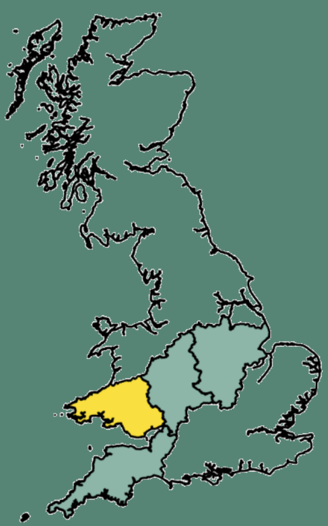

# Shaping Subtransmission to 2030

*South Wales –Report January 2017*

WESTERN POWER DISTRIBUTION

*Serving the Midlands, South West and Wales*

## Version Control

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## Contact Details


### Email

wpdnetworkstrategy@westernpower.co.uk

### Postal

Network Strategy Team
Western Power Distribution
Feeder Road
Bristol
BS2 0TB


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# Contents

# 1 – Executive summary

As part of a wider trend across Great Britain, WPD's South Wales licence area has experienced unprecedented growth in the connection of Distributed Generation (DG). There is now over 1.7GW of generation connected to WPD's South Wales network. This contrasts against an annual maximum demand of nearly 2.1GW and minimum demand of less than 0.8GW.

Initially we were able to minimise connection costs for generation customers 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. Where these have not been available customers have generally preferred to pursue connections elsewhere in South Wales or in other Distribution Network Operator (DNO) licence areas with little or no reinforcement cost.

As a wider consequence of the rapid connection of DG to our network at all voltage levels, limits are being reached on key parts of our network and National Grid's network. Several DG driven reinforcement requirements have been identified in South Wales, particularly thermal restrictions on 132kV overhead lines.

Meanwhile, National Grid's responses to WPD's South Wales Statement of Works (SoW) submissions highlighted that DG output in South Wales is further limited by the capability of transmission network components both in South Wales and further afield.

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 SW, we have developed scenarios for the growth of DG and demand in South Wales from 2016 to 2030. These scenarios correspond to National Grid's Future Energy Scenarios: No Progression, Slow Progression, Consumer Power and Gone Green. They cover the growth of several types of generation and the electrification of transport and heating; Solar PV and Onshore Wind generation are both identified as having the potential for very strong growth. Developers have proved very capable of deploying Solar PV in South Wales, but its growth brings significant challenges. Its output is dictated by weather and seasons, and is not coincident with times of peak demand for electricity. Without electricity storage or output curtailment on a vast scale, there will inevitably be a limit to how much Solar PV can usefully contribute to Great Britain's energy needs.

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) and the 132kV and 66kV 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:

- A generation-dominated summer peak day;
- A demand-dominated winter peak day; and
- A typical spring or autumn day.

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. WPD’s expected transition to become a Distribution System Operator 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 132kV and 66kV lines. The studies also identified the requirement for significant further reinforcement by 2020 including new transformers, line reconductoring and cable overlays if the expected growth in DG occurs.

Looking beyond 2020 to 2025 and 2030, the scenarios diverge but further reinforcement is required under every scenario. Under the No Progression scenario this is limited to the further 132kV overloading in the Carmarthenshire and West Wales network. In contrast the Gone Green scenario triggers:

- Establishing 132kV supplies to the Llynfi Valley;
- A third Super Grid Transformer (SGT) at Pembroke GSP and fourth 132kV circuit to the Pembrokeshire BSPs;
- A third SGT at Rassau GSP;
- Transformer replacement and further reactive compensation on the mid-Wales 66kV ring;
- 66kV reconductoring between Abergavenny and Panteg BSPs;
- Extensive reinforcement across in the Swansea North GSP area, potentially including one or two new GSPs;
- 132kV reprofiling north of Upper Boat GSP; and
- Various Grid Transformers (GTs) and primary transformers to be replaced with larger units or newly established.

It is expected that some – but not all – of this reinforcement could be alleviated by using Active Network Management (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.

While the forecast reinforcement requirements were dominated by the connection of DG, the electrification of transport and heating also has an impact. The studies are particularly sensitive to electric vehicle usage patterns, which may change dramatically as electric vehicles enter the mainstream.

It is recommended that National Grid assess the impact of our scenarios on their network. It is clear from the SoW process that DG can no longer be connected in South Wales without transmission constraints or reinforcement. The initial constraints are for infrequent and unlikely combinations of outages, but as more generation connects these constraints may become more frequent.

It is 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 by:
    - fuel type,
    - general location, and
    - year of connection

  against potential demand changes that may result due to changes in end use such as electrification of transport and heating;
- Identify thermal and voltage constraints that may occur on our 132kV and 66kV network which will limit the ability of those connections to take place;
- Assess options for reinforcement; and
- 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 2015 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 Network

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

These GSPs are in turn supplied from the interconnected 275kV and 400kV 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 132kV. The 132kV and 33kV networks supplied from Upper Boat GSP are remotely coupled by a 132/33kV Grid Transformer at Mountain Ash Bulk Supply Point.

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

- The Llynfi Valley 66kV network, supplied directly from Margam GSP; and
- The East Wales 66kV network, supplied via the 132kV 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 66kV ring, originating at Abergavenny BSP;
  - The Southern 66kV ring, interconnecting Abergavenny and Panteg BSPs; and
  - The Llantarnam 66kV network, supplying Rogerstone Primary Substation and part of Pontypool North Primary Substation.

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

The overall network configuration is shown in Figure 1.

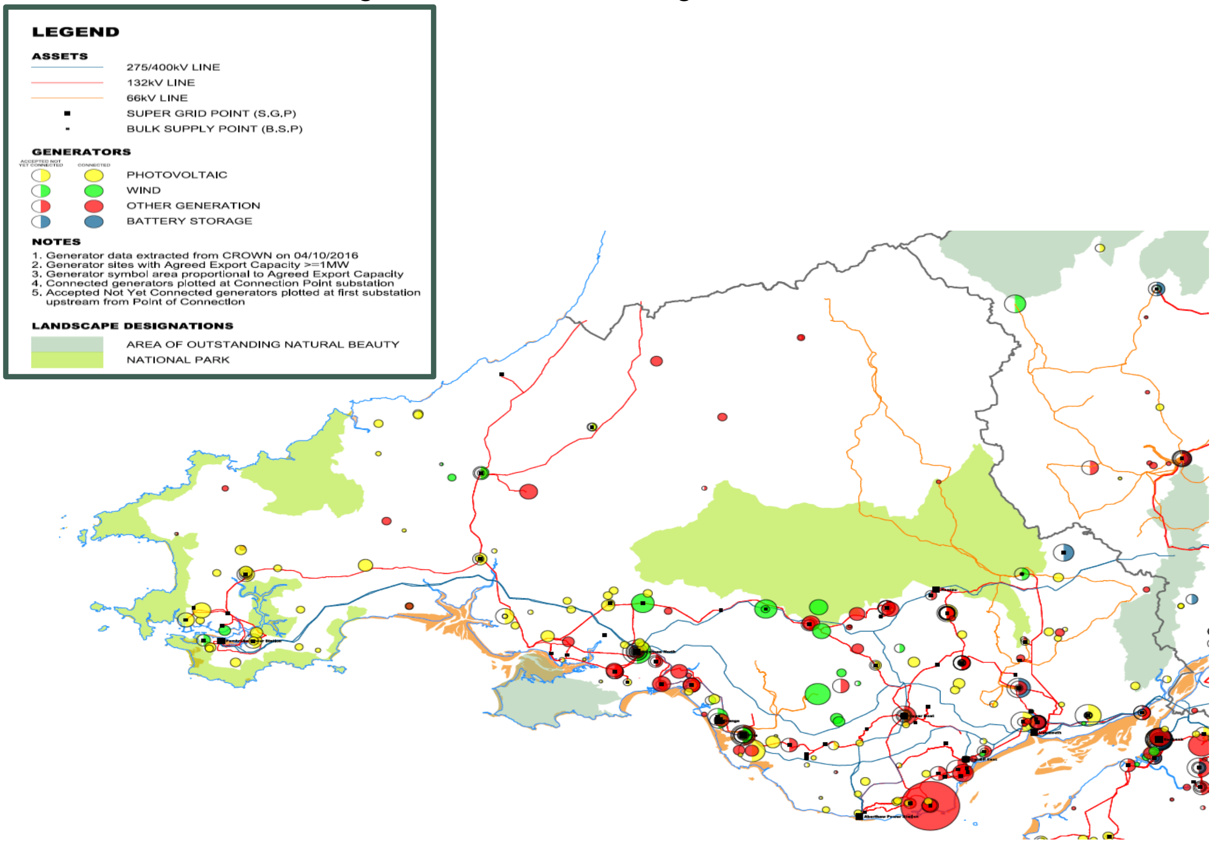



**Figure 1: Network in South Wales showing 400kV, 132kV and 66kV networks together with generation in excess of 1MW capacity connected to the distribution network**

# Demand usage of the network

Current forecast units distributed and historic system maximum demands are shown in Table 1 and Figure 2.

**Table 1: Forecast units distributed in South Wales (more detailed breakdown available in published CDCM models)**

| | Rate 1 (Peak/Red) Units (MWh) | Rate 2 (Off-Peak/Amber) Units (MWh) | Rate 3 (Green) Units (MWh) | MPANs | Import Capacity (kVA) | Reactive Power units (MVArh) |
|---|---|---|---|---|---|---|
| **Domestic** | 3,391,429 | 176,357 | - | 1,033,972 | - | - |
| **Other LV NHH (incl. Unmetered)** | 1,293,397 | 225,205 | 123,810 | 83,042 | - | - |
| **Other LV HH** | 114,045 | 721,339 | 540,284 | 3,997 | 659,615 | 113,950 |
| **HV (incl. LV Substation)** | 159,684 | 963,473 | 900,253 | 677 | 706,379 | 142,887 |
| **LV Generation** | 23,061 | 1,132 | 1,197 | 289 | - | 2,110 |
| **HV Generation** | 120,916 | 57,665 | 64,975 | 87 | - | 1,750 |
| **Total** | **5,102,532** | **2,145,170** | **1,630,518** | **1,122,064** | **1,365,994** | **260,697** |

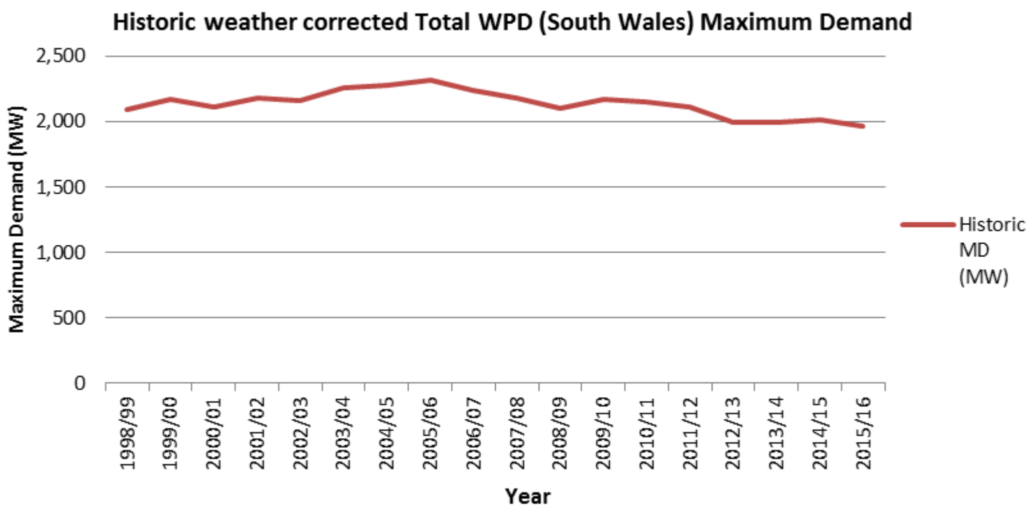



**Figure 2: South Wales historic system maximum demand**

The studies undertaken have used three representative days for each year studied:

- A winter peak demand day;
- A summer ‘maximum generation’ day – i.e. low demand with high levels of DG output; and
- A typical spring/autumn day – i.e. period when there are planned outages.

Using data from the settlement system the contribution to demand on these typical days from different segments of demand has been estimated and is shown in Figure 3, Figure 4, Figure 5 and Figure 6.

