Strategic Investment Options

Shaping Subtransmission

South West – July 2018

WESTERN POWER DISTRIBUTION

Serving the Midlands, South West and Wales

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1 – Executive Summary

Due to the abundance of renewable resources in the South West, and as part of a wider trend across Great Britain, WPD's South West licence area has experienced significant growth in the connection of Distributed Generation (DG). There is now around 2.3GW of generation connected within the area, with another 0.7GW accepted-not-yet-connected and a further 1.1GW offered-not-yet-accepted. This contrasts against an annual maximum demand of around 2.6GW and minimum demand of less than 0.8GW.

With the reduction in subsidies for generation, particularly for solar photovoltaic installations, there has been a slight reduction in the speed of DG deployment, however, demand for new connections is still high, with applications for energy storage connections becoming increasingly popular, with almost 300MW currently being considered by customers. There has also been a large reduction in the capacity waiting to connect on the network due to the proactive approaches to capacity management taken by WPD.

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

WPD's Distribution Future Energy Scenarios (DFES) work has highlighted the potential for as much as 5GW of renewables to be connected in the South West by 2030 and further recent studies with the system operator (GBSO) under a Regional Development Programme (RDP) has highlighted the benefits that increased visibility and control of DER could bring to the transmission network.

WPD has committed to the rolling out of Active Network Management (ANM) across all its licence areas by 2021 in order to manage the output of generators to reduce reinforcement requirements. With the majority of the South West network now under ANM, we will be implementing the recommendations from the RDP and providing the system operator (GBSO) with increased visibility and control of all new generation connections over 1MW in the South West using WPD systems. Customers will benefit from quicker connections and will have the opportunity to access additional revenue streams by participating in transmission constraint management markets.

The South West network is also headed towards a resurgence in demand growth. Local authorities' plans propose developments that would result in strong growth in domestic, industrial and commercial demand. Additionally, the potential for widespread electrification of heating and transport is likely to strongly affect demand growth in the longer term scenarios.

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

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

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

This methodology highlighted that although many onerous network conditions occur at the expected peaks; this is not always the case. In particular, some demand-driven constraints occur in the early evening (domestic demand dominated), while others occur around midday (industrial and commercial dominated). Many demand-driven constraints are most onerous during arranged outages, typically scheduled for spring, summer and autumn. Reactive power constraints are often met when the network is lightly loaded. WPD’s transition to become a Distribution System Operator (DSO) will require more analysis of this type to manage the network in real time.

The studies also identified the requirement for significant further reinforcement by 2020 including new transformers, overhead line reconductoring and cable overlays if the expected growth in demand and DG occurs. Looking beyond 2020 to 2025 and 2030, the scenarios diverge but further reinforcement is required under every scenario, including additional Super Grid Transformers (SGTs) and new GSPs in some scenarios. Recommendations are given to investigate particular reinforcement requirements in further detail.

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

WPD is now exploring the use of Demand Side Response (DSR) to manage network loadings and has sought expressions of interest from flexibility providers for a total of 14 zones in 2017 and a further 18 zones in 2018. By contracting with industrial and commercial customers who can adjust or shift their electricity consumption at key times, DSR can be used to defer demand-driven reinforcement, or maintain network compliance during reinforcement.

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

Significant analysis was undertaken within the RDP alongside National Grid to assess the impact of our scenarios on their network. We have also forecast demand and generation scenarios for networks outside our geographic area, but which are fed from our area and operated by other network companies. We will jointly publish an addendum later in the summer in conjunction with Scottish and Southern Energy Networks (SSE) on our findings from additional studies carried out in the area supplied by Axminster GSP.

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

2 – Objective of this Report

The overall aim of this report is to:

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

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

We have used the four background Energy Scenarios developed by National Grid (NGET) in their Future Energy Scenarios (FES) for 2017 as a framework to develop detailed scenarios for the growth of demand and DG in South West. South West 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 West Licence Area

Western Power Distribution (WPD) is the Distribution Network Operator for (DNO) the South West. The area covers approximately 14,400 square kilometres and extends from Bristol and Bath in the north east, along the peninsula to Land's End some 300km to the south west, and also includes the Isles of Scilly. The area is largely rural but includes the cities and towns of Bath, Bristol, Exeter, Plymouth, Taunton, Torquay and Weston-Super-Mare as well as many other costal resorts. The entire area serves approximately 1.4 million customers.

There is a wide spread of industrial and commercial activities within the area. Tourism and farming are also important to local communities. Business activity is generally concentrated on the population centres, in particular the north east of the area around Bristol and Bath. In contrast to the major cities we are also responsible for some of the most sparsely populated areas in the UK including Dartmoor and Exmoor National Parks.

Current Network

Western Power Distribution's South West licence area receives supplies from National Grid at 132kV at eleven Grid Supply Points (GSPs):

- Iron Acton – shared with WPD West Midlands and National Grid
- Seabank
- Melksham - shared with Scottish and Southern Electricity Networks' Central Southern England licence area
- Bridgwater
- Taunton
- Axminster - shared with Scottish and Southern Electricity Networks' Central Southern England licence area
- Exeter
- Abham
- Landulph
- Alverdiscott
- Indian Queens

These GSPs are in turn supplied from National Grid's interconnected 275kV and 400kV networks.

