SGT Overloads

CP TD

Following demand growth to 2027, the group demand of Pyle GSP exceeds 240 MW under the Consumer Power and Two Degrees scenarios. For an SGT fault on a winter peak demand case, the remaining SGT in service would overload up to 102% under the Consumer Power and Two Degrees scenarios.

Whilst this overload could be resolved by commissioning a 3rd SGT at Pyle, it may be more appropriate to manage SGT loading through of use of flexible connections.

For fault level restrictions, Aberthaw GSP is run split into 2 nodes at 275 kV with remote bussing at Pyle GSP at 275 kV, Cilfynydd GSP at 400 kV and Uskmouth at 275 kV, with various loose couples at lower voltages which could be exposed in the absence of one of more of these remote couples. As an example, the SCO combination which splits the 275 kV bussing at Pyle and via Uskmouth would result in the 275 kV network being loose coupled through the132 kV bar at Pyle GSP. This SCO combination would overload an SGT at Pyle GSP up to as much as 104% for a summer peak generation case under the Consumer Power and Two Degrees scenarios.

It is recommended that detailed studies are carried out with National Grid to determine a suitable running arrangement for the arranged outage.

Bridgend BSP

CP TD

Following further demand growth to 2027 in the Bridgend area, the fault of Pyle SGT2 (which also results in the loss of the U-route circuit to Bridgend GT1) would overload the grid transformer GT2 at Bridgend up to as much as 106% in summer and 104% for an intermediate warm peak demand case under a Consumer Power scenario.

It is recommended that as demand growth in Bridgend continues, a permanent demand transfer onto Waterton Industrial can be made to mitigate overloads at Bridgend BSP.

Margam GSP

By 2027, group demand is projected to grow from 146 MW in Baseline to:

Scenario	Group demand
TD	156 MW
CP	155 MW
SP	152 MW
SS	152 MW

Llynfi Valley

Loading on Grange/Llynfi 66 kV circuits

TD

By 2027, installed generation capacity in the Llynfi valley (not including connections to Pyle BSP) is projected to grow from 123 MW in Baseline to 162 MW under Two Degrees. In particular, 23 MW of onshore wind is projected to connect to Caerau Road primary.

Under peak generation conditions, the arranged or fault outage of either 66 kV circuit from Grange to Llynfi would overload the remaining circuit:

- Grange/Llynfi 66 kV number 1 circuit (Grange 1L5 to Llynfi Main 1) up to 111% of summer rating
- Grange/Llynfi 66 kV number 2 circuit (Grange 4L5 to Llynfi 4L3) up to 128% of summer rating

Reprofiling the existing 0.2 sq.in. HDC conductors of the Grange/Llynfi 66 kV number 1 circuit for operation at 65°C would resolve the studied overload.

Further reprofiling from the 65° proposed in Baseline would not be sufficient to resolve the studied overload of the Grange/Llynfi 66 kV number 2 circuit. Instead, the overload could be resolved by:

- **Reconductoring 14km of overhead line with a minimum of 250mm² AAAC (Sycamore) operating at 65°C; and**
- **Overlaying 500m of cable with 630mm² copper EPR cable.**

Upper Boat GSP

Dowlais GT Capacity

CP

The combination of continued demand growth, the connection of a 3 MW battery storage site and demand transfers into Dowlais from Merthyr East in 2022 overloads both GTs for a first circuit fault to as much as 102% under Consumer Power only.

There are a number of approaches that could be utilised to alleviate this overload:

1. **Merthyr East GT loadings are at 80% for any credible outage condition, so a small portion of the Dowlais demand can be transferred back to Merthyr East without overloading the Merthyr East GTs.**
2. **These studies assumed the Battery will be importing at the time of peak demand, however Flexibility could be used to resolve this marginal overload at times of peak demand.**
3. **If neither of the above are viable, then replacing both Dowlais GTs with larger (40/60 MVA) units will resolve all overloads.**

Mountain Ash GT Capacity

TD

Demand growth at Mountain Ash increases the loading under Two Degrees to the point where a first circuit fault of one GT overloads the remaining GT to as much as 103% for the intermediate warm peak demand case.

It is not possible to transfer additional demand onto the Upper Boat 275/33 kV SGTs as they are also overloaded under a Two Degrees scenario (see below).

It is recommended that the 30/60 MVA and 40/60 MVA transformer are replaced with 60/90 MVA units.

Upper Boat 33 kV SGT Capacity

CP TD

Demand growth at Upper Boat 33 kV means both SGTs are overloaded for the loss of the other SGT under Consumer Power and Two Degrees. A first circuit fault causes overloads to as much as 112% (Two Degrees) and 104% (Consumer Power).