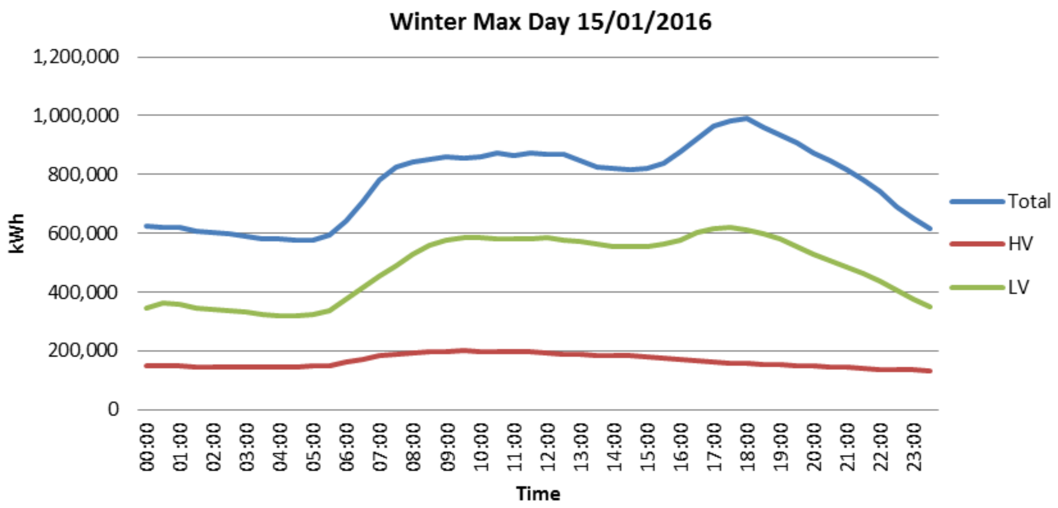



Figure 3: Typical Winter day energy usage profile

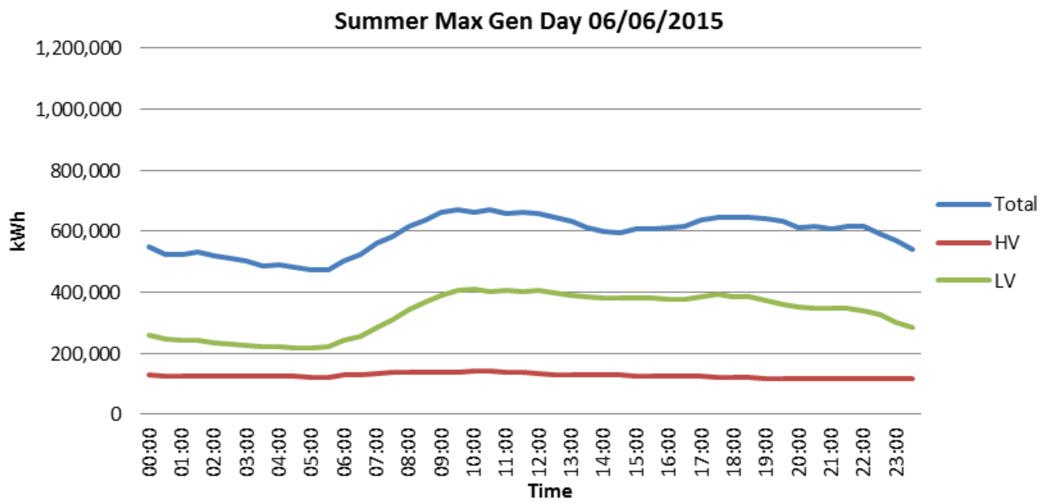



Figure 4: Typical Summer day energy usage profile

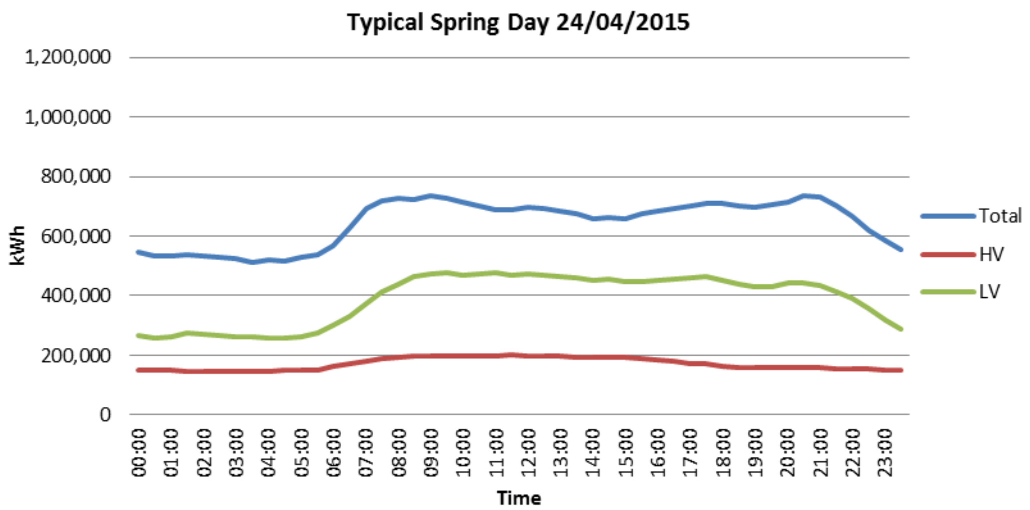



Figure 5: Typical Spring day energy usage profile

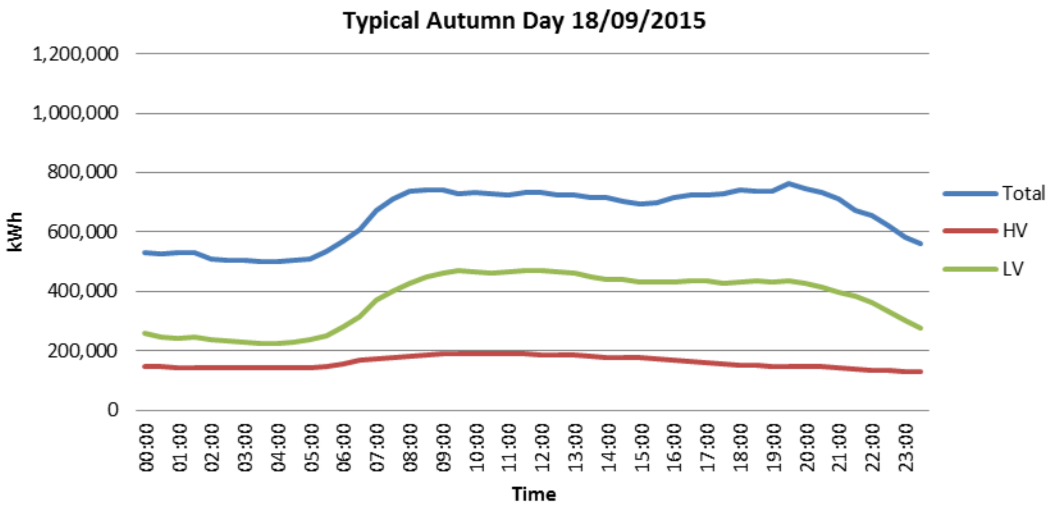



**Figure 6: Typical Autumn day energy usage profile**

The results show that the demand on the HV network is relatively constant throughout a daily and annual period. The LV network demand (and as a result the total network demand) is highest in winter and lowest in summer. In winter, the daily peak demand tends to occur in the evening hours (17:00 to 19:00) whereas in the summer the daily peak occurs in the morning (08:00 to 11:00). In spring and autumn, the demand throughout the day is relatively constant, with peaks in the morning and evening as aforementioned.

The growth of new demand such as Electric Vehicles (EVs) and Heat Pumps (HPs) is expected to change demand profiles. As these technologies develop and smart meters are rolled out, opportunities for Demand Side Response (DSR) may arise, allowing demand profiles to be modified by network operators and suppliers. DSR opportunities are likely to be available for commercial and industrial customers initially, with future extension to domestic customers. WPD has a number of innovation projects underway to further explore this area:

- ENTIRE - a project for industrial and commercial customers to develop the necessary forecasting, contracting, despatch, metering and settlement functions whilst alleviating winter demand congestion in the South-East Midlands.
- SYNC - a project for industrial and commercial customers operated in parallel with the system operator's Demand Turn Up (DTU) to reduce the need for local generation constraints as well as assisting with system balancing.
- A range of projects which aim to develop WPDs understanding of domestic 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

# Growth in Distributed Generation

At privatisation, in 1990, there were virtually no generators connected to the distribution network. Those that existed were mainly embedded within customer-owned internal networks and primarily used for standby purposes. Since the early 1990's there has been a moderate growth of Onshore Wind generation supported by various subsidy arrangements.

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 there has been a growing interest in the connection of storage. 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 position of DG in South Wales is shown in Table 2. This shows the breakdown between those connected to the distribution network, those with accepted connection agreements to connect and those with outstanding connection offers.

**Table 2: Connected, Accepted and Offered Distributed Generation in WPD South Wales at the end of December 2016**

| ***Generator type*** | **Connected [MVA]** | **Accepted [MVA]** | **Offered [MVA]** | **Total [MVA]** |
|---|---|---|---|---|
| *Photovoltaic* | 522.3 | 511.2 | 43.0 | 1,076.5 |
| *Wind* | 332.3 | 395.5 | 56.7 | 784.5 |
| *Landfill Gas, Sewage Gas, Biogas and Waste Incineration* | 51.3 | 87.6 | 21.0 | 159.9 |
| *Combined Heat and Power (CHP)* | 6.6 | 33.7 | 0.3 | 40.6 |
| *Biomass and Energy Crops* | 2.0 | 81.3 | 0.0 | 83.3 |
| *Hydro, Tidal and Wave Power* | 12.2 | 17.9 | 0.1 | 30.2 |
| *Storage* | 0.0 | 61.0 | 95.0 | 156.0 |
| *All Other Generation* | 812.3 | 483.3 | 245.8 | 1,541.4 |
| ***Total*** | **1,739.0** | **1,671.5** | **461.9** | **3,872.4** |

# Issues resulting from the growth of DG and demand in South Wales to 2016

## Distribution network constraints

Some parts of the South Wales network are already constrained due to the growth of DG. Several reinforcements that will allow existing assets to be better utilised are planned, in particular the reprofiling of overhead lines. ANM zones have been opened to applications covering Pembroke GSP and part of Swansea North GSP.

In addition, the reinforcement of networks including Upper Boat/Mountain Ash 33kV and the Mid-Wales 66kV ring is planned for ED1 to maintain P2/6 compliance in light of projected demand growth.

## 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. The initial assessment is carried out via a Statement of Works (SoW) which confirms whether NGET work or connection conditions will be required. Where works are required, a Modification Application is made to NGET. NGET then specifies the precise works or conditions needed before connection can take place.

This process was put in place prior to the substantial growth in DG and whilst originally designed to address the impact of single large DG plant being connected onto distribution networks, it has been used to assess the cumulative impact of large numbers of smaller DG plant.

Two bulk SoW applications have been made to NGET for South Wales which, after subsequent modification applications have led to the following conditions being imposed:

- 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 to 0.99 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 or Upper Boat 33kV GSP areas will be required to participate in an ANM scheme to manage reverse power flow through the Super Grid Transformer.

The second bulk SoW response in May 2016 resulted in a 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. 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. Any long term reinforcement programmes to increase capacity will require significant investment and long lead times for completion.

WPD are currently involved in the SoW Appendix G trial process whereby every month WPD assess acceptances, connections and withdrawals on GSP basis. These changes in generation status are documented in the relevant Appendix G parts. In addition SGT flows and radial fault infeed are amended in the summary table of the Appendix G document to reflect the relevant changes in generation.

Currently, WPD are awaiting the Modification Application responses from NGET to the most recent SoW submission regarding thermal constraints for thermal generation connections. The results are expected to be published on the website in early February 2017. Please visit the website for further details.

# 4 – Scenarios

National Grid produces Future Energy Scenarios each year which provides:

- A range of credible futures.
- An output of an annual stakeholder consultation process regarding the future of the energy landscape.
- A document covering the model inputs to the scenario analysis, new technologies, social and economic developments, government policies and progress against targets.
- A set of scenarios which can be used to frame discussions and perform stress tests.
- A set of scenarios that are projected out from the present to 2050.
- Scenarios which 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 SW to produce a set of forecasts for the growth of DG and demand in South Wales. Forecasts were made for four scenarios:


**Figure 7: National Grid's Future Energy Scenarios[1]**

[1] – From National Grid's Future Energy Scenarios in five minutes, July 2016

These scenarios are named after and correspond to the economic scenarios developed by National Grid in the FES. Each scenario was forecast for each year from baseline in 2016 to 2030.

**Table 3: Key DG, storage and demand technologies which were assessed by the WPD and Regen SW forecasts**

| **Key Distributed Generation, storage and demand technologies assessed** | |
|---|---|
| **Electricity Generation Technologies**<br><br>• Solar PV – ground mounted<br>• Solar PV – roof mounted<br>• Onshore wind – large scale<br>• Onshore wind – small scale<br>• Anaerobic digestion – electricity production<br>• Combined Heat and Power Heat pumps (communal/commercial)<br>• Hydropower<br>• Emerging and new DG technologies<br>    ○ Geothermal<br>    ○ Tidal stream<br>    ○ Wave energy<br>    ○ Floating wind | • Conventional and Short Term Operating Reserve DG capacity<br>• Gas, diesel and gas CHP<br><br>**Electricity Demand Technologies**<br><br>• Electric vehicles<br>• Heat pumps (domestic)<br><br>**Energy (electricity) storage**<br><br>• Energy storage ‘network support’<br>• Energy storage ‘generation support’<br>• Energy storage ‘own use’ |

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.

For each DG and demand technology shown in Table 3, 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 spring 2016 with a high degree of accuracy;
2. Pipeline – WPD’s database of Accepted-not-yet-Connected DG was combined with an assessment of the 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 by 2017 or 2020 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.

In order to map scenarios for demand and DG growth to the distribution network, the South Wales licence area was divided into 91 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 66kV;
- The geographical area supplied by a Primary Substation supplied at 66kV (or group or part thereof);
- A customer directly supplied at 132kV or 66kV (or by a dedicated BSP or 66kV Primary Substation); or
- A Future Wind Development Zone.

The BSP and Primary substation ESAs are shown geographically in Figure 8. Two additional ESAs outside the South Wales licence area have been included to represent SP Energy Networks' Aberystwyth, Rhydlydan and Cefn Croes BSPs, which are supplied from WPD's Swansea North 132kV network.