Ryeford and Chipping Sodbury Bulk Supply Points (BSPs) both form part of West Midlands licence area but are supplied from Iron Acton GSP in the South West. Whilst Ryeford and Chipping Sodbury BSPs have been included in these studies to assess the Super Grid Transformer (SGT) flows at Iron Acton, both were studied in depth as part of the West Midlands strategic studies. The report on these studies, *Shaping Subtransmission to 2030 West Midlands 2018*, is available from www.westernpower.co.uk/netstratwmid

Studies of Melksham GSP were limited to WPD's 132kV circuits and Bath BSP. Studies of Axminster GSP have been carried out in collaboration with SSE; results for this area will be jointly published with SSE in an addendum later in the summer.

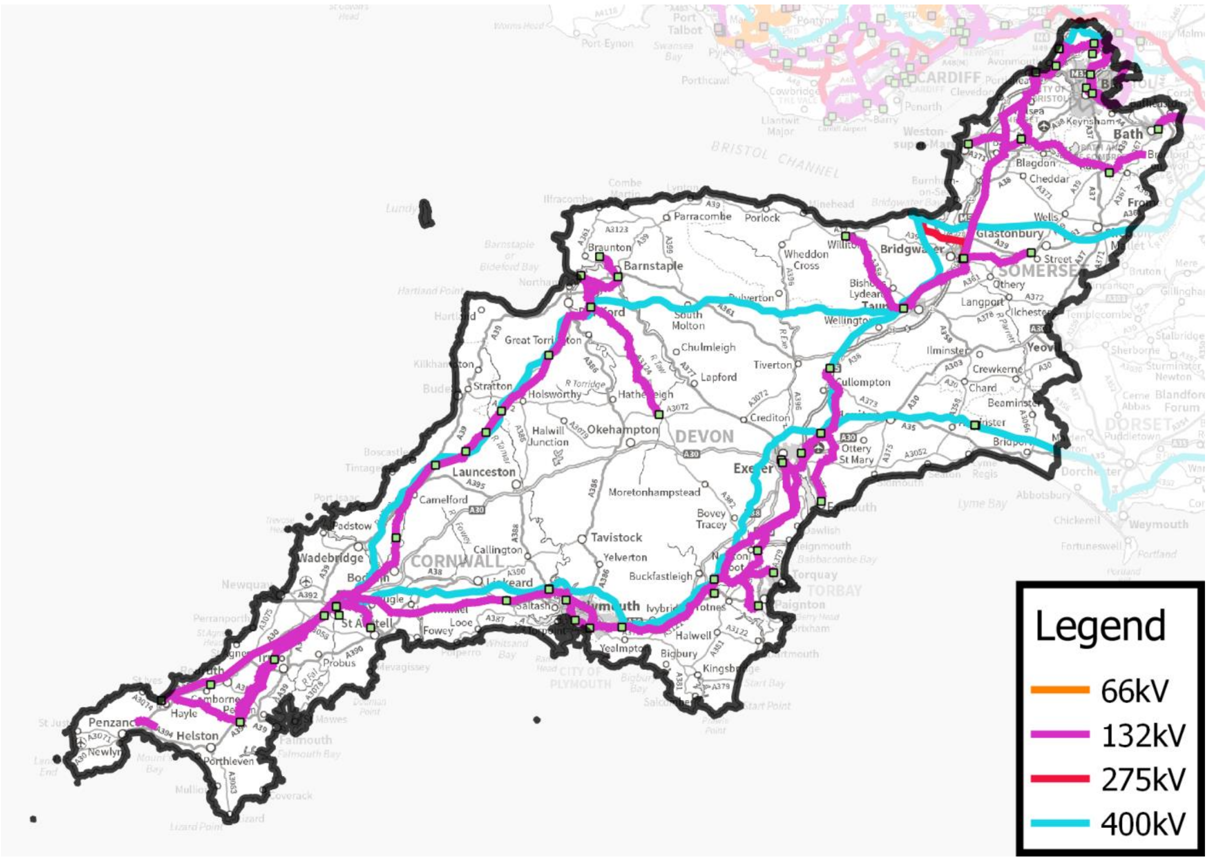

Figure 1: Network in South West showing 400kV, 275kV and 132kV networks. The South West licence area also includes the Isles of Scilly about 45km south west of the tip of Cornwall.