The current SGTs are currently rated at 100 MVA, which is the largest size available for a 275/33 kV transformer.

It is recommended that under Two Degrees, where the Mountain Ash GTs require uprating, demand is transferred from the Upper Boat to Mountain Ash at 33 kV to utilise this additional capacity. Under Consumer Power, where the Mountain Ash GTs do not require uprating, there is sufficient capacity on the Mountain Ash network with the 30/60 MVA and 40/60 MVA GTs, so demand can still be transferred at 33 kV to resolve the overloads.

Upper Boat to Mountain Ash circuits

CP TD

In 2022 under all scenarios, parts of the YE, Y and D routes required reprofiling to operate at 75°C due to the additional demand at Mountain Ash and the demand growth seen at Merthyr East.

By 2027, under Two Degrees and Consumer Power the reprofile is insufficient to resolve all overloads. A first circuit fault of either circuit overloads the remaining circuit to as much as 114% under Two Degrees and Consumer Power.

It is recommended that the YE, Y and D route circuits are reconductored tees with 300mm² AAAC (Upas) @ 75°C. This additional circuit capacity will resolve all overloads and would give sufficient capacity that Hirwaun can be more easily transferred into the Upper Boat network for arranged outages at Swansea North without having to single leg Dowlais and Merthyr East.

It would also help resolve the Upper Boat busbar split identified in baseline by providing a remote couple at Mynydd Y Bwllfa with circuits that are suitably rated so they can pick up the demand at Talbot Green, Pontyclun and Pencoed.

Aberthaw and Cardiff East GSPs

By 2027, group demand is projected to grow from 433 MW in Baseline to:

Scenario	Group demand (East Aberthaw projections moderated to 20%)
TD	612 MW
CP	592 MW
SP	547 MW
SS	527 MW

Load-share and transmission through-flow

SS SP CP TD

As in 2022, existing issues are exacerbated, and new issues arise. In particular, generation-driven issues become particularly severe in Two Degrees, with 132 kV cable overloads of up to 121% of summer rating and Cardiff East SGT overloads of up to 188% of rating.

Even if the studied through-flow and load-share issues are resolved, the projected demand and generation growth would be likely to trigger major SGT and 132 kV circuit reinforcement.

Cardiff East BSP and Cardiff North BSP 132/33 kV GT capacity

By 2027, group demand of the 33 kV network is projected to grow from 122 MW in Baseline to:

Scenario	Group demand
TD	143 MW
CP	138 MW
SP	134 MW
SS	131 MW

Access window restricted

SS SP TD

Following this demand growth, the SCO of any two of the three GTs would overload the remaining GT up to 118% of seasonal cyclic rating for a winter or intermediate warm peak demand case in Steady State, Slow Progression and Two Degrees. No overload occurs for a summer peak demand case.

It is recommended that the adequacy of the remaining access window for the GTs is assessed. If it is not long enough, alternative 33 kV running arrangements, load management schemes, flexibility services and reinforcement should be considered as means to extend it.

Access window eliminated

CP

Due to higher summer peak demands, the SCO of any two of the three GTs would overload the remaining GT up to 119% of seasonal cyclic rating for all peak demand cases in Consumer Power.

The studied overloads could be resolved by:

- **Installing a second 90 MVA 132/33 kV GT at Cardiff North BSP; and**
- **Splitting the 33 kV network between Cardiff East BSP and Cardiff North BSP.**

10 – Next Steps

Baseline Constraints

It is recommended that the operability constraints identified in the baseline studies are assessed in further detail, and mitigated where necessary. Constraints involving transmission outages or SGT capacity should be assessed in conjunction with National Grid and constraints involving equipment owned by adjacent network operators should be subject to further joint studies.

Comparing Investment Options for 2022

This study has identified some areas of the network which would require reinforcement under the forecasted demand, generation and storage scenarios. It is recommended that for each of the reinforcement requirements identified in the 2022 studies, a preferred solution is developed and triggered as necessary. Each preferred investment option could comprise of conventional network build, novel technologies, flexibility services, or a combination of those solutions. Each strategic investment should be chosen through technical and cost-benefit assessment, to ensure the efficient, co-ordinated and economic development of the network. The timing of planned asset replacement should be taken into account when choosing and coordinating options. The affected networks and potential reinforcements are:

- Mountain Ash GT and upstream 132 kV circuits
- Establishing a 132 kV bussing point at Mynydd Y Bwllfa
- Establishing a 33/11 kV primary substation in the Newport South 33 kV network
- Milford Haven GT and works to provide further 132 kV infeed into the Milford Haven, Golden Hill and Haverfordwest group
- SGT and 132 kV circuit reinforcement at Pyle GSP
- Third SGT at Pembroke GSP
- Second GT at Rhos BSP and works to provide further 132 kV infeed into Rhos BSP
- Establishing a new GSP to the west of Swansea North to provide further 400kV infeed into West Wales
- SGT and 132 kV circuit reinforcement in the Aberthaw/Cardiff East GSP group
- Additional GTs and 33 kV network splits for the Barry/East Aberthaw and Cardiff West/Cardiff Central BSP groups
- Widespread SGT, 132 kV circuit, GT, 66 kV circuit and primary transformer reinforcement in the Rassau GSP network

Where additional reinforcement requirements have been identified in the 2027 studies, then these should also be taken into account to minimise the risk of stranded assets.

Further modelling

WPD's 132 kV network north of Rhos BSP provides supplies to part of SP Manweb's network. As part of this project, we have studied the impact of the scenarios on this network with input from SP Manweb.

It is recommended that this area of network is assessed in greater detail in conjunction with SP Manweb.

WPD's interconnected 132 kV network between Aberthaw and Cardiff East GSPs is heavily interdependent with National Grid's transmission network in the area.

It is recommended that this area of network is assessed in greater detail in conjunction with National Grid.

National Grid have chosen the South Wales area to explore opportunities for reactive power services from non-traditional providers. While there may be opportunities for distribution-connected customers to provide reactive services, the impact of this on the distribution network needs to be studied and understood in more detail.

It is recommended that further studies are carried out in conjunction with National Grid to understand the impact on transmission and distribution systems of new reactive power services in South Wales.

11 – Definitions and References

References

External documents

P18

Engineering Recommendation P18 (*Complexity of 132 kV circuits*), sets out the normal limits of complexity of 132 kV circuits.

P2

Engineering Recommendation P2 (*Security of Supply*), is currently in its sixth revision (P2/6). P2/6 gives requirements for security of supply towards demand customers which form a condition of WPD's licence. The proposed seventh revision (P2/7) has been written and publically consulted upon, and is currently with Ofgem for approval.

P27

Engineering Recommendation P27 (*Current Rating Guide for High Voltage Overhead Lines Operating in the UK Distribution System*). Used in conjunction with ST:SD8A/2 to determine the ratings applicable to overhead lines.

Electricity Act 1989 as amended

Section 9 of the Electricity Act (*General duties of licence holders*) states that:

1. *It shall be the duty of an electricity distributor—*
    a. *to develop and maintain an efficient, co-ordinated and economical system of electricity distribution;*
    b. *to facilitate competition in the supply and generation of electricity.*
2. *It shall be the duty of the holder of a licence authorising him to transmit electricity—*
    a. *to develop and maintain an efficient, co-ordinated and economical system of electricity transmission; and*
    b. *to facilitate competition in the supply and generation of electricity.*

Future Energy Scenarios (FES) 2015, 2016, 2017

Annual report published by National Grid which sets out possible scenarios for the future development of energy generation and consumption in Great Britain.

National Electricity Transmission System Security and Quality of Supply Standard (SQSS)

Standard by which NGET must comply with in the planning and operation of the National Grid Electricity Transmission System

Distribution Future Energy Scenarios (DFES) – Technology growth scenarios to 2032, South Wales licence area 2018

Report written by Regen to forecast the future changes in demand and generation in the South Wales WPD licence area. Available from our website at: www.westernpower.co.uk/netstratswales

Insight Report Electric Vehicles
Report published by the Customer-Led Network Revolution project (reference CLNR-L092) in December 2014, describing research into the charging behaviour of Electric Vehicle users.

Air Conditioning Demand Assessment Report
Report published by the Tyndall Centre as part of the NIA Demand Scenario project (ENWL001) in May 2016, describing research into the behaviour of air conditioning units.

Managing the future network impact of electrification of heat Report
Report publish by Delta EE as part of the NIA Demand Scenario project (ENWL001) in May 2016, describing research into the behaviour of heat pumps.