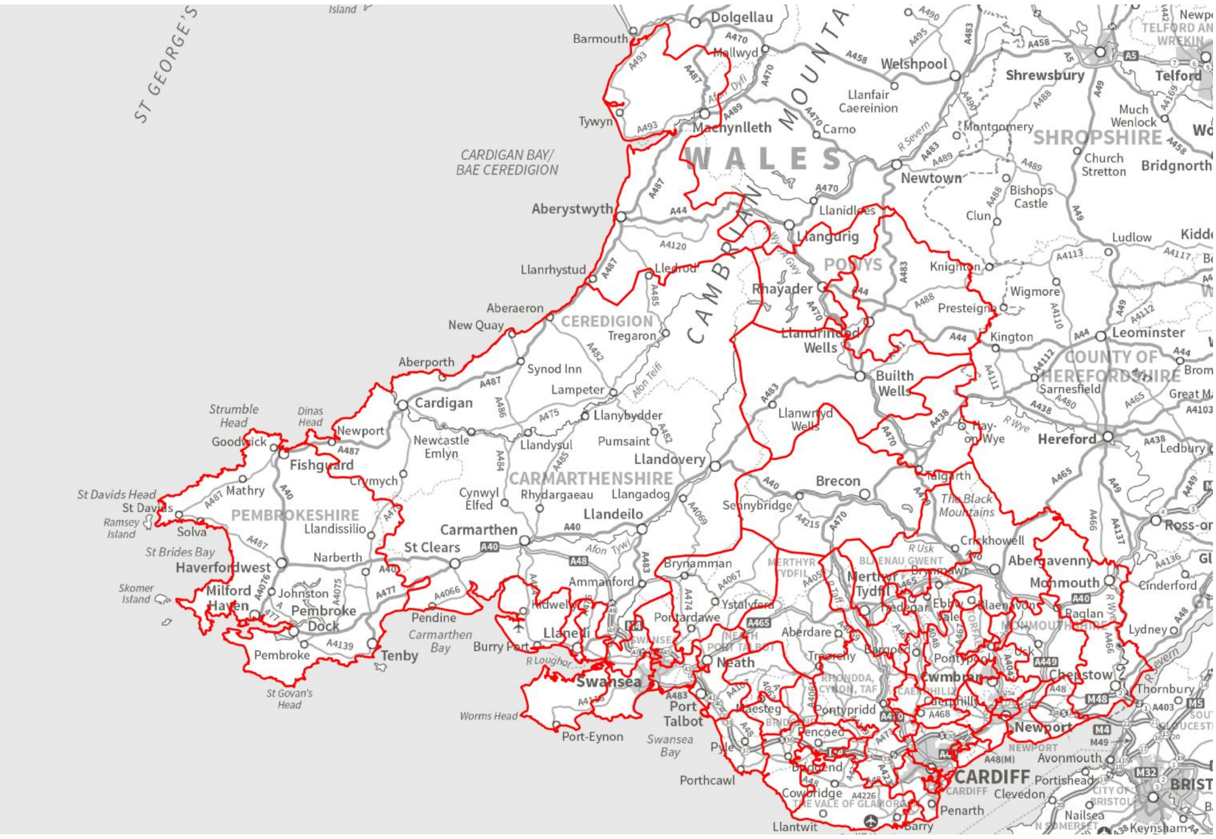



Figure 8: Geographical ESAs

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 SW report and provide a projection of annual capacity deployment, by technology and scenario, for the period from 2016 to 2030. The complete Regen SW report, *Distributed generation and demand study -Technology growth scenarios to*

*2030, South Wales licence area* is available from our website at: www.westernpower.co.uk/About-us/Our-Business/Our-network/Strategic-network-investment.

A summary of the DG forecasts is shown in Figure 9. From the baseline capacity of circa 1,400MW in spring 2016, capacity grows to 4,600MW by 2030 under the most ambitious Gone Green scenario. Growth estimates for the other scenarios, Consumer Power, Slow Progression and No Progression are lower overall. However, even under the lowest No Progression scenario, there is an expected growth pathway to 2,400MW of DG capacity by 2030. A summary of demand forecasts is shown in Figure 10. This demand growth is based on the growth of EVs and HPs, which are expected to dominate demand growth in South Wales for the foreseeable future.

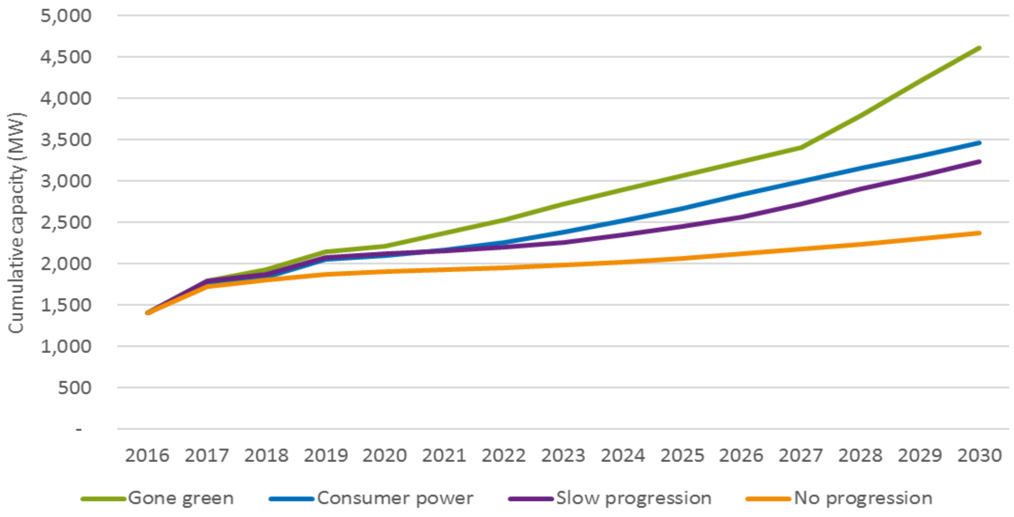



**Figure 9: Total Distributed Generation capacity growth in WPD South Wales licence area from 2016 to 2030 under each scenario**

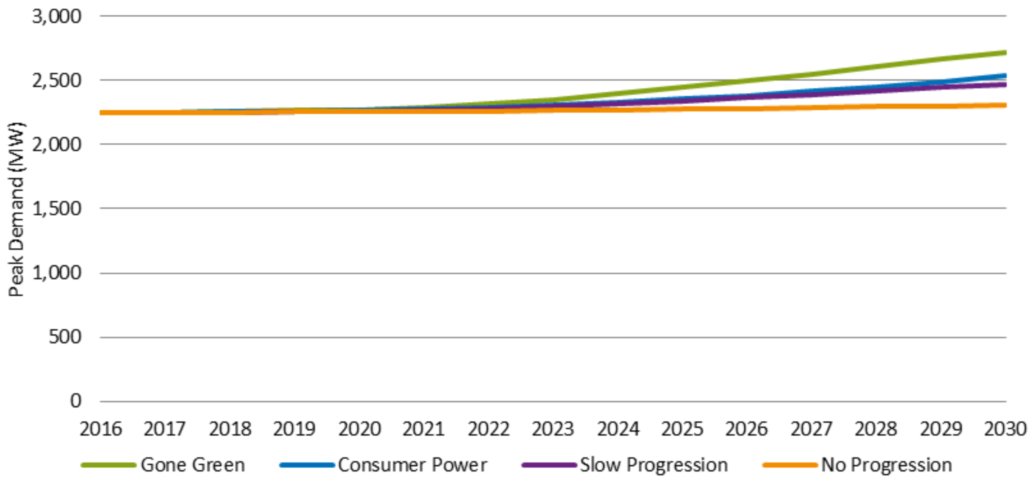



**Figure 10: Total Demand growth in WPD South Wales licence area from 2016 to 2030 under each scenario**

# 5 – Network modelling 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 because of 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 both demand and DG is rapidly changing, it has become difficult to predict what network condition will be most onerous.

For this project, a broader approach was taken. The network was assessed for each of the four scenarios, for 2016, 2020 and 2025. To cover a range of likely onerous cases, each half-hour of three representative days was assessed for:

- A winter peak demand day;
- A summer ‘maximum generation’ day – i.e. low demand with high levels of DG output; and
- A typical spring/autumn day – i.e. period when there are planned outages.

Demand and DG was aggregated by ESA to be modelled at the appropriate node(s) to assess the impact on the Subtransmission network. For BSPs this was the 33kV or 11kV busbar; for 66/11kV Primary Substations this was the 11kV busbar. Networks at 33kV and below were removed from the model, except where necessary to represent interconnection between BSPs or 66/11kV primaries.

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

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

## Demand and Generation 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; and
- Each type of DG is measured in MW of installed capacity.

The profiles for underlying demand, Solar PV and Onshore Wind generation were derived from measured flows on WPD South Wales network. The other profiles were derived from various sources as described below. A particular focus was placed on the Solar PV and Onshore Wind due to the high level currently installed on the network and forecast out to 2030 under all scenarios.

## Demand Profiles

### *Underlying demand*

The underlying demand profiles for South Wales are shown in Figure 11. The maximum daily load curve peaks at approximately 2,058MW for the whole South Wales region. The specific load curve for each BSP will vary depending on a number of factors such as population density and levels of industry in the area. A representative sample of ESAs were categorised into urban, rural and mixed and their historic demand was used to generate demand profiles for the 3 distinct ESA types. In addition, there are a number of industrial ESAs in South Wales. Due to the nature of industrial customers, and the uncertainty of when they will be operating, a seasonal worst case industrial profile was assumed.

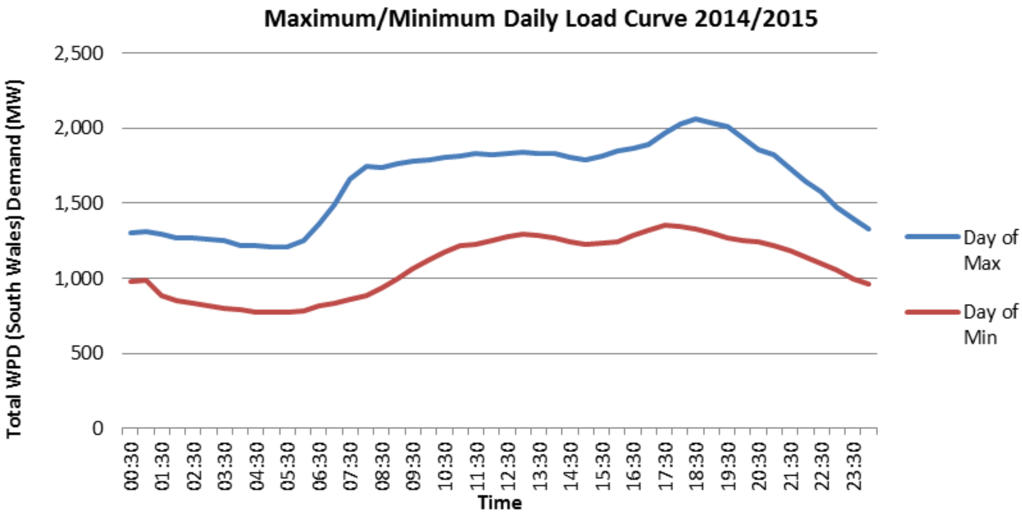



**Figure 11: South Wales maximum and minimum demand profiles**

### *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.

Outside air temperature is a critical factor influencing heat pump load profiles. Profiles were derived for the ‘average’ peak winter day and the ‘1 in 20’ (extreme) peak winter day. On an average peak winter day, the back-up electrical heater is not required and the electrical demand of the heat pump peaks at approximately 2.5kW. During a 1-in-20 peak winter day, the back-up electric heater is needed for large portions of the day resulting in an additional 3kW of peak demand on very cold days. The 1-in-20 undiversified day was used in the winter peak demand studies to represent the worst case demand from heat pumps. The profiles assumed there was no demand in summer from heat pumps during the max gen studies.

### *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 12.

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 SW report considers two different charging profiles, derived from the FES report, dated July 2015. The FES report assumed that a Time Of Use Tariff (TOUT) will be applied for the Gone Green and Slow Progression scenarios from 2020, while uninhibited charging was assumed for the Consumer Power and No Progression scenarios up to 2035. The TOUT results in a two-hour delay in peak demand, but no reduction in total energy consumption.

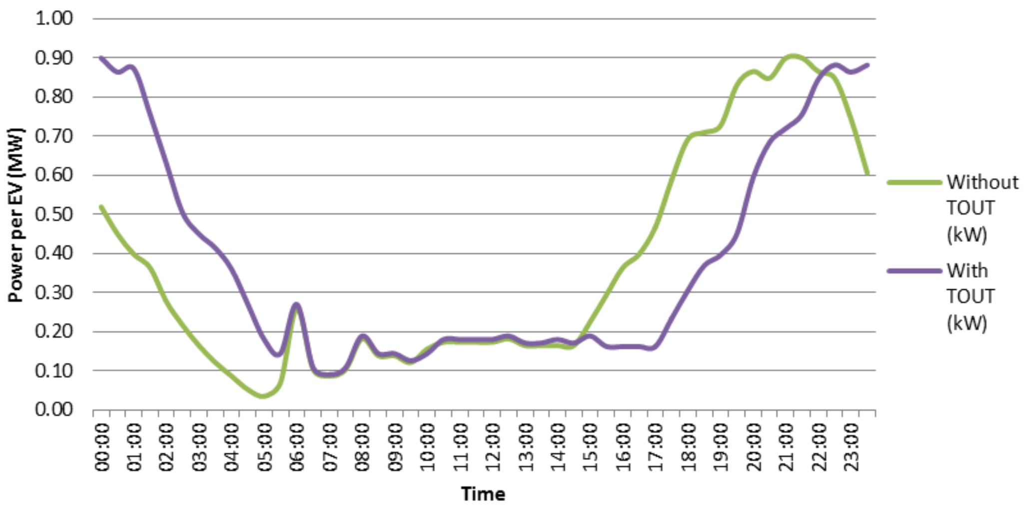



**Figure 12: EV Winter Profile (per EV)**

## Generation Profiles

### *Solar PV*

Data from all existing PV plants with installed capacity of 1MW or greater was used to generate the profiles. This comprised 60 sites, with a total installed capacity of 398MW. The geographical spread of solar PV plants in the sample is shown in Figure 13.