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 the South West (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	5,023,185	708,437	828	,450,451	-	-
HV (Incl. LV Substation)	215,538	1,539,965	1,631,779	2,915	1,301,457	236,438
HV Generation	372,278	76,165	104,845	389	369,000	10,588
LV Generation	63,626	1,370	1,827	796	64,499	5,879
Other LV HH	88,714	638,873	544,346	7,247	704,852	104,335
Other LV NHH (incl. Unmetered)	1,789,089	421,730	226,177	144,451	-	-
Total	**7,552,430**	**3,386,539**	**2,509,803**	**606,249**	**439,808**	**357,239**

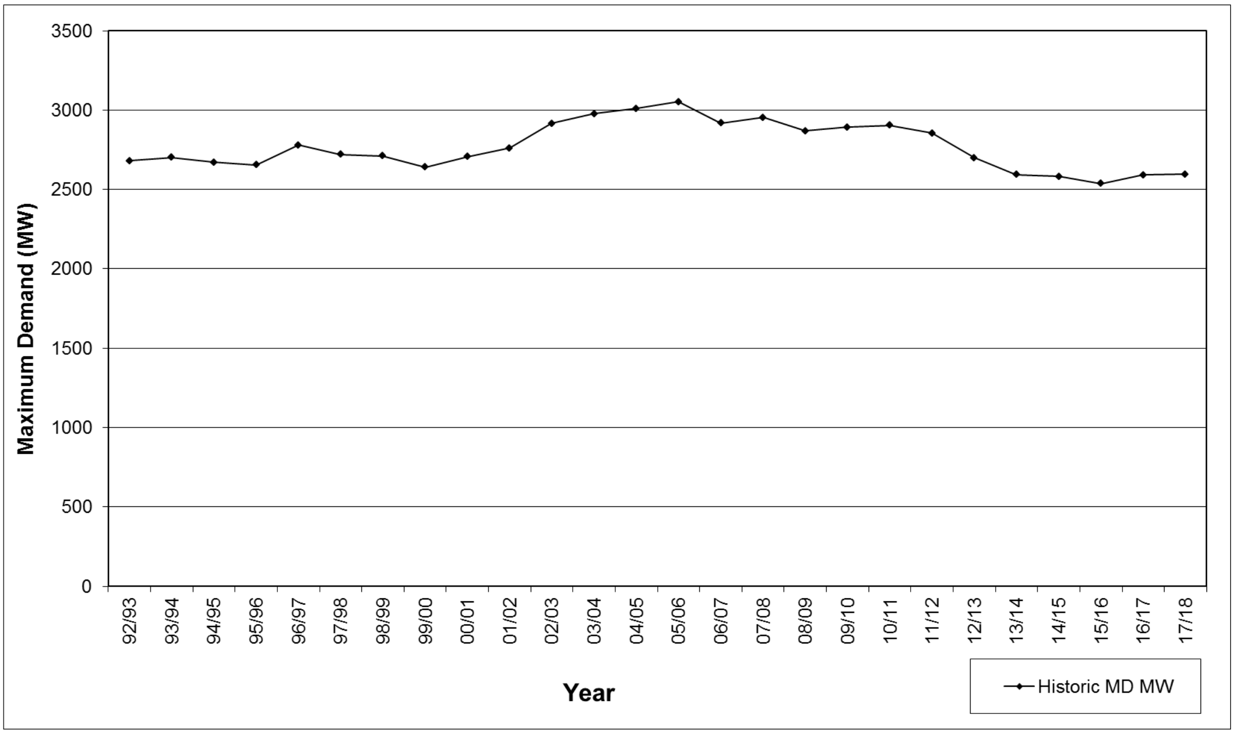

Figure 2: Historic system maximum demand in the South West

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.

DSR innovation projects

WPD has a number of recent and ongoing innovation projects to further explore this area:

- ENTIRE, focusing on the use of DSR to manage network loading. By contracting with industrial and commercial customers who can adjust or shift their electricity consumption at key times, DSR can be used to defer reinforcement, or maintain network compliance during reinforcement.
- SYNC - a project for industrial and commercial customers operated in parallel with the GBSO'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

Signposting

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

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

Growth in Distributed Generation

At privatisation, in 1990, there were virtually no generators connected to the distribution network. Those that existed were mainly embedded within customer-owned internal networks and primarily used for standby purposes. Since the early 1990s 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, battery-based energy storage systems have started to be connected to the distribution network. This has been driven by the falling cost of storage, reduced subsidies for renewable technologies, the growing value of flexibility in timing of import/export to the network and NGET seeking frequency support services.

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

Table 2: Connected, Accepted and Offered Distributed Generation in WPD South West at the end of June 2018

Generator type	Connected [MVA]	Accepted [MVA]	Offered [MVA]	Total [MVA]
Photovoltaic	1,300.3	101.2	553.0	1,954.4
Wind	309.4	8.3	22.0	339.7
Landfill Gas, Sewage Gas, Biogas and Waste Incineration	130.8	12.6	0.5	143.9
Combined Heat and Power (CHP)	34.1	7.7	9.7	51.4
Biomass and Energy Crops	1.0	0.7	1.8	3.4
Hydro, Tidal and Wave Power	35.1	-	-	35.1
Storage	19.9	190.3	298.8	509.0
All Other Generation	421.8	375.9	248.0	1,045.7
Total	**2,252.2**	**696.7**	**1,133.7**	**4,082.7**

Figure 3 shows the breakdown of generation export by technology type for the peak generation day in 2017. The generation is dominated by solar PV with wind and biogas also having a noticeable contribution.