Western Power Distribution documents
1. ST:SD8A/2 (*Relating to Revision of Overhead Line Ratings*), used in conjunction with ER P27 to determine the ratings applicable to overhead lines;
2. ST:SD8C/1 (*Relating to 132 kV, 66 kV and 33 kV Medium Power Transformer Ratings*), used to determine GT ratings.
3. 2015-2023 RIIO-ED1 Business Plan, used for identifying the WPD commitments for the RIIO-ED1 price control period towards network management and connection of renewable generation. Available at: www.westernpower.co.uk/About-us/Stakeholder-information/Our-Future-Business-Plan
4. South Wales Subtransmission network geographic map and single line diagrams; available from our website at: http://www.westernpower.co.uk/netstratswales

Table of Units

Term	Definition
kV	Kilovolt, a unit of Voltage (x10^3)
LV	This refers to voltages up to, but not exceeding 1 kV
HV	Voltages over 1 kV up to, but not exceeding 20 kV
EHV	Voltages over 20 kV (often refers to the common system design principles, applied at 22 kV, 33 kV and 66 kV)
kW	Kilowatt, a unit of Power (x10^3)
MW	Megawatt, a unit of Active Power (x10^6)
GW	Gigawatt, a unit of Active Power (x10^9)
MVA	Mega volt-ampere, a unit of Apparent Power (x10^6)
MVAr	Mega volt-ampere (reactive), a unit of Reactive Power (x10^6)
MWh	Megawatt hour, a unit of energy (x10^6). Equivalent to a constant 1 MW of Active Power delivered for an hour
MVArh	Mega volt-ampere (reactive) hour, the duration or persistence of reactive power flows. Equivalent to a constant 1 MVAr of Reactive Power delivered for an hour

Glossary

Acronym/ Initialism	Term	Definition
AAC	All Aluminium Conductor	Family of overhead line conductors, each of which is composed of strands of electrical-grade aluminium. AAC is often used on wood pole lines where the relatively short span length does not require the additional strength of AAAC.
AAAC	All Aluminium Alloy Conductor	Family of overhead line conductors, each of which is composed of strands of an aluminium alloy which combines mechanical strength with electrical conductivity. Reconductoring from ACSR to a slightly larger AAAC often allows a significant improvement in circuit capacity without requiring major modifications to towers. AAAC is now commonly used for new build and refurbishment of transmission and Subtransmission lines in Great Britain. Each AAAC conductor is named after a species of tree.
AC	Alternating Current	An electric current which periodically reverses its direction, having a magnitude that varies continuously. The rate at which the current's direction changes is known as the frequency. The frequency for UK power systems is 50Hz.
ACSR	Aluminium Conductor, Steel Reinforced	Family of overhead line conductors, each of which combines steel strands for mechanical strength with aluminium strands for electrical conductivity. ACSR is the conductor traditionally used for transmission and Subtransmission lines in Great Britain. Each ACSR conductor is named after a species of mammal.
AD	Anaerobic Digestion	Generation process that utilises energy from waste products such to produce biogas for gas generator sets.
ANM	Active Network Management	The ENA Active Network Management Good Practice Guide [22] summarises ANM as: *Using flexible network customers autonomously and in real-time to increase the utilisation of network assets without breaching operational limits, thereby reducing the need for reinforcement, speeding up connections and reducing costs.*
–	Access Window	The period of spring, summer and autumn in which arranged outages are normally taken
AVC	Automatic Voltage Control	Automatic adjustment of transformer tap position required for transformers on the Primary Distribution and Subtransmission networks to maintain system voltage within limits as the demand changes.
BEIS	Department for Business, Energy & Industrial Strategy	The governmental department responsible for energy and climate change policy. Formed as a merger between the Department for Business, Innovation & Skills (BIS) and the Department for Energy & Climate Change (DECC)
BSP	Bulk Supply Point	A substation comprising one or more Grid Transformers and associated switchgear
CDD	Cooling Degree Days	A measurement to determine how much demand is required to cool a building.
CHP	Combined Heat and Power	Method of utilising the excess heat energy as part of the electricity generation process to produce heat for local customers