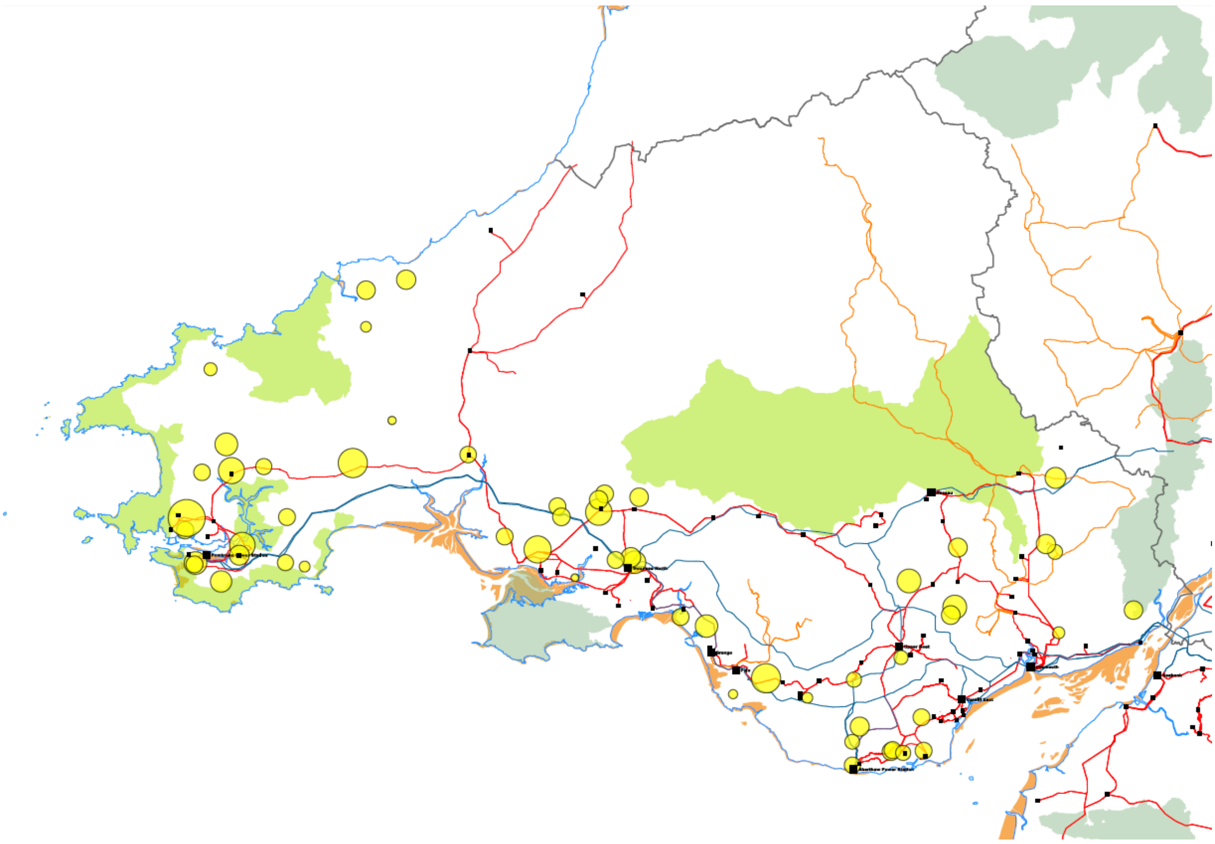


**Figure 13: Map of PV sites contributing to generation profile**

The half-hourly MW data was aggregated and then normalised to produce a maximum, minimum and average profile as shown in Figure 14:

1. Summer (May-August)
2. Winter (December-February)
3. Spring-Autumn (March-April and September-November)

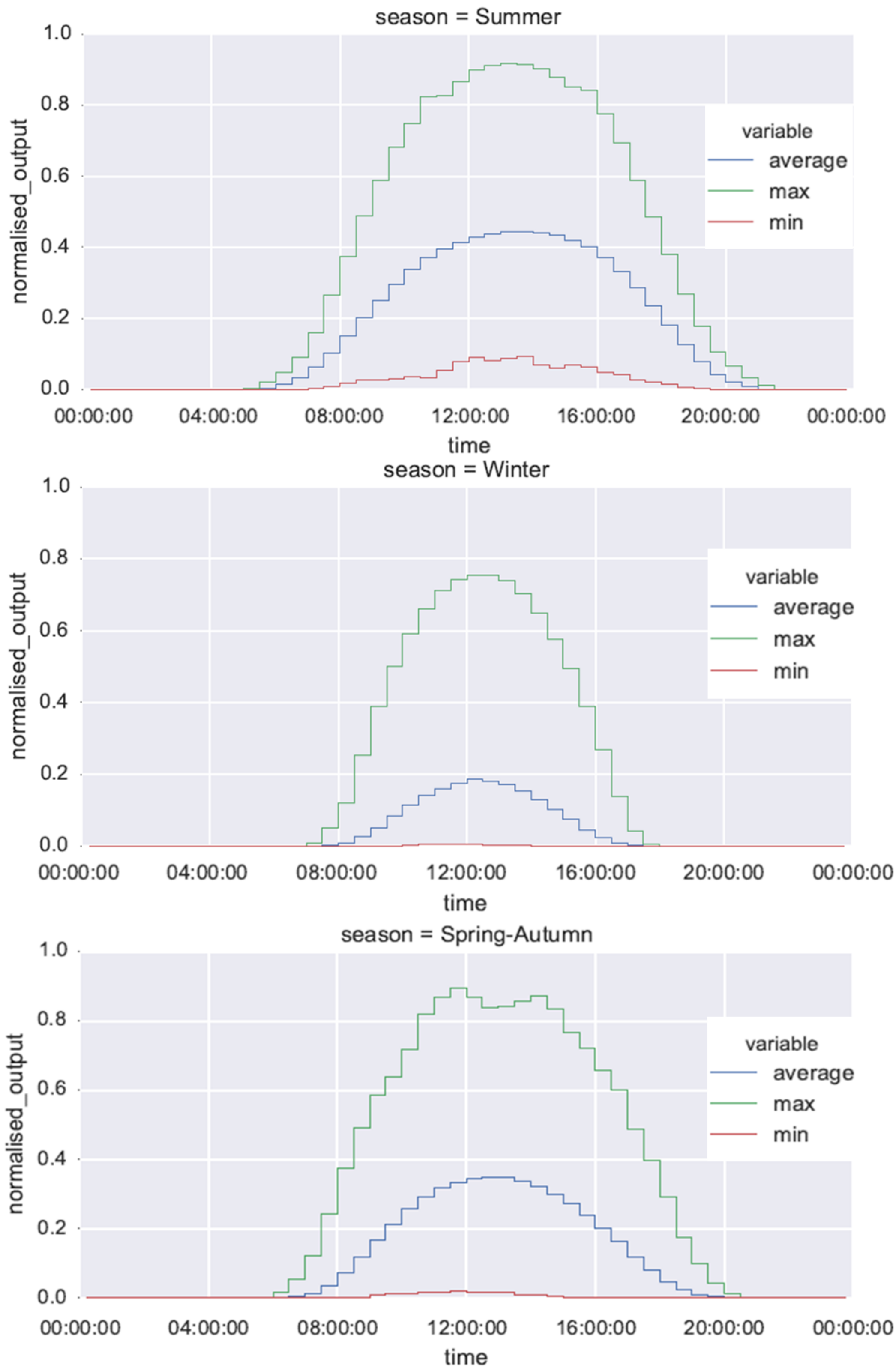



**Figure 14: Normalised PV Profiles based on season**

The installed capacities in the Regen SW study were multiplied by the profiles to produce an approximation of half hourly export from the solar PV plants.

## *Onshore Wind*

A similar process used for the PV was used to generate the Onshore Wind profiles; where all Onshore Wind sites in South Wales with an installed capacity of at least 1MW were aggregated and normalised over installed capacity to produce the profile characteristics. This data comprised 16 sites, with a total installed capacity of 272MW. The Onshore Wind plants used in the sample are shown geographically in Figure 15.

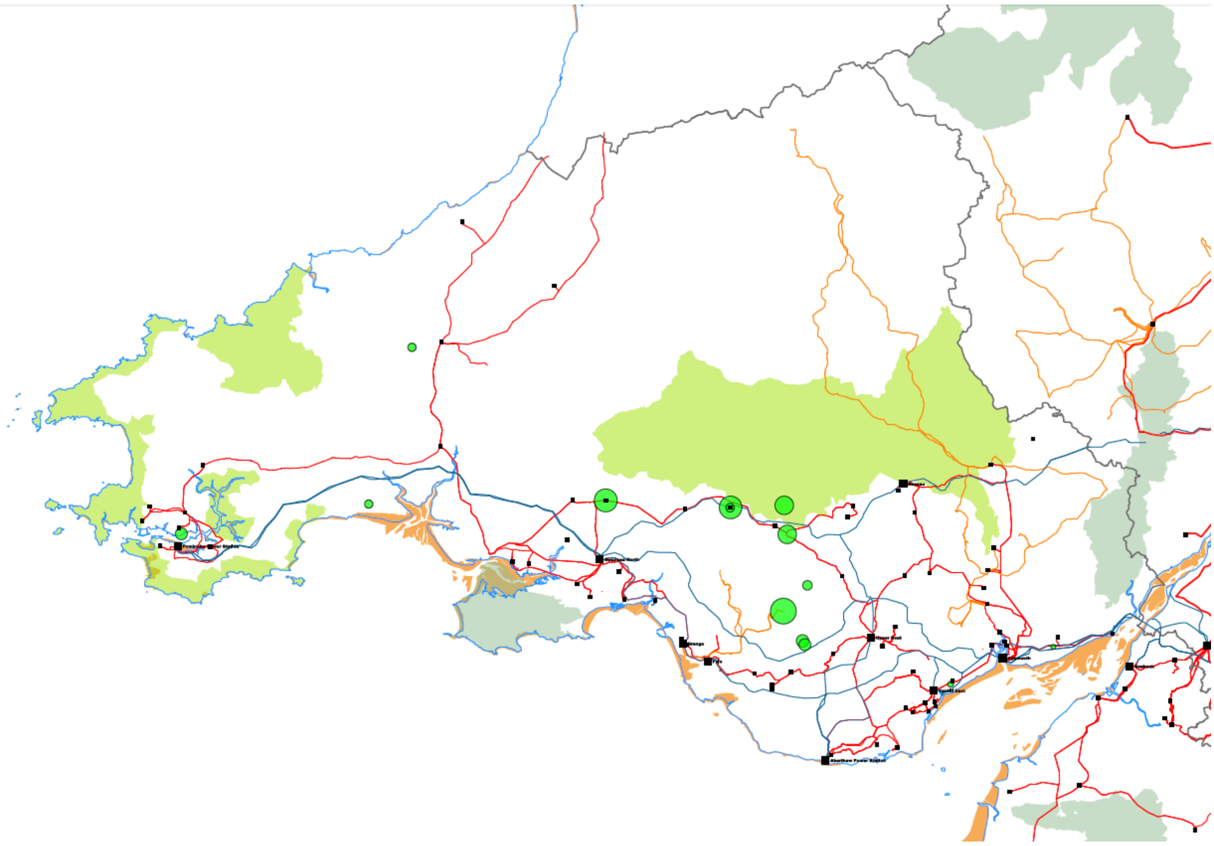


**Figure 15: Map of onshore wind sites contributing to generation profile**

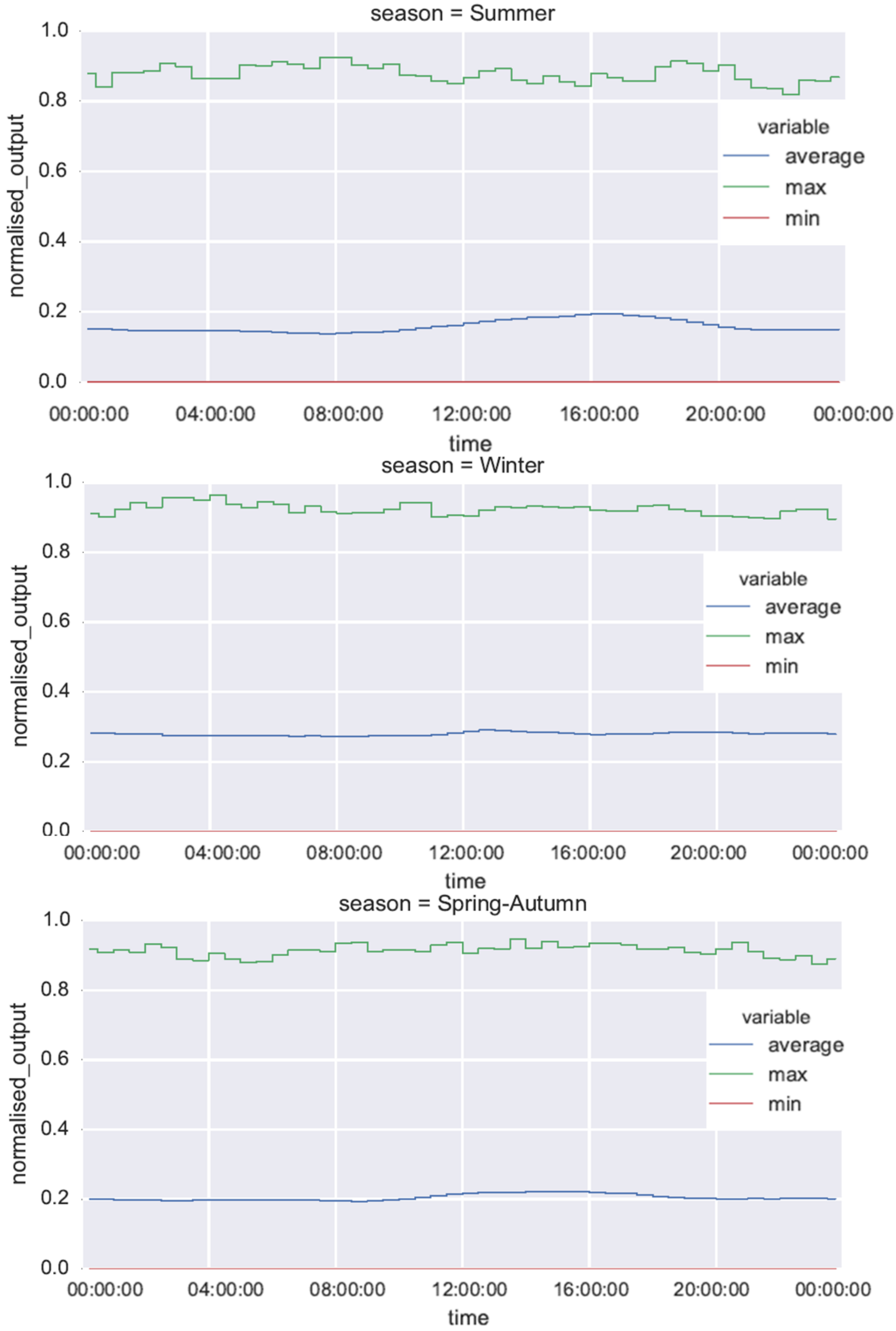



**Figure 16: Normalised Wind Profiles (to be applied to installed capacity)**

Figure 16 highlights how the wind output is not as seasonally dependent as solar. The maximum half hourly outputs are similar for all seasons, but there is a noticeable increase in the average output during winter.