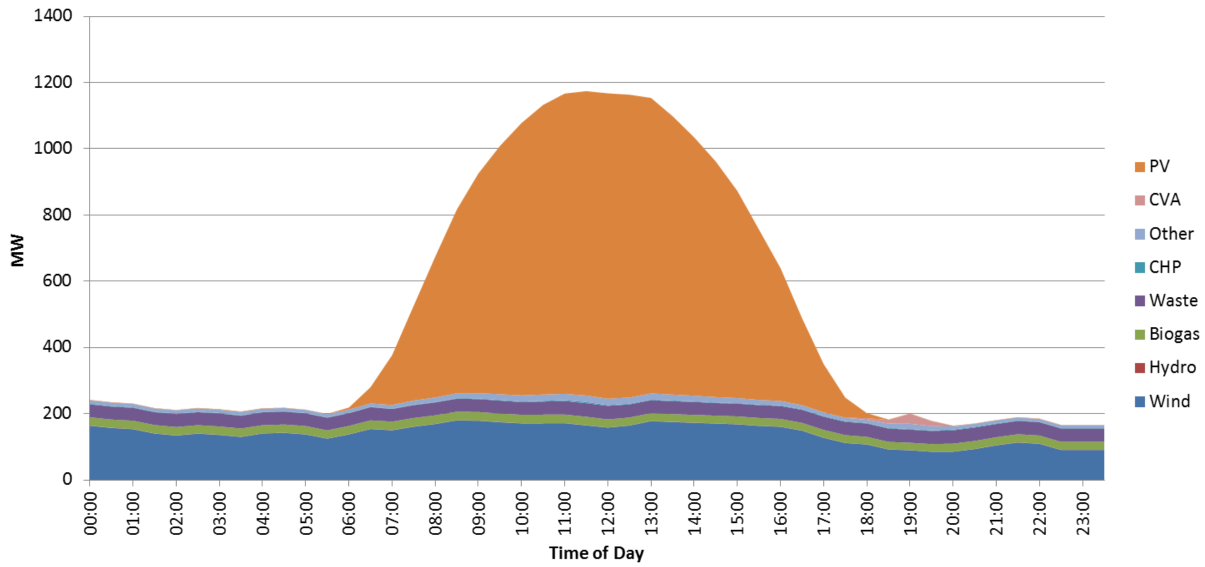

Figure 3: Breakdown of summer day generation mix by technology, MWh per half hour

Issues Resulting from the Growth of DG and Demand in the South West to 2017

Distribution Network Constraints

F-route

In March 2015, we announced that due to the significant growth in acceptances for DG connection to the network it had reach a point where critical circuits (F-route) at the boundary between the South West peninsula and the main interconnected transmission network had reached the limit of its capacity. This part of the 132kV network is due to be substantially reconfigured as part of the planned transmission works for the connection of Hinkley Point C.

In 2017 works were completed to reconfigure and split the F-route, with new 132kV switchgear and connections at Churchill BSP. This brought forward a small part of the works that will be needed to facilitate the transmission works associated with the connection of Hinkley Point C power station.

Fraddon BSP

As a result of large amounts of connected and committed generation at all voltage levels within the Cornwall region, reinforcement of the grid transformers (GTs) at Fraddon BSP and associated 132kV circuits was triggered.

The following equipment has recently been installed at Fraddon BSP:

- Two new grid transformers,
- Two new indoor 33kV boards,
- Four new 132kV cables,
- Five new 132kV circuit breakers, and
- A new 132kV termination tower.

The four 132kV overhead line circuits between Indian Queens GSP and Fraddon BSP have also been reprofiled, increasing their ratings without reconductoring.

The completion of these works has provided increased DG capacity at 33kV and below in mid-Cornwall.

J-route

As a result of large amounts of connected and committed generation at all voltage levels within the North Devon area, reinforcement of the 132kV J-route was triggered. The circuit from East Yelland disconnector 303 to Barnstaple GT2 has recently been recrimped to remove a ratings restriction. It is now planned to further increase the rating of this circuit by reprofiling it from 50°C to 75°C.

K-route

As a result of large amounts of connected and committed generation at all voltage levels in Cornwall and North Devon, reinforcement of the 132kV K-route was triggered. Both circuits of the K-route have recently been reprofiled from 50°C to 75°C to increase their ratings. Works are ongoing to overlay 132kV cables crossing the river Torridge to increase their ratings.

Pyworthy BSP

As a result of large amounts of connected and committed generation at 33kV and below in North Cornwall and North Devon, the reinforcement of Pyworthy BSP has been triggered. Works are ongoing to install:

- Two replacement grid transformers,
- A new indoor 33kV board, and
- Five new 132kV breakers.

When complete these works will provide increased DG capacity at 33kV and below in North Cornwall and North Devon.

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 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 connection onto distribution networks, it has been used to assess the cumulative impact of large numbers of smaller DG plant.