Acronym/ Initialism	Term	Definition
–	Demand	The consumption of electrical energy.
DOC	Directional Over Current	Overcurrent protection which only responds to current flowing in a particular direction. Commonly fitted on the LV side of GTs and primary transformers to detect and operate for faults on the network supply the HV winding.
DSR	Demand Side Response	Ofgem led tariffs and schemes which incentivise customers to change their electricity usage habits
DG	Distributed Generation	Generation connected to a distribution network. Sometimes known as Embedded Generation.
DNO	Distribution Network Operator	A company licenced by Ofgem to distribute electricity in the United Kingdom who has a defined Distribution Services Area.
DSO	Distribution System Operator	A role which may be established in the future whereby the DNO undertakes some of the roles of the GBSO at a regional level to balance supply and demand.
ENA	Energy Networks Association	The Energy Networks Association is an industry association funded by gas or distribution or transmission licence holders.
ER	Engineering Recommendation	A document published by the Energy Networks Association.
ESA	Electricity Supply Area	Each ESA represents a block of demand and generation as visible from the Subtransmission network. Each is one of: - The geographical area supplied by a Bulk Supply Point (or group or part thereof) providing supplies at a voltage below 132 kV; - A customer directly supplied at 132 kV or by a dedicated BSP
EV	Electric Vehicle	A vehicle which uses electric motors as its method of propulsion
FACTS	Flexible Alternating Current Transmission System	A power electronic based system and other static equipment that provide control of one or more AC transmission system parameters to enhance controllability and increase power transfer capability.
FCO	First Circuit Outage	P2/6 defines a First Circuit Outage as: *…a fault or an arranged Circuit outage…* Also referred to as N-1 in some contexts.
FES	Future Energy Scenarios	A set of scenarios developed by Nation Grid to represent credible future paths for the energy development of the United Kingdom.
GB	Great Britain	A geographical, social and economic grouping of countries that contains England, Scotland and Wales.
GBSO	Great Britain System Operator	National Grid is the system operator for the National Electricity Transmission System (NETS) in Great Britain. Responsible for coordinating power station output, system security and managing system frequency.
GSP	Grid Supply Point	A substation comprising one or more Super Grid Transformers and associated switchgear
GT	Grid Transformer	A transformer that steps voltage down from 132 kV to 66 kV, 33 kV or 11 kV.
HP (also ASHP)	Heat Pump	Extracts heat from surroundings which can then be used to produce hot water or space heating. There are a number of types of heat pumps; the common air source heat pumps absorb heat from the outside air.

Acronym/ Initialism	Term	Definition
HVDC	High Voltage Direct Current	A form of electric power transmission or distribution which utilises direct current instead of the conventional alternating current. Converter station can be used to connect HVDC networks to conventional networks. Benefits include controllable power flow, limited fault infeed and the ability to connect between unsynchronised AC networks.
–	National Grid	The Transmission Network Operator in England and Wales.
NIA	National Innovation Allowance	Funding scheme for innovation projects introduced as part of RIIO-ED1. For the RIIO-ED1 period, WPD requested the minimum 0.5% of total regulated income.
Ofgem	Office for Gas and Electricity Markets	Ofgem is responsible for regulating the gas and electricity markets in the United Kingdom to ensure customers' needs are protected and promotes market competition.
–	Primary Distribution	The sections of an electrical distribution network which provide the interface between transmission and primary or Secondary Distribution. In WPD's network the 33 kV circuits and Primary Substations are considered to be Primary Distribution.
–	Primary Substation	A substation comprising one or more primary transformers and associated switchgear
–	Primary Transformer	A transformer that steps voltage down from 66 or 33 kV to 11 kV or 6.6 kV
PV	Photovoltaic	Type of distributed generation which uses solar irradiance to generate electricity.
RAS	Remedial Action Scheme	Add-on module supplied by Siemens for PSS/E power system analysis software that enabled simulation of Corrective Action, control room actions in reaction to specific network conditions
SCO	Second Circuit Outage	P2/6 defines a Second Circuit Outage as: *…a fault following an arranged Circuit outage...* Also referred to as N-1-1 or N-2 in some contexts.
SGT	Super Grid Transformer	A transformer that steps voltage down from 400 kV or 275 kV to 132 kV, 66 kV or 33 kV
SoW	Statement of Works	The process under which DNOs request that National Grid assesses the potential impact of the connection of DG upon the National Electricity Transmission System.
SQC	Sequential Control	Method of managing the network without the need for manual intervention from a Control Engineer.
TOUT	Time Of Use tariff	National Grid's FES 2016 defines a Time Of Use Tariff as: *A charging system that is established in order to incentivise residential consumers to alter their consumption behaviour, usually away from high power demand times.*
UK	United Kingdom	A geographical, social and economic grouping of countries that contains England, Scotland, Wales and Northern Ireland.
WPD	Western Power Distribution	A Distribution Network Operator (DNO) company that is licenced by Ofgem to distributed electricity in the East Midlands, West Midlands, South West, and South Wales regions of United Kingdom.
XLPE	Cross Linked Poly-Ethylene	Commonly used name for type of underground cable, which uses cross linked poly-ethylene insulation. They can be different sizes and are used extensively on the distribution network.

Acronym/ Initialism	Term	Definition
–	Subtransmission	The sections of an electrical distribution network which provide the interface between transmission and primary or Secondary Distribution. In WPD's South Wales network the GSPs, 132 kV circuits, BSPs, 66 kV circuits and 66/11 kV Primary Substations are considered to be Subtransmission.