The assumptions made for the wind profiles for each of the studied representative days were:

- Winter (December-February) - Minimum by half hour
- Spring-Autumn (March-April and September-November) - Average by half hour
- Summer (May-August) - Maximum by half hour

### *Other Generation*

The remaining DG types modelled were:

- Anaerobic Digestion (AD)
- Deep geothermal
- Energy from waste
- Hydropower
- Offshore and marine (split into floating, tidal and wave)
- Other generation (non-renewable Distributed Generation)
- STOR, non-renewable Distributed Generation operating under a Short Term Operating Reserve (STOR) contract or other similar contract

Insufficient data was available to derive profiles from measured flows for these technologies. In the case of infrequently-dispatched non-intermittent generation such as STOR, 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.

#### STOR

- Summer – Continuous output at installed capacity
- Winter – Zero output
- Spring/autumn – Continuous output at 0.2 times installed capacity

#### All other types

- Summer – Continuous output at installed capacity
- Winter – Zero output
- Spring/autumn – Continuous output at 0.8 times installed capacity

# 6 – Results

Results are given by year, GSP and network area within GSP. Any divergence between scenarios is noted. **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.

A single line diagram and geographic map of the South Wales Subtransmission network is available on the website to help understand the results section. www.westernpower.co.uk/About-us/Our-Business/Our-network/Strategic-network-investment

## 2016

In 2016 all four scenarios are identical, representing the demand and DG connected to the network as of 2016. The 2016 studies were used to benchmark the future years. Some apparent deficiencies were identified from the 2016 results.

### Rassau GSP

#### *Mid-Wales (Abergavenny) 66kV ring*

The northern reaches of the mid-Wales 66kV ring, including Llandrindod Wells and Rhayader are approaching the voltage limits of operation. Further generation connections and demand growth will result in winter voltage collapse and summer overvoltage under various First Circuit Outages (FCO). To resolve this in subsequent years, a ±3MVAr Static VAr Compensator (SVC) was modelled at the Rhayader 11kV bar. This did not always keep the voltage above the lower statutory limit, but allowed modelling to continue. This network has already been identified as requiring reinforcement during RIIO-ED1 due to projected demand growth. **It is recommended that detailed studies of reactive demand and voltage-dependent demand in this area are carried out to determine when reinforcement is required.**

### Post-fault Corrective Actions

Certain areas of network have been identified as being heavily reliant on post-fault Corrective Actions to avoid overloading or voltage excursions. It is standard operational practice to utilise network management schemes such as intertripping or Control Engineer action to prevent back-feeding of an isolated network via a lower voltage busbar. Consideration must be given to the point where network management schemes will no longer be suitable and that network reinforcement schemes must be implemented.

# 2020

## Aberthaw and Cardiff East GSPs

No reinforcement requirements were identified, but it was noted that this network is heavily reliant on the operation of a hardwired scheme at Sully BSP which curtails the output of Barry Power Station to prevent 132kV overloads.

## Margam and Pyle GSPs

The Llynfi Valley is currently supplied by two 66kV circuits from Margam GSP. To supply planned generation connections, new 132/66kV transformers are being installed at nearby Pyle GSP, along with new 66kV circuits from Pyle to Llynfi. These circuits will use existing disused 132kV and 66kV routes for part of their length.

### *Existing Grange 66kV network*

The two 66kV lines from Margam GSP to the three primaries and two wind farms in the Llynfi Valley overload by up to 10% under FCO in summer. **These lines are currently being surveyed for reprofiling to 75°C. If this can be achieved it will alleviate the projected overloads.**

### *Planned Pyle 66kV network*

The state of the planned 66kV network from Pyle GSP to new generators in the Llynfi Valley is heavily dependent upon the staging of generator connections. Realistic network designs for 2020 vary from one to three 132/66kV GTs at Pyle and one to three 66kV lines from Pyle to Llynfi 66kV. This could be reduced to two GTs and two lines by interconnecting the lines at Llynfi, profiling the lines for 75°C operation and intertripping generators for the loss of either line. Alternatively, the new circuits could be established at 132kV, providing some room for future expansion but extending consenting and construction timescales.

**It is recommended that consideration is given to the coordination of new connections in the Llynfi Valley to avoid building several low-rating circuits alongside each other in succession. New circuits into the Valley should, where reasonably practicable, be operated (or capable of operation) at 132kV.**

## Pembroke GSP

Pembroke GSP has been identified as an area where ANM is required, to defer reinforcement where large amounts of future generation connections may trigger costly and time delaying reinforcement. WPD is currently accepting applications for alternative connections to this network as an ANM area. The area is scheduled to be active in November 2017. The results for this section do not take the proposed ANM system into account; it is expected that ANM will allow some reinforcement to be deferred.

### *132kV overloading*

Most demand and generation in Pembrokeshire is supplied by three 132kV circuits from Pembrokeshire GSP which are interconnected at Milford Haven BSP. The three circuits use largely different routes on a mixture of underground cable, tower line and wood pole line. Because of this, the three circuits have significantly different impedances and ratings.

The first 132kV circuit is from Pembroke 305 to Milford Haven mesh corner 7, teed to Waterston GT1. The western side of the RR-route tower line from RR1 (Milford Haven BSP) to RR6 (Gulf tee) forms part of one of this circuit. This section overloads under FCO of either circuit in summer. The section is currently composed of 1.6km of 175mm² ACSR (Lynx) on steel towers, with an assigned rating for 50°C operation. The existing conductor has been reprofiled for operation at 75°C, and rating limiting joints upgraded. An increased rating will be assigned shortly. The new rating is sufficient under No Progression and Slow Progression scenarios, but not Consumer Power and Gone Green. **It is recommended that a reinforcement scheme is developed to reconductor the section with 300mm² AAAC (Upas) profiled for 75°C operation, then triggered as necessary.**

The second 132kV circuit is from Pembroke 205 to Milford Haven mesh corner 3, teed to Golden Hill GT2. The eastern side of the EE-route tower line from Milford Haven BSP mesh corner 3 to Golden Hill BSP GT2-side forms part of this circuit. It overloads under FCO in summer in both Gone Green and Consumer Power. The line is composed of 10.5km of 175mm² ACSR (Lynx) on steel towers, with an assigned rating for 50°C operation. The existing conductor has been reprofiled for operation at 75°C, and rating limiting joints upgraded. An increased rating will be assigned shortly. **The new rating will alleviate the projected overloads.**

The third 132kV circuit is from Pembroke 105 to Milford Haven mesh corner 9, teed to Golden Hill GT1. The CW route wood pole line from Golden Hill BSP GT1-side to Pembroke GSP 105 forms part of this circuit. The CW route has relatively high impedance, and so shares load poorly with the other two circuits. For an FCO of the first circuit, poor load share causes the second circuit to overload in summer under Gone Green. **A reinforcement plan is being developed to replace the CW route with a 132kV cable following the route of a previous 132kV gas filled cable. A contract has been placed to assess the feasibility of using the steel casing of the disused cable as a duct for the new cable, which would minimise excavation. This technique was previously used to establish the cable section of the second 132kV circuit. The new cable would increase the circuit rating and improve load share. Alternatively, means of controlling load share such as series reactors could be considered.**

### *33kV splits*

The Pembrokeshire 33kV system currently has five Grid Transformers at three sites running in parallel. There is no means of controlling load share between these GTs. In summer the lower rated GTs (at Golden Hill and Milford Haven) are well into their forced-cooling ratings even when the network is intact, and become overloaded under FCO. The large number of GTs in parallel runs the risk of cascade failure if one GT trips due to overloading or an unrelated fault. **Both GTs at Golden Hill BSP are due to be replaced with 60/90MVA units, which will alleviate the projected overloads. It is recommended that a second (40/60MVA) GT is established at Milford Haven BSP, and 33kV reinforcement carried out at as necessary to allow each of Golden Hill BSP, Haverfordwest BSP and Milford Haven BSP to be run independently or in smaller groups at 33kV. A 33kV circuit from Golden Hill BSP to Broadfield Primary Substation is currently being considered; this would allow Haverfordwest BSP to be run independently and may defer the second GT at Milford Haven.**

## Rassau GSP

### *Mid-Wales (Abergavenny) 66kV ring*

The 66kV network suffers very low volts (around 0.85 per unit) for various FCOs in winter. This network has already been identified as requiring reinforcement during ED1 due to projected demand growth. **It is recommended that reactive compensation of the order of 15MVAr capacitive is installed at Builth Wells, Brecon and/or Glasbury to support network voltage in winter; similar reinforcement is being considered as part of the ED1 plan. 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.**

The northern reaches of the 66kV network suffers from overvoltage (around 1.07 per unit) for various summer FCOs. This overvoltage is masked by the ±3MVAr SVC modelled at the Rhayader 11kV bar to resolve apparent issues in the 2016 model. **It is recommended that variable reactive compensation of the order of 3MVAr inductive is installed at Rhayader to control network voltage in summer.**

Llandrindod Wells and Rhayader Primary Substations operate in parallel at 11kV. For the FCO of the 66kV circuit between Builth Wells 1L5, Rhayader 1H0 and Llandrindod Wells T1, the entire 11kV network is supplied by Llandrindod Wells T2. Under these conditions Llandrindod Wells T2 is heavily overloaded in both summer and winter. **It is recommended that Llandrindod Wells T2 is replaced with a 12/24MVA CER unit.**

Under Gone Green and Slow Progression, Rhayader T1 is heavily overloaded in summer, even when the network is intact. **It is recommended that a scheme to replace Rhayader T1 with a 12/24MVA CER unit is developed and triggered as necessary by the growth of generation.**

### *Southern (Abergavenny/Panteg) 66kV ring*

Due to the growth of generation, both primary transformers at Usk are overloaded under FCO in summer. **It is recommended that both transformers are replaced with 12/24MVA CER units.**

Due to the growth of generation, the eastern half of the ring via Monmouth and Usk suffers from overvoltage to approximately 1.075 per unit in summer when Panteg 1L5 is open. **It is recommended that one or more of the following schemes are developed to prevent overvoltage:**

- **Automatic generator curtailment under outage conditions**
- **Reactive compensation**
- **Advanced Automatic Voltage Control (AVC) schemes such as directional or seasonal settings**

## Swansea North GSP

### *Carmarthenshire and West Wales*

#### 132kV

The 132kV B, C, CC, H, V, W, W23 and XY routes provide supplies to the Llanelli, Carmarthen, Rhos, Lampeter and Llanarth BSPs, Blaengwen wind farm and SP Energy Networks' network in the Aberystwyth area. Due to the growth of generation, all are heavily overloaded in summer under FCO. The B, C, CC, V, W and W23 routes have already been surveyed for 75°C operation; some remedial work will be required before an enhanced rating can be assigned. **If a 75°C rating can be assigned to these lines, it will alleviate the projected overloads. It is recommended that the H and XY routes are also reprofiled for 75°C operation, and the short cable from Swansea North to the XY-route is overlaid with a minimum of 630mm² Cu XLPE cable.**

#### BSPs and 33kV network

The 33kV system in this area is currently fed by seven GTs at five sites running in parallel. By 2020 it would be heavily dependent upon control engineer intervention to prevent overloading or cascade failure under FCO. **It is recommended that 33kV and GT reinforcement schemes are developed to allow the BSPs to be run independently or in smaller groups at 33kV. Rhos BSP is already supplied by two 132kV circuits, so would be suitable for a second GT. It is recognised that aggregating demand and generation at the 33kV bars of BSPs in these studies may exacerbate some contingencies; detailed studies taking into account the distribution of demand and generation are recommended.**

### *North of Swansea and Heads of the Valleys area*

This group comprises Ammanford, Ystradgynlais and Hirwaun BSPs, and two 132kV connected wind farms. It is normally supplied on two 132kV circuits from Swansea

North GSP. Two alternate 132kV circuits from Upper Boat GSP are available at Hirwaun BSP.

The two 132kV circuits have been identified as an area where ANM is required, to defer reinforcement where large amounts of future generation connections may trigger costly and time delaying reinforcement. WPD is currently accepting applications for alternative connections to these circuits as an ANM area. The area is scheduled to be active in November 2017. The results for this section do not take the proposed ANM system into account; it is expected that ANM will allow some reinforcement to be deferred.