Two bulk statement of works applications have been made to NGET for the South West 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.
- Installation of a South West Operational Tripping Scheme to allow management by National Grid of the levels of generation under certain combinations of transmission outages when export flows from the South West are high. The timing of the installation of this scheme (1 September 2019) and associated enabling transmission works will result in some connections

being allowed before completion of those works (but with constraint during planned outages), while other connections need to wait for the transmission works to be completed.

- The enabling transmission works associated with the above are the hotwiring of the Hinkley Point – Melksham 1 and 2 circuits to increase their thermal rating (due by 31 October 2017), reconductoring of the Fleet – Lovedean OHL circuits to increase their capacity (due by 31 October 2020) and reconductoring the Bramley – Fleet OHL to increase capacity (due by 31 October 2021).
- Installation of an Active Network Management (ANM) at Alverdiscott GSP to manage flows within the rating of the SGTs at Alverdiscott.
- WPD and NGET have worked collaboratively to find an alternative solution to undertaking conventional transmission system reinforcement. This includes the use of analysis to identify instances where it is more beneficial to address transmission system constraints in the South West through NGET better management, visibility and control of Distributed Energy Resources (DER). We call this solution, 'Connect & Manage'. Facilitating this Connect & Manage approach will reduce costs and timescales for connection, therefore WPD is working with NGET to roll out the Connect & Manage arrangements throughout the South West, alongside existing arrangements for providing connections to the distribution network. For more information on Connect & Manage, please visit https://www.westernpower.co.uk/Connections/Generation/Connect-and-Manage.aspx

4 – Scenarios

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

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

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

Figure 4: National Grid’s Future Energy Scenarios[1]

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

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

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

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

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

Distributed Generation and Storage Forecasting

For each DG technology shown in Table 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 December 2017 with a high degree of accuracy;

2. Pipeline – WPD's database of Accepted-not-yet-Connected DG was combined with an assessment of the Department for Business, Energy & Industrial Strategy (BEIS) Renewable Energy Planning Database, current market conditions and recent policy changes, to give a forecast shared between all scenarios of what is expected to connect by 2018 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 West licence area under that scenario.

New Demand Technology Forecasting

The new demand technology forecasted consisted of electric vehicles, heat pumps and domestic air conditioning, all considered to be disruptive technologies with high growth potential. The forecasted data did not include a pipeline section; instead the forecasts were purely scenario based from 2017 to 2030.

Conventional Demand Forecasting

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

For the conventional demand forecasting, Regen used a variety of data sources to identify areas of domestic and non-domestic development out to 2030. A key input was the local development and infrastructure development plans published by local authorities. As part of the South West study, Regen and Western Power Distribution hosted a demand stakeholder engagement event to gain feedback from local authorities and other stakeholders. The forecast data did not include a pipeline; instead the forecasts were based on two different scenarios from 2017 to 2030. The two scenarios chosen were based wholly on economic prosperity, effectively grouping Consumer Power/Two Degrees and Slow Progression/Steady State into two scenarios.

Mapping the Forecasts to our Network

In order to map scenarios for demand and DG growth to the distribution network, the South West licence area was divided into 50 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 132kV; or
- A customer directly supplied at 132kV (or by a dedicated BSP).

The BSP and Primary Substation ESAs are shown geographically in Figure 5. It should be noted that ESA boundaries do not necessarily follow local authority or other administrative boundaries. Two additional ESAs were included in the studies to represent the Ryeford and Chipping Sodbury areas which are in WPD's West Midlands licence area but shares Iron Acton GSP with WPD South West. In addition, both of the WPD and SSE parts of Yeovil BSP have been included in the forecasts in order to comprehensively study Axminster GSP.