Transformer Ratings

Transformer Cooling Methods

Term	Acronym	Definition
Oil Forced, Air Forced	OFAF	Transformer cooled by thermosiphon flow of its insulating oil assisted by oil pumps and external air flow forced by fans.
Oil Forced, Air Natural	OFAN	Transformer cooled by thermosiphon flow of its insulating oil assisted by oil pumps and natural convection of external air.
Oil Natural, Air Forced	ONAF	Transformer cooled by the natural thermosiphon flow of its insulating oil and external air flow forced by fans.
Oil Natural, Air Natural	ONAN	Transformer cooled by the natural thermosiphon flow of its insulating oil and natural convection of external air.

Rating Categories

Term	Acronym	Definition
Continuous Maximum Rating	CMR	The allowable sustained loading of a transformer for given cooling conditions that leads to a yearly average winding hot-spot temperature of 98°C (and so unity ageing) under the following ambient temperature conditions: -Maximum yearly average 20°C -Maximum monthly average 30°C -Absolute maximum 40°C Also known as the sustained rating.
Cyclic rating	–	The allowable peak loading of a transformer for given cooling conditions and season or ambient conditions that leads to a peak hot-spot temperature of 120°C for a typical daily load curve.
Continuous Emergency Rating	CER	Primary transformer with a nameplate forced rating based on a very high ageing rate during emergency operation -– usually 140^{0}C hotspot temperature. CER transformers cannot be uprated beyond that rating.
Final rating	–	The rating of a transformer for a given set of conditions with all fitted cooling equipment operating.

Applied ratings

Grid Transformers

Nameplate rating [MVA]	Final Forced cooling method	CMR_{ONAN}	CMR_{FINAL}	$Cyclic_{WINTER\ FINAL}$	$CER_{SUMMER\ FINAL}$
15/30	OFAF	15	30	39	34
20/40	OFAF	20	40	52	46
22.5/45	OFAF	22.5	45	58	51
30/60	OFAF	30	60	78	69
37.5/75	OFAF	37.5	75	97	86
40/60	ONAF	40	60	78	69
45/90	OFAF	45	90	117	103
60/90	ONAF	60	90	117	103

Conventional 66/11 kV primary transformers

Nameplate rating [MVA]	Final Forced cooling method	CMR_{ONAN}	CMR_{FINAL}	$Cyclic_{WINTER\ FINAL}$	$CER_{SUMMER\ FINAL}$
6	ONAN	6	6	7.8	7
7.5	ONAN	7.5	7.5	9.75	9
7.5/10	OFAF	7.5	10	13	11
8	ONAN	8	8	10.4	9.5
10.5/21	OFAF	10.5	21	27.3	23.5
12/16	OFAF	12	16	20.8	17.5
15/21	OFAF	15	21	27.3	23.5

CER-type 66/11 kV primary transformers

Nameplate rating [MVA]	Final Forced cooling method	CMR_{ONAN}	$CMR_{FORCED\ TYPICAL}$	$CYCLIC_{SUMMER\ FORCED}$	$CER_{SUMMER\ FORCED}$	$CER_{WINTER\ FORCED}$
7.5/15	OFAF	7.5	**12**	11.2	12.6	14
12/24	OFAF	12	**19**	18	20.5	23
20/40	OFAF	20	**32**	30	34	38

Notes:

1. *No spring, autumn, intermediate warm or intermediate cool ratings are tabulated in ST:SD8C/1, so summer emergency ratings were used as a proxy to intermediate warm cyclic ratings in the studies.*
2. *No ONAN Cyclic ratings are tabulated for transformers fitted with forced cooling in ST:SD8C/1, so a notional ONAN Cyclic rating was approximated where required by:*

$$Cyclic_{ONAN} = Cyclic_{Forced}\frac{CMR_{ONAN}}{CMR_{Forced}}$$

Appendix

Network Modelling and Analysis

WPD's South Wales Subtransmission network and Primary Distribution network are normally analysed using Siemens PTI's PSS/E version 32 power system software. PSS/E is designed to analyse a snapshot of the network and has the functionality to perform fault level and contingency analysis.

Analysis Program

A bespoke power system analysis program has been written for the studies underlying the Shaping Subtransmission series of reports. The program is written in Python 2.7. It uses PSS/E version 34 as its core analysis engine to perform the actual load-flow calculations, and uses some of PSS/E's built-in contingency analysis tools for efficiency.

To better represent network operations throughout a representative day, the custom program was written so each half hour or the representative day could be overlaid with the demand and generation onto the master model. For each half hour a full intact, first outage and second outage contingency analysis was run to assess the state of the network.

All the study input data were stored on a centralised server-side database. The following inputs were combined for each half hour, day, year and scenario studied:

- An appropriate network model;
- The underlying demand capacity on each BSP;
- The forecast capacity of each DG and new demand on each BSP;
- Half-hourly profiles for each type of demand and DG; and
- The appropriate ratings of network component; and
- Existing network automation and manual switching schemes ('corrective actions').