### 132kV

Both 132kV circuits on the PP and C routes from Swansea North 205 and 505 toward Ammanford BSP, Ystradgynlais BSP, Hirwaun BSP and various wind farms are heavily overloaded under FCO. **It is recommended that the PP and C routes are surveyed to allow reprofiling for 75°C operation. Plans are currently being developed to overlay the two ~700m 132kV cables from Swansea North 205 and 505 to tower PP32 with new cables that match the rating of the PP route (likely to be 1000mm² Cu XLPE).**

### Hirwaun BSP

Both GTs at Hirwaun BSP are well into their forced-cooling ratings even when the network is intact, and become overloaded under FCO. This overloading is exacerbated by the 33kV parallel between Hirwaun BSP and Travellers Rest (Ystradgynlais BSP). The 33kV interconnector is already frequently opened to reflect 132kV running arrangements. Transformer reinforcement is a condition of accepted connection offers on the Hirwaun 33kV network. **It is recommended that a reinforcement scheme is developed to replace both GTs at Hirwaun BSP with 60/90MVA units, and then triggered by customer connections as necessary. Consideration should be given to operating Hirwaun and Travellers Rest independently at 33kV, or installing intertripping to automatically break the parallel between the BSPs when necessary.**

## Upper Boat GSP

This unconventional network is supplied by two 275/132 and two 275/33kV SGTs at Upper Boat. The 132kV and 33kV networks are remotely coupled by a small GT at Mountain Ash. The 132kV busbar at Upper Boat is arranged as a ring of 12 section breakers, without line or transformer-incomer breakers. Various Second Circuit Outage (SCO) conditions can cause the entire 33kV or 132kV network to be fed through the GT at Mountain Ash. The 33kV network has already been identified as requiring reinforcement during ED1 due to projected demand growth. **It is recommended to take this opportunity to rationalise this network and simplify its operation by establishing a second (40/60) GT at Mountain Ash and carrying out 33kV**

**reinforcement as necessary to allow Upper Boat and Mountain Ash to be run independently at 33kV while resolving the 33kV reinforcement requirement.**

In the unlikely event that a fault causes a mesh corner to open during a planned mesh corner outage, the ring will be split into two separate sections. These splits can cause parts of the 132kV network to be back-fed only via the 11kV bar at Upper Boat, causing overloading and unacceptable voltages. The network is currently dependent upon control engineer intervention to avoid these conditions. The growth of generation to 2020 exacerbates these problems. **Consideration should be given to operational measures or intertripping to mitigate this risk.**

## Uskmouth GSP

No specific reinforcement requirements were identified. These studies did highlight a poor load share on the Llantarnam 132/11kV transformers under intact running, whilst Uskmouth power station is generating, this is shown in Figure 17. In the 2020 Gone Green scenario, this poor load share does not cause the higher loaded GT2B to exceed its ONAN rating, but does result in accelerated ageing.

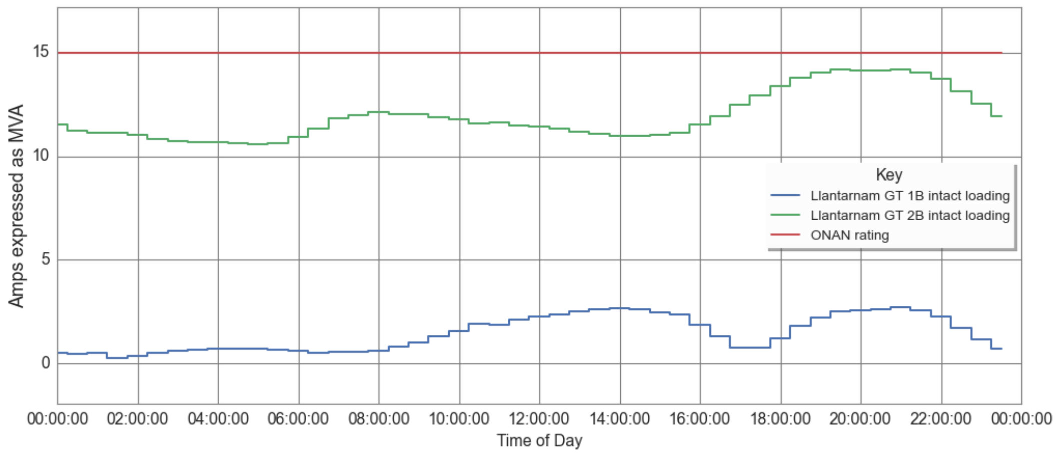



**Figure 17: Graph showing poor Llantarnam load share under intact network conditions during Gone Green summer representative day 2020**

# 2025

Between 2020 and 2025 the four scenarios move beyond the pipeline of Accepted-not-yet-Connected generation schemes and diverge considerably. The growth of EVs and HPs begins to trigger winter demand reinforcements, but the majority of reinforcements are still generation driven.

Under No Progression, the majority of reinforcements proposed for 2020 remain sufficient in 2025. In contrast, Gone Green triggers extensive reinforcement across the network, including a significant expansion in SGT capacity.

## Aberthaw and Cardiff East GSPs

Under Gone Green, an outage of the 275kV National Grid circuit between Pyle, Aberthaw and Cardiff East GSPs causes overloading on Cardiff East SGT3 in summer. Only those 275 and 400kV outages that included SGTs were modelled; this outage highlights the impact that transmission outages can have on interconnected distribution networks at 132kV. Transmission outages can change load share or cause through-flow at lower voltages, with the potential to cause overloading. Aberthaw and Cardiff East is the only GSP group normally operated interconnected in South Wales, but other pairs of GSPs are sometimes operated interconnected during SGT outages. **It is recommended that relevant transmission outages are incorporated into contingency analysis so that their impact on the South Wales Subtransmission network can be better understood.**

## Margam and Pyle GSPs

Under all scenarios except for No Progression, the further expansion of generation in the Llynfi Valley heavily overloads the 66kV circuits from Margam GSP to Llynfi despite the reinforcement proposed for 2020. Under Gone Green, the SGTs at Pyle and Primary transformers at Llynfi and Ogmore Vale are also overloaded. Under Consumer Power the far ends of the circuits suffer from overvoltage conditions. **It is recommended that, as far as is reasonably practical, new circuits into the Llynfi Valley are operated (or capable of operation) at 132kV. This should avoid the need to build several independent 66kV circuits along parallel routes. Establishing a BSP in the Llynfi Valley would allow the existing 66kV circuits from Margam to be deloaded.**

## Pembroke GSP

The Pembroke GSP area is currently accepting applications for alternative connections as an ANM area. The area is scheduled to be active in November 2017. The results for this section do not take the proposed ANM system into account.

Under Gone Green and Consumer Power, the expansion of generation in Pembrokeshire heavily overloads both SGTs at Pembroke and various downstream 132kV circuits under a FCO. GTs at Golden Hill, Haverfordwest and Milford Haven BSPs are also overloaded, despite reinforcement at Golden Hill and Milford Haven proposed for 2020. A small number of these overloads are also seen in the Slow Progression scenario. **A third SGT at Pembroke GSP and fourth 132kV circuit from Pembroke to the load centres of Pembrokeshire would alleviate the projected overloads. Depending on the distribution of new generation and demand within Pembrokeshire, the existing BSPs could be expanded or a new BSP could be established. If the CW route wood pole line from Pembroke GSP to Golden Hill BSP has been superseded by a new 132kV cable, it could be reutilised to supply a third GT at Golden Hill BSP.**

## Rassau GSP

Under all scenarios except for No Progression, demand growth marginally overloads both SGTs at Rassau under a FCO. **A third SGT at Rassau GSP would alleviate the projected overloads. It may be possible to defer reinforcement by transferring demand to Upper Boat or Uskmouth GSP, or using DSR to reduce HP and EV demand in the event of an SGT outage.**

### *Mid-Wales (Abergavenny) 66kV ring*

Under Gone Green and Slow Progression, generation growth overloads T1 at Rhayader Primary Substation. **Replacing T1 at Rhayader with a 20/40MVA CER unit would alleviate the projected overloads. Alternatively, a second 66kV circuit could be established from Llandrindod Wells to Rhayader, and a second transformer installed at Rhayader. This would also improve winter FCO voltage performance.**

Because of demand growth, the network suffers winter undervoltages on the 66kV ring for a small number of FCOs. **Careful design of the reactive compensation proposed for 2020 would likely alleviate these.**

### *Southern (Abergavenny/Panteg) 66kV ring*

Under all scenarios except for No Progression, generation growth causes overvoltage at several points around the eastern half of the ring via Monmouth and Usk under various FCOs. Under Gone Green and Consumer Power, it also causes overloading of the 66kV circuits themselves. **Reconductoring the 66kV circuits from Abergavenny BSP to Monmouth and Panteg BSP to Usk with 200mm² AAAC would alleviate both the overloads and the overvoltages.**

## Swansea North GSP

Under Gone Green and Consumer Power, all SGTs at Swansea North are heavily overloaded in summer under FCO. SGT7 and whichever of SGT4B or SGT3 is in service are also overloaded in winter under FCO. Under Gone Green, the overloads extend to intact conditions. **Swansea North is already a large GSP with five SGTs, ten outgoing circuits and three local GTs. Given the large geographic area supplied, it may be more appropriate to establish a new GSP to transfer load away instead of expanding Swansea North further. Suitable locations include:**

- **Ferryside, where National Grid's 400kV circuits to Pembroke cross the 132kV B-route approximately 6km south of Carmarthen BSP. Supplies to Carmarthenshire and West Wales could be transferred to the new GSP, deloading Swansea North GSP.**
- **Between Ystradgynlais and Hirwaun BSPs, where National Grid's 400kV circuits run alongside the 132kV D-route for approximately 17km. Supplies to the North of Swansea and Heads of the Valleys areas could be transferred to the new GSP, deloading Swansea North GSP. It may also be possible to transfer BSPs east of Hirwaun, deloading Upper Boat GSP.**

### *Local BSP*

All three 132/33kV GTs at Swansea North BSP are overloaded for the FCO of any other of the three. All three are 60/90MVA units, the largest standard size. **A fourth 60/90MVA GT at Swansea North would alleviate the overloads. Alternatively, load could be transferred to an adjacent BSP such as Swansea West, or a new BSP established.**

### *Carmarthenshire and West Wales*

#### 132kV

Despite the line reprofiling and cable overlay proposed for 2020, the growth of generation causes extensive overloads and unacceptable voltages under all scenarios except No Progression. **Establishing a GSP at Ferryside would mitigate many of these issues by segmenting and shortening circuits, but would not negate the need to rebuild 132kV circuits to accommodate much larger conductors, or establish new 132kV circuits.**

#### BSPs and 33kV network

The growth of generation overloads GTs at Carmarthen, Llanarth and Rhos BSPs under Gone Green and Consumer Power. **Replacing GTs at Carmarthen and Rhos would alleviate the overloads. Llanarth would prove more challenging to reinforce as a single-transformer BSP supplied from a single circuit 132kV wood pole line. It may be possible to interconnect the NN and CC routes and establish additional 132/33kV GTs at Lampeter, Llanarth or a new BSP.**

### *North of Swansea and Heads of the Valleys area*

#### 132kV

Despite the line reprofiling and cable overlay proposed for 2020, the growth of generation causes further overloads on the PP and C routes under Gone Green. Under all scenarios except No Progression, new overloads appear on the D route between Ystradgynlais BSP and Hirwaun BSP. **Reprofiling the existing 175mm² ACSR conductors to 75°C would alleviate the overload on the D-route. Further ratings increases on the PP and particularly C routes would be difficult without extensive rebuilding or high-temperature, low-sag conductors. Load transfers to**

**Upper Boat GSP would exacerbate the projected overload of the D and Y routes between Upper Boat and Mountain Ash. In light of the associated overloads at Swansea North GSP, establishing a new GSP in the vicinity of Ystradgynlais may prove more appropriate.**

## BSPs and 33kV network

The growth of generation causes intact overloads on Ammanford GT1 and FCO overloads on both 30/60MVA GTs at Ammanford BSP under Gone Green and Consumer Power. The peak summer loading under Gone Green 2025 on Ammanford GT1 under intact and FCO conditions are shown in Figure 18. **Under Consumer Power, it is likely that a cyclic rating could be assigned that alleviates the marginal overload. Under Gone Green, replacement with 60/90MVA units would alleviate the overload.**

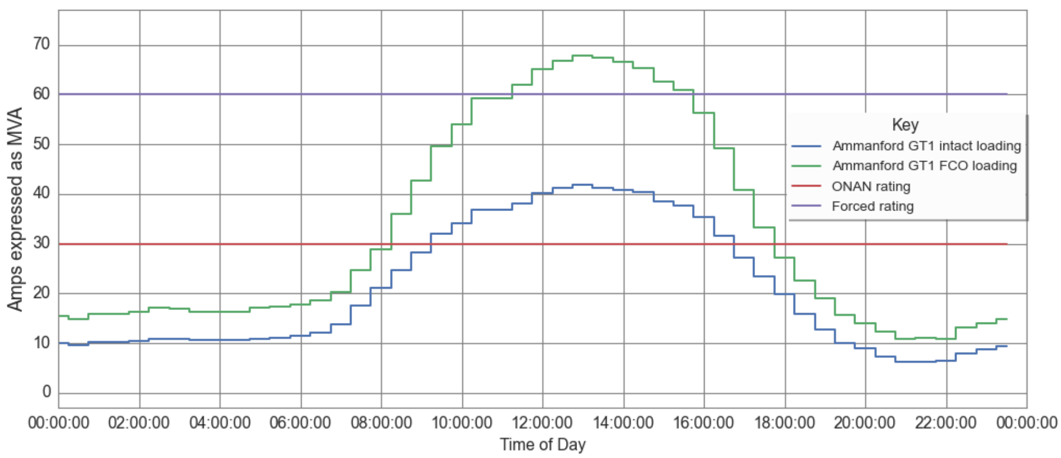



**Figure 18: Ammanford G1 intact and FCO peak summer flows under Gone Green 2025**

The growth of generation causes intact summer overloads at Hirwaun BSP on GT2 under Gone Green and FCO summer overloads on both GTs under all scenarios except No Progression, despite the proposed reinforcement by replacement with 60/90MVA units in 2020. This is shown in Figure 19. **Under Slow Progression and Consumer Power, it is likely that a cyclic rating could be assigned that alleviates the marginal overload. Under Gone Green, additional GTs at Hirwaun or additional capacity at another nearby BSP would be necessary.**