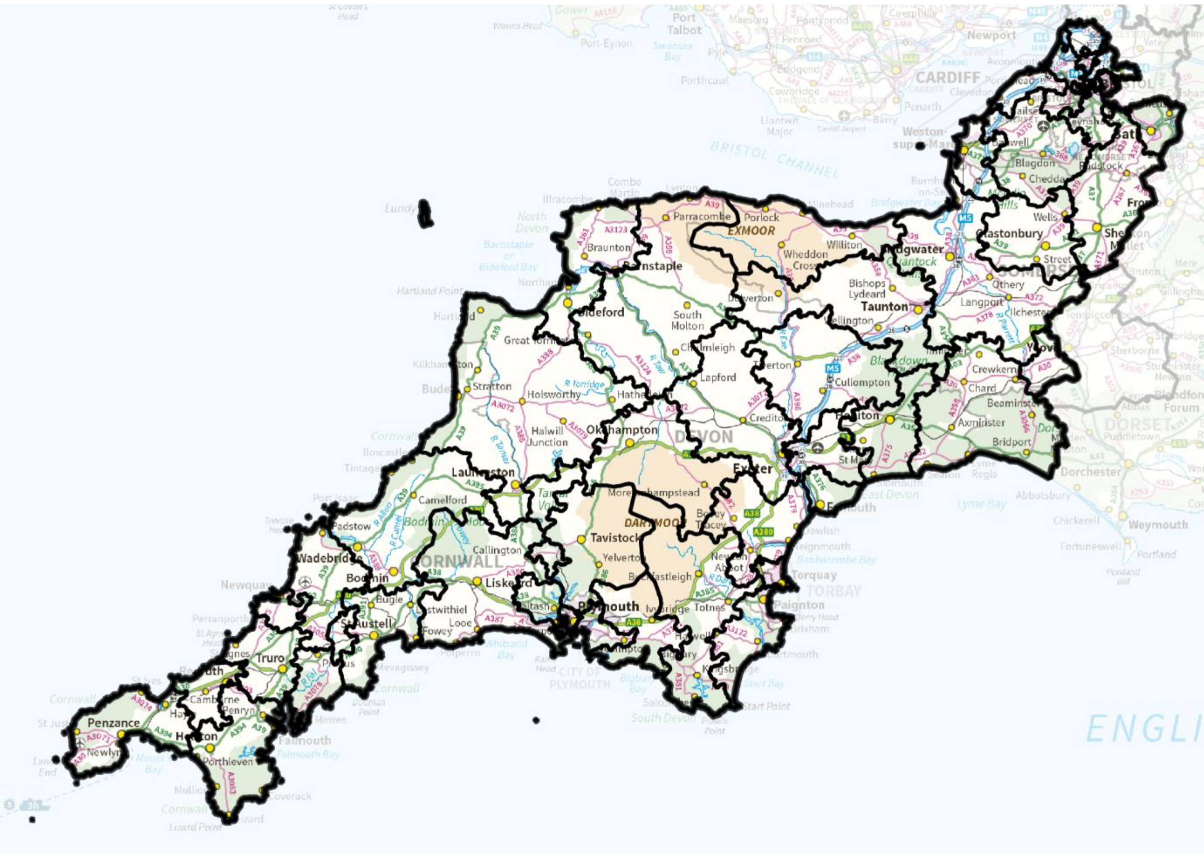

Figure 5: South West geographical ESAs. The South West licence area also includes the Isles of Scilly about 45km south west of the tip of Cornwall; they form part of the Hayle ESA.

Scenarios were developed for each ESA, taking into account historic and planned DG developments, local industry, population and natural resources. The results of the assessment are presented in each of the technology chapters in the Regen report and provide a projection of annual capacity deployment, by technology and scenario, for the period from 2017 to 2032. The complete Regen report, *Distribution Future Energy Scenarios -Technology growth scenarios to 2032, South West licence area 2018,* is available from our website at:

www.westernpower.co.uk/netstratswest

A summary of the DG forecasts is shown in Figure 6. From the baseline profiled capacity for a summer peak generation representative day of circa 1,780MW in May 2017. This grows to 5,358MW by 2032 under the most ambitious Two Degrees scenario. Growth estimates for the other scenarios, Consumer Power, Slow Progression and Steady State are lower overall. However, even under the lowest Steady State scenario, there is an expected growth pathway to 3,270MW of DG capacity by 2032. Figure 7 shows a half hourly profile of the generation export for the South West licence area for a summer peak generation representative day, which was used in the baseline studies. Figure 8 shows the same breakdown for a Two Degrees scenario in 2030.