For each half hour, day, year and scenario studied, the program returns:

- MVA flow on all branches of interest for all network conditions detailed in 'Contingency Analysis' below;
- Voltage exceedances for all nodes of interest for all network conditions detailed in 'Contingency Analysis' below;
- Lost load (i.e. the amount of demand disconnected) for all network conditions detailed in 'Contingency Analysis' below;
- Group load (i.e. the demand and generation of each GSP, BSP and primary substation group) for all networks; and
- Any studies where the program was unable to calculate valid results (non-convergences).

These results are processed within the program and exported to a results database. A separate 'report writer' program was written to summarise the results in tabular and graphical formats for further evaluation.

To significantly decrease the runtime per study, a distributed computing approach was used, where each study was broken into a half hour and representative day. This gave 192 unique tasks for the 4 representative days studied, which were stored on the centralised database and run on all available pool computers. Each active computer checks if any tasks are available from the server and runs a full intact, first outage and second outage study for any available task and writes the processed results to the database. To further improve runtime efficiency, the python multiprocessing module was utilised which allowed up to 6 parallel processes to run on each computer: significantly increasing CPU utilisation.

The processes followed by the analysis program are summarised in Figure 46.

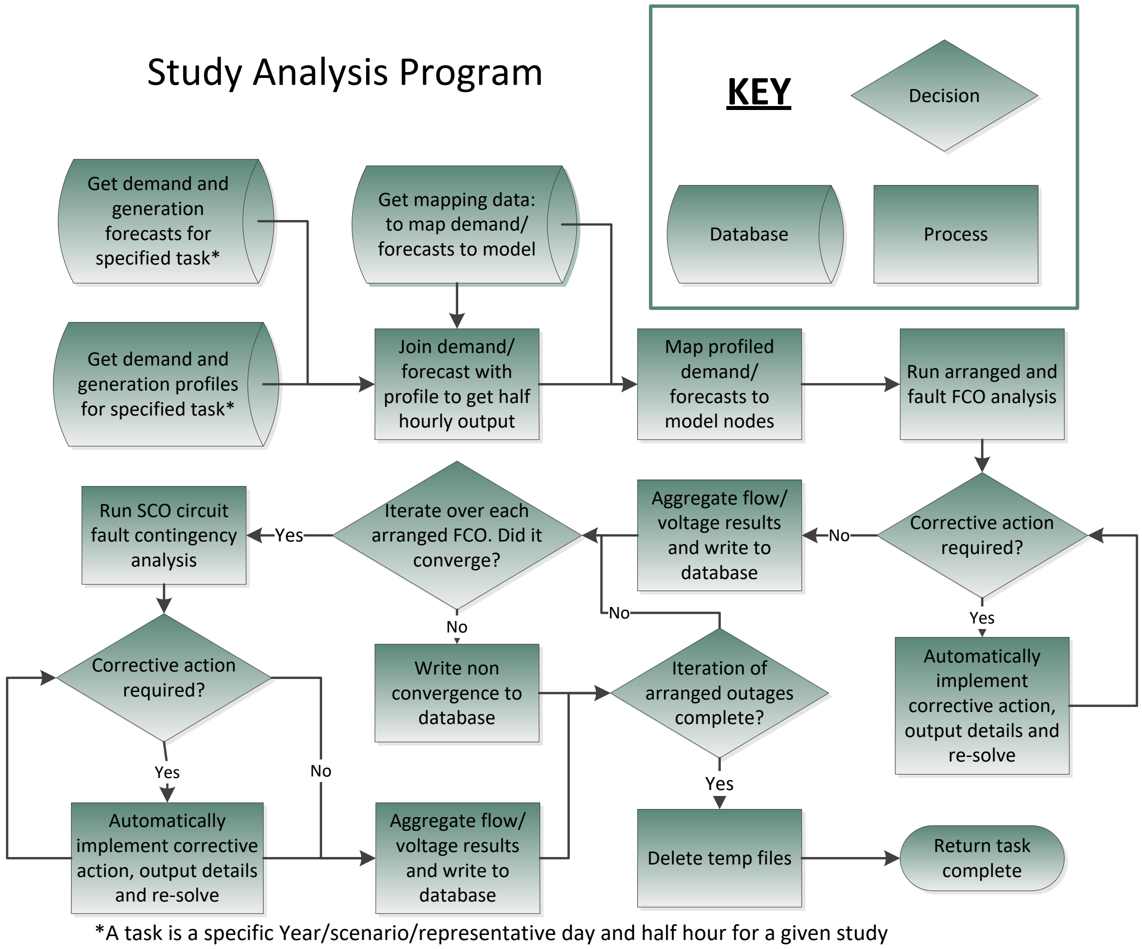

Figure 46: Summary of network analysis process

Modelling Network Automation and Manual Switching Schemes

One of the limitations found with previous versions of PSS/E was the inability to model the behaviour of network automation and manual switching schemes. Networks often rely on such schemes to maintain compliance under outage conditions. Consequently, the results were not always representative of how the network would react to specific outages; extensive manual analysis was required to confirm the impact of these outages. This limitation is avoided in WPD's strategic studies through the use of the PSS/E Advanced Contingency and Remedial Action Scheme (RAS) add-on module. This module takes user defined conditions and will perform an action dependant on the outcome of the condition. WPD has used this module to model the behaviour of network automation and manual switching schemes including:

- Auto-close schemes,
- ANM,
- Intertripping,
- Sequential Control (SQC), and
- Load transfers.

Contingency Analysis

The demand and generation capacity of a network is not normally limited by its characteristics under normal running conditions, but by its characteristics under abnormal running conditions. Abnormal running arrangements occur due to faults, maintenance, network construction and other reasons. WPD's network is required to comply with Engineering Recommendation (ER) P2/6 for demand security, and must safely cope with credible fault conditions beyond the scope of ER P2/6. There is currently no standard for providing security of supply to DG. Contingency analysis is the analysis of the network under abnormal conditions to confirm that the network complies with these requirements.

Circuit breakers were included in the network model in order to determine the protective zones bounded by circuit breakers which are de-energised under fault conditions. Isolators were included in the network model to determine the isolatable zones bounded by isolators which are de-energised to take arranged outages. The following outages types and combinations of outage types were studied:

- The intact (normal running) network;
    - Each circuit fault;
    - Each busbar fault;
    - Each arranged circuit outage;
        - Each arranged circuit outage followed by each circuit fault;
    - Each arranged busbar outage;
        - Each arranged busbar outage followed by each circuit fault;

The outage of each zone that includes at least one 132 kV, 275 kV or 400 kV node was assessed, including all SGTs and GTs. Only those transmission contingencies within the South Wales area were considered.

Modelling Limitations

1. A minor limitation of the program was that a very small minority of contingencies were unable to converge for the most onerous scenarios. Where this occurred the condition was evaluated separately to ensure that it did not indicate an issue with the network model or the network itself.
2. Fault outages were modelled by assuming that each area of network enclosed by circuit breakers represents a protective zone. Sectionalising and subsequent auto-reclose operations were not modelled. Circuit breaker failure outages were not modelled.
3. Arranged outages were modelled by assuming that each area of network enclosed by isolators represents a zone of isolation. The outage required to maintain each isolator was also modelled.
4. Flows on the WPD network can be influenced by the transmission network. Better results are obtained by having accurate data about the transmission network, and the other demands and generators connected to it. The network model used for these studies includes a detailed representation of the transmission network in South Wales, with a reduced equivalent of the wider transmission network. This allowed transmission outages within South Wales to be assessed, but not transmission outages on the wider network that may affect flows within South Wales. Although transmission outages close to the boundary of the reduced network were studied, the accuracy of results for those outages was limited.
5. In the absence of more detailed models of credible worst-case customer behaviour, battery storage was modelled as:
    a. Importing at full capacity when assessing demand security, and
    b. Exporting at full capacity when assessing generation security.
6. At present, there is limited data available on the charging behaviour of large populations of fast-charging, high-capacity EVs with a broad range of users. WPD's is currently hosting the Electric Nation project in partnership with EA. The aim of this project is to determine the impact EVs will have on the network and the effectiveness of demand side management.

There is not currently sufficient data to derive new profiles from this project, but the available data will be periodically reviewed. For this reason, EV charging profiles were derived from the Electric Vehicles Insight Report of the Customer-Led Network Revolution project. This was based on a trial involving 143 domestic EV owners that took place in 2014. It is possible that increases in power and energy consumption per EV will plateau at some point (despite improvements in charging speed and battery capacity) as EV capabilities come to match the demands of EV users, but it is not known when this will happen or at what level. The EV profiles used in the studies peaked at just 0.9kW per EV after diversity. Whilst there is not currently enough data from the Electric Nation trial to create new profiles, there was sufficient data to back up the Customer-Led Network Revolution profiles used. More information on WPD's Electric Nation project is available at www.electricnation.org.uk

7. Only load-flow assessing steady-state voltage and power flows have been undertaken. No power quality, protection or stability studies have been carried out.

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