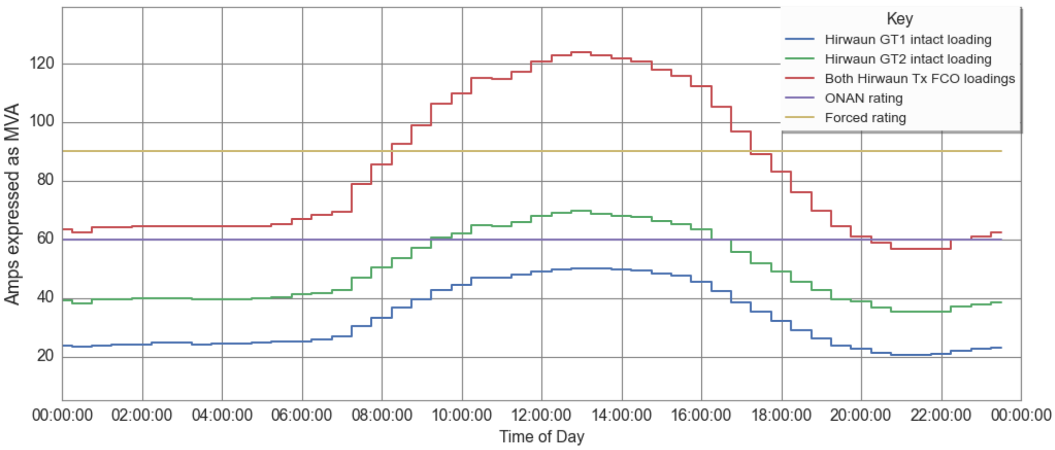



**Figure 19: Hirwaun BSP GT1 and GT2 peak summer intact and FCO loadings under Gone Green 2025**

## Upper Boat GSP

### 132kV

The growth of generation causes the 132kV circuit on the D and Y routes between Upper Boat mesh corner 10 and Mountain Ash BSP (GT1 side) to overload in summer under Gone Green. **Reprofiling the existing 175mm² ACSR conductors to 75°C would alleviate the overload.**

### BSPs

Each 22.5/45MVA GT at Dowlais BSP overloads by approximately 5% for the FCO of the other in summer under Consumer Power, the loadings for GT1 are shown in Figure 20. **Because of the solar-dominated cyclic loading of the transformers, it is likely that a cyclic rating could be assigned that alleviates the overload.**

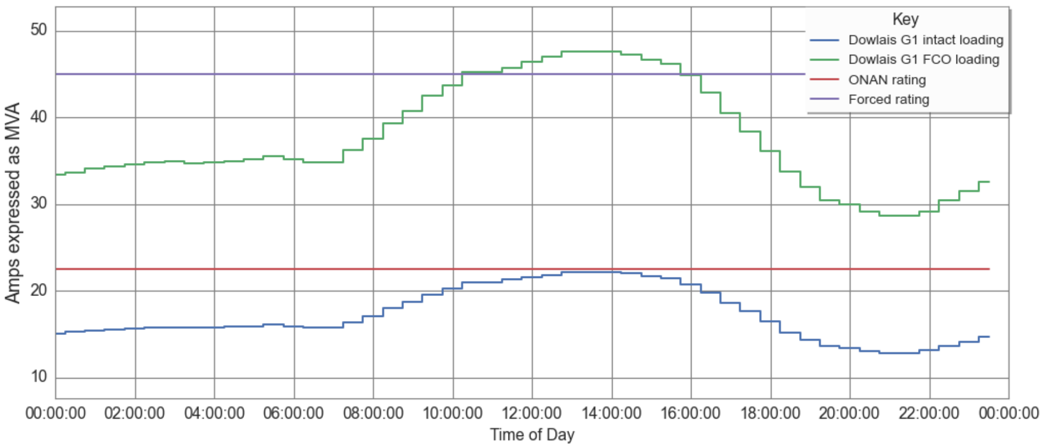



**Figure 20: Dowlais Intact and FCO loading under Summer Consumer Power 2025**

## Uskmouth GSP

### 132kV

The growth of generation causes summer overloading of SGT2A and (when in service) SGT4A at Uskmouth. To mitigate high fault levels, Uskmouth is currently operated with one SGT on hot-standby and the remaining two coupled through a series reactor. **Solidly coupling the 132kV bar at Uskmouth would alleviate the overloads, but trigger fault level reinforcement. The cost of this would have to be weighed against alternative reinforcements for the overloads.**

# 7 – The use of network management and automation to defer reinforcement

## Network Security

Our demand security standard (P2/6) is a licence condition and whilst it defines the contribution that DG makes to demand security of supply, there is no standard for the security of connection of DG to the network or its ability to export to the network. P2 is currently under review, but the focus of this review so far has been demand security. The only standard that sets security of supply standards for generation is the National Electricity Transmission System Security and Quality of Supply Standard (SQSS), which defines the maximum amount of generation that can be lost following a credible event. This is unlikely to affect the connection of DG on the WPD network in most cases.

### Underlying assumptions

Our networks shall, as a minimum:

1. Comply with ER P2/6 (Demand Security of Supply); and
2. Minimise the risk of equipment damage or danger and contain the potential loss of supply to demand customers for any credible FCO or SCO condition beyond the requirements of P2/6. Credible outages include busbar faults, faults during planned outages and, by operational rearrangement of the network or other control action a further fault following a fault.

## Active Network Management

One method of deferring reinforcement is Active Network Management. In the RIIO-ED1 business plan for 2015-2023, WPD committed to improve network performance, provide excellent customer service and connect more renewable generation to the network.

ANM was introduced as a method of enabling generator connections without the requirement for costly and time-delaying EHV and 132kV network reinforcement. With the potential transition from a DNO to more of a Distribution System Operator (DSO), the use of ANM will become more important to accommodate any more DG connections. WPD has identified the first ANM areas in South Wales will be at Pembroke GSP and part of Swansea North GSP, which will be active in November 2017.

However; there is a balance between the cost of conventional reinforcement and the impact of DG output curtailment through ANM or other automated responses. This is driven by two factors:

1. The cost of curtailment of the generator output, which is outside the scope of this document (at present this risk is carried by the generator as a trade-off for the lower cost of initial connection or faster connection time) ; and
2. The technical capabilities of the ANM scheme and the network it is managing.

## Technical capabilities of ANM

### *Network complexity*

Not all distribution networks are necessarily suitable for ANM. For instance, managing the flows on a radial network affected by a small number of generators is more straightforward than managing the flows on an interconnected network affected by a large number of geographically diverse generators which may even be connected to different Distribution Network Operators' networks.

### *Network monitoring and control*

Distribution networks are traditionally operated passively, and have limited facilities for remote monitoring and control. In particular, very few circuits are fitted with directional power flow monitoring. In addition to the installation of monitoring and control equipment at generator sites, monitoring equipment will need to be installed across the network to allow the ANM system to appropriately manage network behaviour.

### *Operating timeframe and network transient ratings*

For this study, it is assumed that an ANM scheme can operate in 3 minutes, from stimulus to resolution, taking into account:

1. Measurement
2. Communication of measurement
3. Calculation and determination of instructions
4. Communication of instructions
5. Generator ramp-down (and last-ditch trip)

3 minute transient ratings for both current and voltage can be determined for network components including:

1. Switchgear
2. Transformers
3. Overhead lines
4. Cables
5. Protection equipment

These ratings should take into account the current/voltage applied before and after the transient period, and the frequency of events that utilise the transient ratings. It is likely that in order to provide thermal headroom for transient ratings, the normal ratings of some network components will have to be reduced.

Where network behaviour would result in voltages or flows that exceed the 3 minute ratings of equipment, ANM will not be capable of managing the constraint by post-event curtailment. Instead pre-event curtailment or conventional reinforcement will be required. Pre-event curtailment of generator output is likely to reduce the energy output of generators much more than post-event curtailment.

# 8 – Next Steps

## Low regret reinforcement schemes

This study has identified some areas of the network which would require reinforcement under the forecasted demand and generation scenarios. It is recommended that all reinforcement requirements identified in the 2016 and 2020 studies are assessed in further detail to determine if a reinforcement scheme is required based on actual demand and generation uptake. The affected networks are:

1. The Mid-Wales (Abergavenny) 66kV ring;
2. The Grange-Llynfi and Pyle-Llynfi 66kV networks;
3. The Pembrokeshire 132kV and 33kV networks;
4. The Southern (Abergavenny/Panteg) 66kV ring;
5. The Carmarthenshire and West Wales 132kV and 33kV networks;
6. The North of Swansea and Heads of the Valleys area 132kV and 33kV networks; and
7. The Upper Boat/Mountain Ash 33kV network.

Given the further requirements identified in the 2025 studies, it is recommended that consideration is given to coordinating any future connections into the Llynfi valley. The feasibility of partially deloading Swansea North GSP onto a new GSP closer to new generation should also be assessed.

The studies have highlighted the extent to which the network is reliant upon the curtailment of generator output by means such as intertripping or ANM to provide cost-effective generator connections. It is recommended that:

1. The technical capabilities of these schemes and the networks they manage are investigated further so that their limitations can be better understood; and
2. Serious consideration is given to installing such schemes to enforce existing contractual constraints. This would help to minimise the risk of equipment damage or danger and contain the potential loss of supply to demand customers; and
3. The mechanism and impact of a common mode failure of the control system are assessed, to determine the effect it would have on the network.

## Further modelling

It is recommended that these studies are repeated in cooperation with National Grid, taking into account:

1. More appropriate models of the transmission network, taking into account the conditions being modelled;

2. Transmission network contingencies to assess their impact on WPD’s interconnected networks; and
3. The impact of these scenarios on National Grid’s own network. Where it is decided that it is more appropriate to curtail generator output than to reinforce National Grid’s network, the level and impact of this curtailment should be assessed.

WPD is currently working with National Grid to develop a Regional Development Programme that would carry out transmission/distribution interface studies. This is currently limited to a trial covering WPD’s South West licence area.

As our understanding of the behaviour of battery storage develops, it should be incorporated into future studies. Similarly, any data on the charging behaviour of large populations of fast-charging, high-capacity EVs with a broad range of users should be used to refine the EV charging profiles used in these studies.

It is intended that these studies and the underlying scenarios will be revisited on a two-yearly basis. The scope of future studies and related work will be broadened to include:

1. Fault level;
2. Protection;
3. Dynamics; and
4. Power quality.

# 9 – Definitions and references

## References

### External documents

#### *P2*

Engineering Recommendation P2 (*Security of Supply*), 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. P2 is currently under review by a working group of the Energy Networks Association (ENA).

#### *P18*

Engineering Recommendation P18 (*Complexity of 132kV Circuits*). Used throughout the studies to determine the complexity of the Subtransmission network.

#### *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*

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

### *Distributed generation and demand study -Technology growth scenarios to 2030, South Wales licence area 2017*

Report published by Regen SW to forecast the future changes in demand and generation in the South Wales WPD licence area.

### *ENA Active Network Management Good Practice Guide*

Report published by the ENA to give consistent guidance on the application of ANM schemes.

### *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.

## 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 132kV, 66kV and 33kV Medium Power Transformer 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 single line diagram; available from our website at: www.westernpower.co.uk/About-us/Our-Business/Our-network/Strategic-network-investment
5. South Wales Subtransmission network geographic map; available from our website at: www.westernpower.co.uk/About-us/Our-Business/Our-network/Strategic-network-investment

# General definitions, initialisms and acronyms

## Table of Units

| Term | Definition |
|---|---|
| kV | Kilo-volt, a unit of Voltage ($x10^3$) |
| LV | This refers to voltages up to, but not including, 1kV |
| HV | Voltages over 1kV up to, but not including, 22kV |
| EHV | Voltages over 20kV up to, but not including, 132kV |
| kW | Kilo-watt, a unit of Power ($x10^3$) |
| MW | Mega-watt, a unit of Active Power ($x10^6$) |
| GW | Giga-watt, 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 | Mega-watt-hour, a unit of energy ($x10^6$). Equivalent to a constant 1MW of Active Power delivered for an hour |
| MVAh | Mega-volt-ampere-hour, a unit of energy ($x10^6$). Equivalent to a constant 1MVA of Apparent Power delivered for an hour |
| MVArh | Mega-volt-ampere-reactive-hour, a unit of energy ($x10^6$). Equivalent to a constant 1MVAr of Reactive Power delivered for an hour |