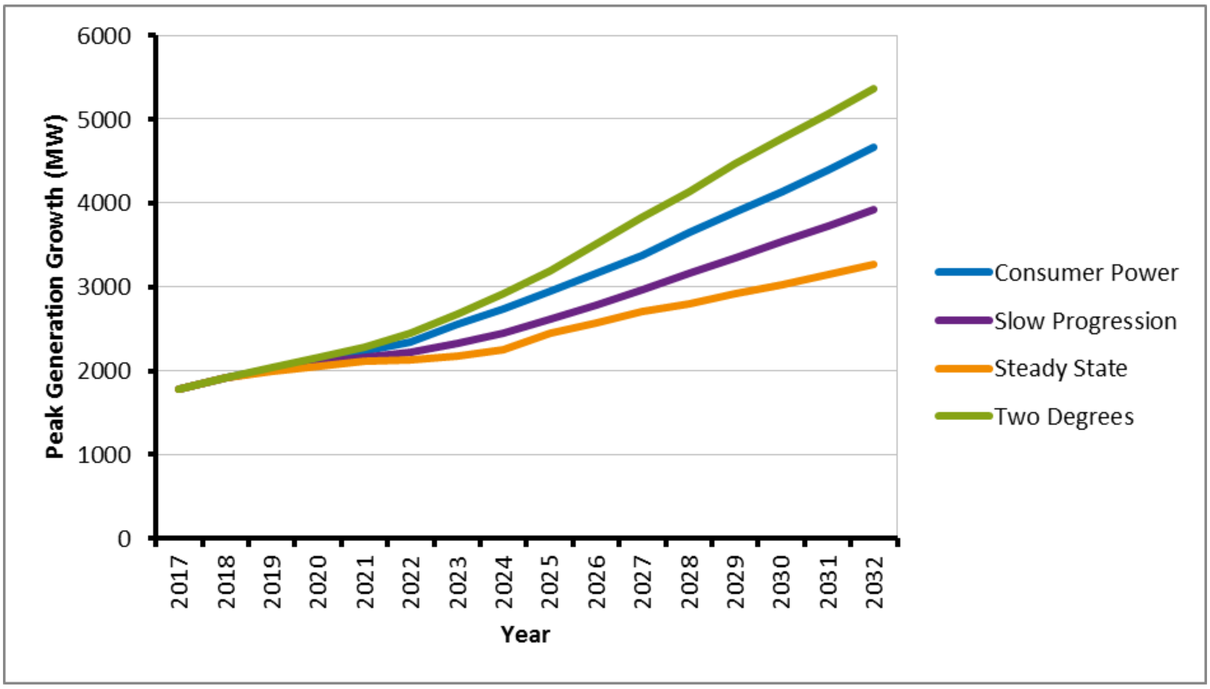

Figure 6: Total Distributed Generation capacity growth in WPD South West licence area from 2017 to 2032 under each scenario

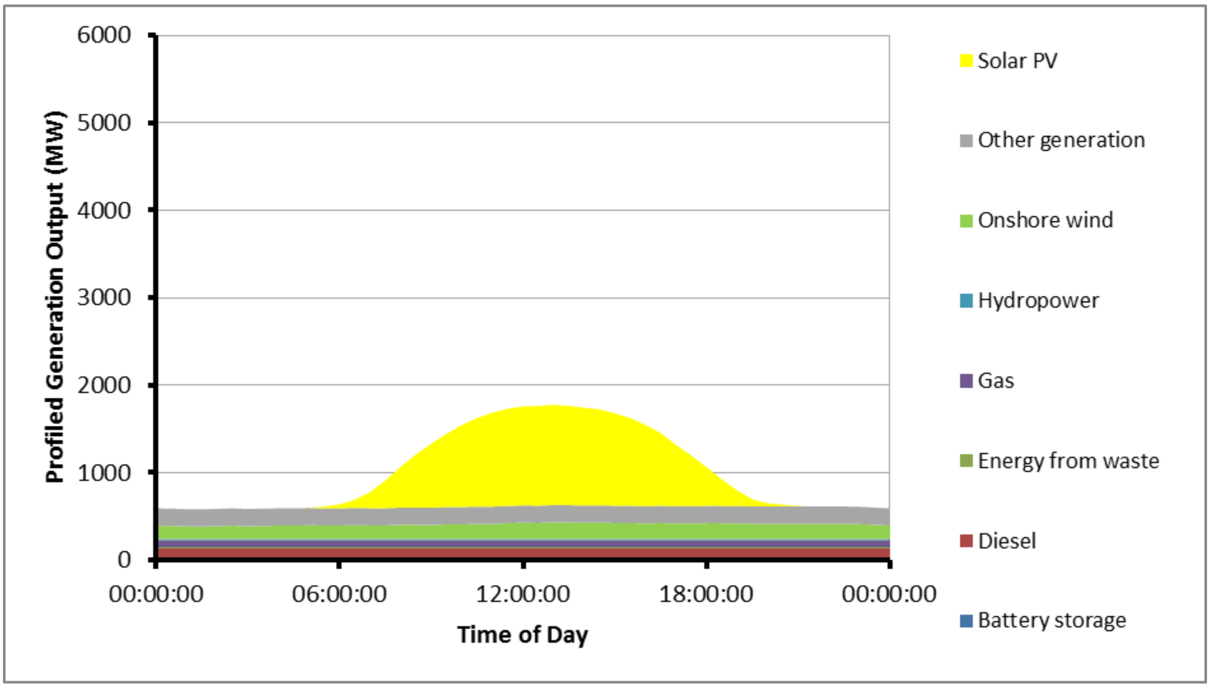

Figure 7: A half hourly profile of the South West licence area generation export for a summer peak generation representative day, as used in the baseline studies