## General Glossary

| Term | Acronym/ initialism | Definition |
|---|---|---|
| Active Network Management | ANM | The ENA Active Network Management Good Practice Guide 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.* |
| Automatic Voltage Control | AVC | 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. |
| Department for Business, Energy & Industrial Strategy | BEIS | 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) |
| Distribution Network Operator | DNO | A DNO is a holder of an electricity distribution licence. |
| Distribution System Operator | DSO | A role which may be established in the future whereby the DNO undertakes some of the roles of the System Operator at a regional level to balance supply and demand. |
| Electricity Supply | ESA | Each ESA represents a block of demand and |

| | | |
|---|---|---|
| Area | | generation as visible from the Subtransmission network. Each is one of:<br>• The geographical area supplied by a Bulk Supply Point (or group or part thereof) providing supplies at a voltage below 66kV;<br>• The geographical area supplied by a Primary Substation supplied at 66kV (or group or part thereof);<br>• A customer directly supplied at 132kV or 66kV (or by a dedicated BSP or 66kV Primary Substation); or<br>• A Future Wind Development Zone. |
| Energy Networks Association | ENA | Taken from the ENA website:<br>*…Represent the 'wire and pipes' transmission and distribution DNOs for gas and electricity…Influence regulation and the wider representation in UK, Ireland and the rest of Europe…* |
| Engineering Recommendation | ER | National standard engineering document published by the ENA |
| First Circuit Outage | FCO | P2/6 defines a First Circuit Outage as:<br>*…a fault or an arranged Circuit outage…*<br>Also referred to as N-1 in some contexts. |
| Office for Gas and Electricity Markets | Ofgem | Ofgem is responsible for regulating the gas and electricity markets in the UK to ensure customers' needs are protected. |
| National Grid | NGET | Transmission Network Operator in England and Wales |
| National Innovation Allowance | NIA | 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. |
| Remedial Action Scheme | RAS | 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 |
| Second Circuit Outage | SCO | P2/6 defines a Second Circuit Outage as:<br>*…a fault following an arranged Circuit outage.*<br>Also referred to as N-1-1 or N-2 in some contexts. |
| Sequential Control | SQC | Method of managing the network without the need for manual intervention from a Control Engineer. |
| Statement of Works | SoW | The process under which DNOs request that National Grid assesses the potential impact of the connection of DG upon the National Electricity Transmission System. |
| Thermal Generation | - | For the purposes of the issues and constraints referred to in the South Wales Statement of Works, the following generation technologies are considered 'Thermal Generation': |

| | | |
|---|---|---|
| | | • CHP Waste<br>• CHP Biomass<br>• CHP Thermal (e.g. gas driven)<br>• Waste<br>• Anaerobic Digestion (including CHP)<br>• Biomass Dedicated<br>• Sewage<br>• Landfill Gas<br>• OCGT & CCGT<br>• Diesel (Oil)<br>• Market Driven Storage (including batteries) |
| Time Of Use tariff | TOUT | National Grid's FES 2016 defines a Time Of Use Tariff as:<br>*A charging system that is established in order to incentivise residential consumers to alter their consumption behaviour, usually away from high power demand times.* |

## Distribution Network Topology Glossary

| **Term** | **Acronym/ initialism** | **Definition** |
|---|---|---|
| Bulk Supply Point | BSP | A substation comprising one or more Grid Transformers and associated switchgear |
| Distribution Substation | – | A substation comprising one or more Distribution Transformers and associated switchgear |
| Grid Supply Point | GSP | A substation comprising one or more Super Grid Transformers and associated switchgear |
| Primary Substation | – | A substation comprising one or more primary transformers and associated switchgear |
| Primary Distribution | – | The sections of an electrical distribution network which provide the interface between transmission and primary or Secondary Distribution.<br>In WPD's South Wales network the 33kV circuits and Primary Substations are considered to be Primary Distribution. |
| Subtransmission | – | The sections of an electrical distribution network which provide the interface between transmission and primary or Secondary Distribution.<br>In WPD's South Wales network the GSPs, 132kV circuits, 66kV circuits, BSPs and 66/11kV Primary Substations are considered to be Subtransmission. |
| Secondary Distribution | – | The final section of an electrical distribution network which provides the interface between Subtransmission or Primary Distribution and most final customers.<br>In WPD's South Wales network the 11kV, 6.6kV and LV circuits and the distribution substations are considered to be Secondary Distribution. |

## Distribution Network Equipment Glossary

| Term | Acronym/ initialism | Definition |
|---|---|---|
| All Aluminium Alloy Conductor | AAAC | Family of overhead line conductors, each of which is composed of strands of an aluminium alloy which combines mechanical strength with electrical conductivity.<br>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.<br>Each AAAC conductor is named after a species of tree. |
| Aluminium Conductor, Steel Reinforced | ACSR | Family of overhead line conductors, each of which combines steel strands for mechanical strength with aluminium strands for electrical conductivity.<br>ACSR is the conductor traditionally used for transmission and Subtransmission lines in Great Britain.<br>Each ACSR conductor is named after a species of mammal. |
| Cross Linked Poly-Ethylene | XLPE | 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. |
| Copper | Cu | – |
| Distribution Transformer | – | A transformer that steps voltage down from 11kV or 6.6kV to LV |
| Grid Transformer | GT | A transformer that steps voltage down from 132kV to 66kV, 33kV or 11kV. |
| Primary Transformer | – | A transformer that steps voltage down from 66 or 33kV to 11kV or 6.6kV |
| Static VAr Compensator | SVC | A device capable of providing fast-acting reactive power to the network |
| Super Grid Transformer | SGT | A transformer that steps voltage down from 400kV or 275kV to 132kV, 66kV or 33kV |

## Future Technologies Glossary

| Term | Acronym/ initialism | Definition |
|---|---|---|
| Anaerobic Digestion | AD | Generation process that utilises energy from waste products such to produce biogas for gas generator sets. |
| Combined Heat and Power | CHP | Method of utilising the excess heat energy as part of the electricity generation process to produce heat for local customers |

| | | |
|---|---|---|
| Demand Side Response | DSR | Ofgem led tariffs and schemes which incentivise customers to change their electricity usage habits |
| Distributed Generation | DG | Generation connected to a distribution network. Sometimes known as Embedded Generation. |
| Electric Vehicle | EV | A vehicle which uses electric motors as its method of propulsion |
| Heat Pump | HP (Also ASHP) | Extracts heat from surroundings which can then be used to produce hot water or space heating. Heat Pumps can be in different forms, Air Source Heat Pumps absorb heat from the outside air. |
| Photovoltaic | PV | Type of Distributed Generation which uses solar irradiance to generate electricity. |
| Short Term Operating Reserve | STOR | National Grid reserve contract to respond to periods of peak demand using fast response generator sets. |

# Seasons

For the derivation of demand and generation profiles, application of equipment ratings and similar purposes, the seasons of the year were assumed to be as follows in accordance with ST:SD8A/2:

- Spring: March and April;
- Summer: May to August;
- Autumn: September to November; and
- Winter: December to February.

# Transformer ratings

The ratings applied to Transformers were derived from ST:SD8C/1.

## 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. |

*Note: OFAF, OFAN and ONAF are collectively referred to as 'Forced' ratings.*

## 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:<br>• Maximum yearly average 20°C<br>• Maximum monthly average 30°C<br>• Absolute maximum 40°C<br>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 | $CMR_{ONAN}$ | $CMR_{Final}$ | $Cyclic_{Winter\ Final}$ |
|---|---|---|---|---|
| 15/30 | OFAF | 15 | 30 | 39 |
| 20/40 | OFAF | 20 | 40 | 52 |
| 22.5/45 | OFAF | 22.5 | 45 | 58 |
| 30/60 | OFAF | 30 | 60 | 78 |
| 37.5/75 | OFAF | 37.5 | 75 | 97 |
| 37.5/90 | OFAF | 37.5 | 90 | 117 |
| 40/60 | ONAF | 40 | 60 | 78 |
| 45/90 | OFAF | 45 | 90 | 117 |
| 60/90 | ONAF | 60 | 90 | 117 |

### Conventional 66/11kV primary transformers

| Nameplate rating [MVA] | Final Forced cooling method | $CMR_{ONAN}$ | $CMR_{Forced}$ | $Cyclic_{Winter\ Forced}$ |
|---|---|---|---|---|
| 6 | ONAN | 6 | 6 | 7.8 |
| 7.5 | ONAN | 7.5 | 7.5 | 9.75 |
| 7.5/10 | OFAF | 7.5 | 10 | 13 |
| 8 | ONAN | 8 | 8 | 10.4 |
| 10.5/21 | OFAF | 10.5 | 21 | 27.3 |
| 12/16 | OFAF | 12 | 16 | 20.8 |
| 15/21 | OFAF | 15 | 21 | 27.3 |

### CER-type 66/11kV 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 or autumn ratings are tabulated in ST:SD8C/1, so Summer ratings were applied to the Spring/Autumn 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:*

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

3. *$CMR_{Forced}$ is not a specified parameter of CER-type primary transformers, and so can vary between units. For these studies, typical values were assumed for all units.*
4. *No OFAF winter cyclic ratings are tabulated for CER-type primary transformers in ST:SD8C/1, so a notional winter forced Cyclic rating was approximated where required by:*

$$Cyclic_{Winter\ Forced} = CER_{Winter\ Forced} \frac{Cyclic_{Summer\ Forced}}{CER_{Summer\ Forced}}$$

# Appendix

## Program Summary

WPD South Wales Subtransmission network and Primary Distribution network are normally analysed using Siemens PSS/E power system software. The PSS/E load flow tool is designed to analyse a snapshot of the network and has the ability to run multi-level contingency analysis.

For this project a custom power system analysis program was written in Python 2.7 to analyse the multitude of conditions. The program uses PSS/E 33 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, N-1 and N-1-1 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 corrective actions such as: intertripping, curtailment and automated reconfiguration.

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;
- MW/MVAr flows at the interface between WPD and National Grid for the intact network; and
- Any studies where the program was unable to calculate valid results.

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

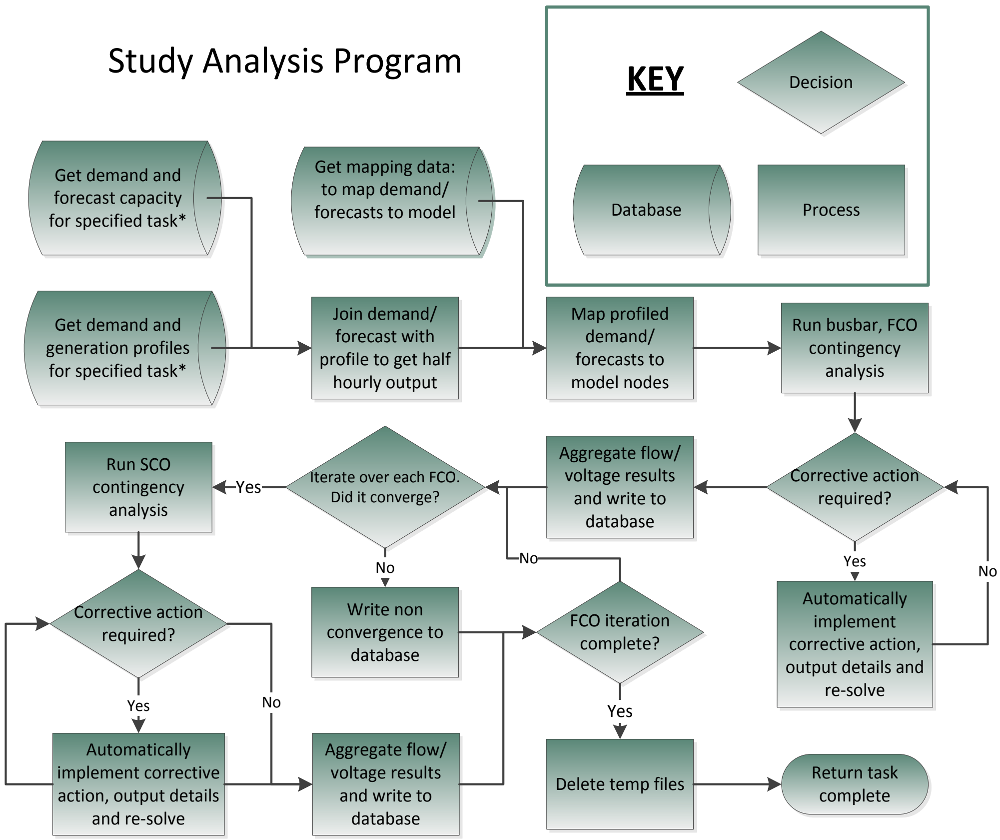
To significantly decrease the runtime per study, a distributed computing approach was used, where each study was broken into a half hour and representative day. This gave 144 unique tasks for the 3 representative days studied, which were stored on the centralised database and run on all available pool computers. Each active computer checks if any tasks are available from the server and runs a full intact, N-1 and N-1-1 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.

## Corrective Action

One of the main limitations found with previous versions of PSS/E was the inability to model any user defined Corrective Action which would operate post contingency. Consequently, the results were not always representative of how the network would react to specific contingencies; meaning extensive manual analysis was required. To remove this limitation from the South Wales strategic studies, the new PSS/E Advanced Contingency and Remedial Action Scheme (RAS) add-on module was utilised. This module takes user defined conditions and will perform an action dependant on the outcome of the condition. This module was utilised to implement manual or automated network reconfiguration such as:

- Intertripping
- Sequential Control (SQC)
- Overload schemes
- Replicate generator curtailment

The simplified processes followed by the analysis program is summarised in Figure 21.




*A task is a specific Year/scenario/representative day and half hour for a given study

**Figure 21: Simplified summary of analysis for a full N-1-1 analysis**

# 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. A limitation of the contingency analysis is the assumption that planned outages would always apply to the same zones as faults, rather than using isolators, links or jumpers to allow part of the zone to be brought back into service for the bulk of the duration of the outage. The following conditions were modelled:

1. The intact (normal running) network – 'BASE';
2. The network following each First Circuit Outage as defined by ER P2/6 -

3. The network following each Second Circuit Outage (i.e. combination of any two First Circuit Outages) as defined by ER P2/6; and
4. The network following each outage of a busbar that is not within a wider circuit protective zone – ‘BUSBAR’.

The contingency of each protective zone that includes at least one 66kV or 132kV node was assessed. This included all Super Grid Transformers (SGTs), GTs and 66/11kV primary transformers. In order to accurately represent the protective zones encompassing SGTs, some 400kV and 275kV contingencies were modelled. Transmission contingencies were not modelled exhaustively, as the static model of the transmission network would limit the accuracy of results.

## Modelling Limitations

1. A limitation of the program was that in a very small minority of studied conditions PSS/E was unable to converge (i.e. calculate valid results). 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. Flows on the WPD network can be influenced by the transmission network. Better results are obtained by having accurate data about the transmission network in South Wales together with a representation of the GB transmission network. For these studies a static representation of the South Wales transmission network, tailored to winter peak demand conditions, was used.
3. No model of battery storage behaviour was available, so their impact was excluded from the studies.
4. No data was available on the charging behaviour of large populations of fast-charging, high-capacity EVs with a broad range of users. 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.
5. Only load-flow studies have been carried out, assessing steady-state voltage and power flows. No fault level, power quality, protection or stability studies have been carried out.