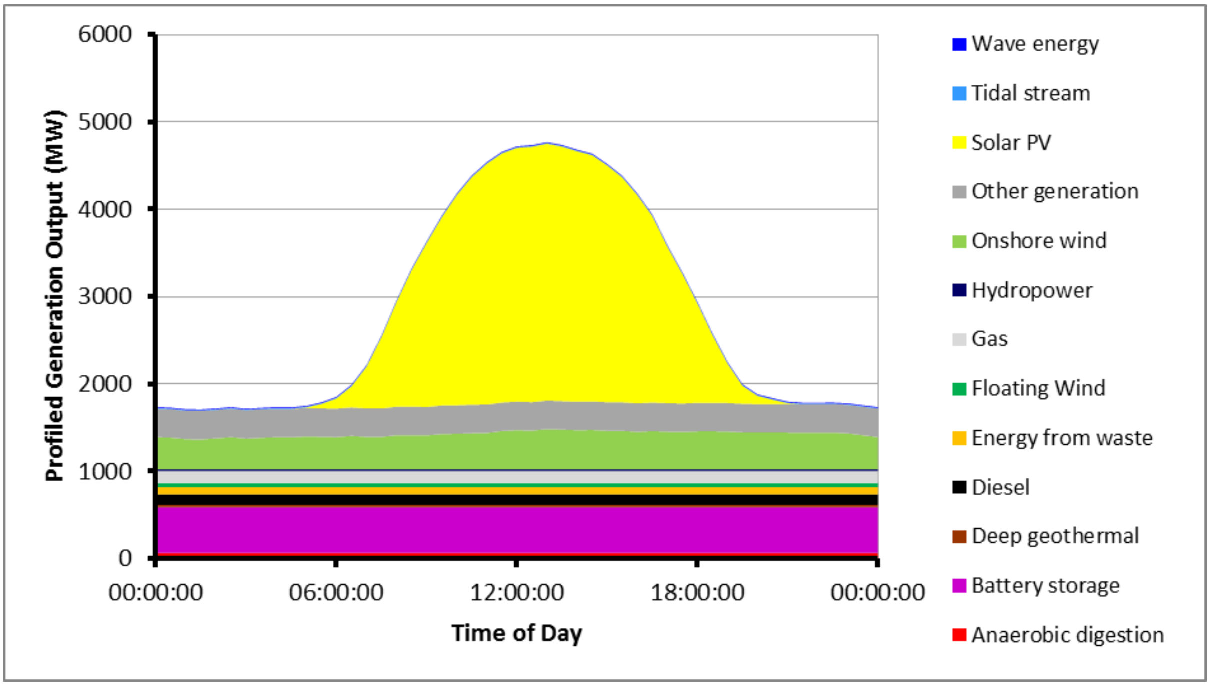

Figure 8: A half hourly profile of the South West licence area generation export for a summer peak generation representative day, under a Two Degrees scenario in 2030

A summary of peak demand growth across the South West licence area is shown in Figure 9. The demand growth is based on the growth of EVs, HPs and conventional demand growth. The total demand in 2017 was approximately 2.8GW. Demand is expected to increase to as much as 5.6GW by 2032. Figure 10 shows a half hourly demand profile for the South West licence area for a winter peak demand representative day, which was used in the baseline studies and includes any forecasted demand growth until the end of 2017. Figure 11 shows the same breakdown for a Two Degrees scenario in 2030.

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

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

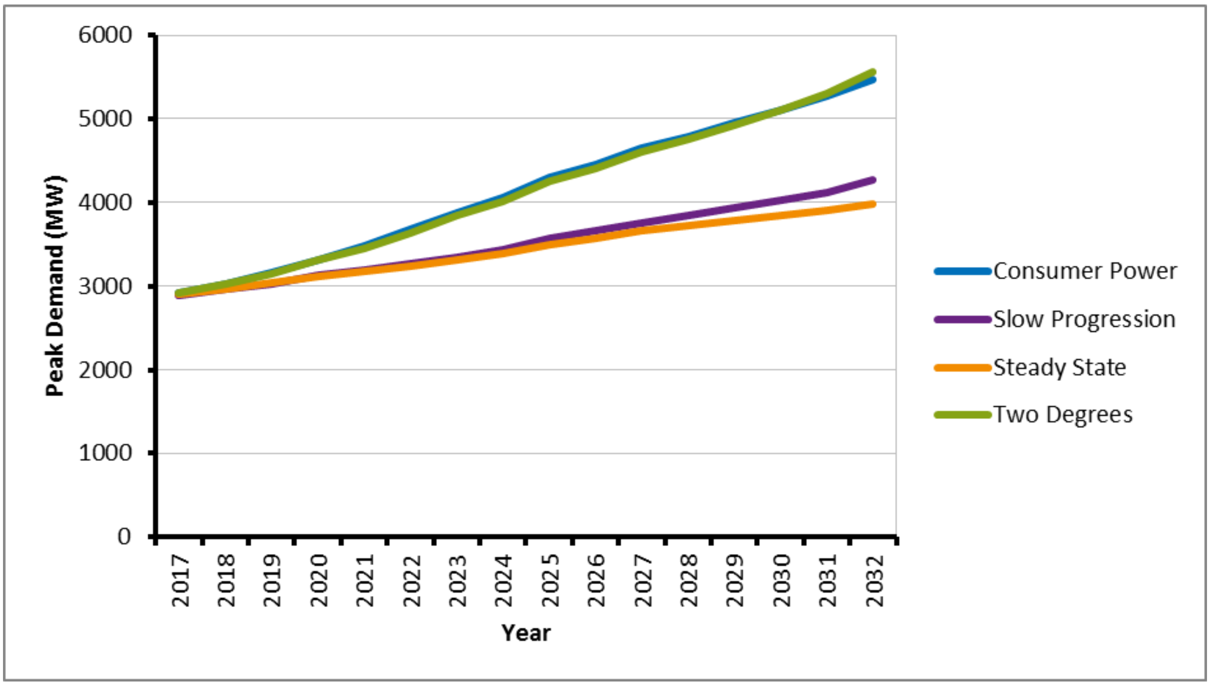

Figure 9: Total peak demand growth in WPD South West licence area from 2017 to 2032 under each scenario

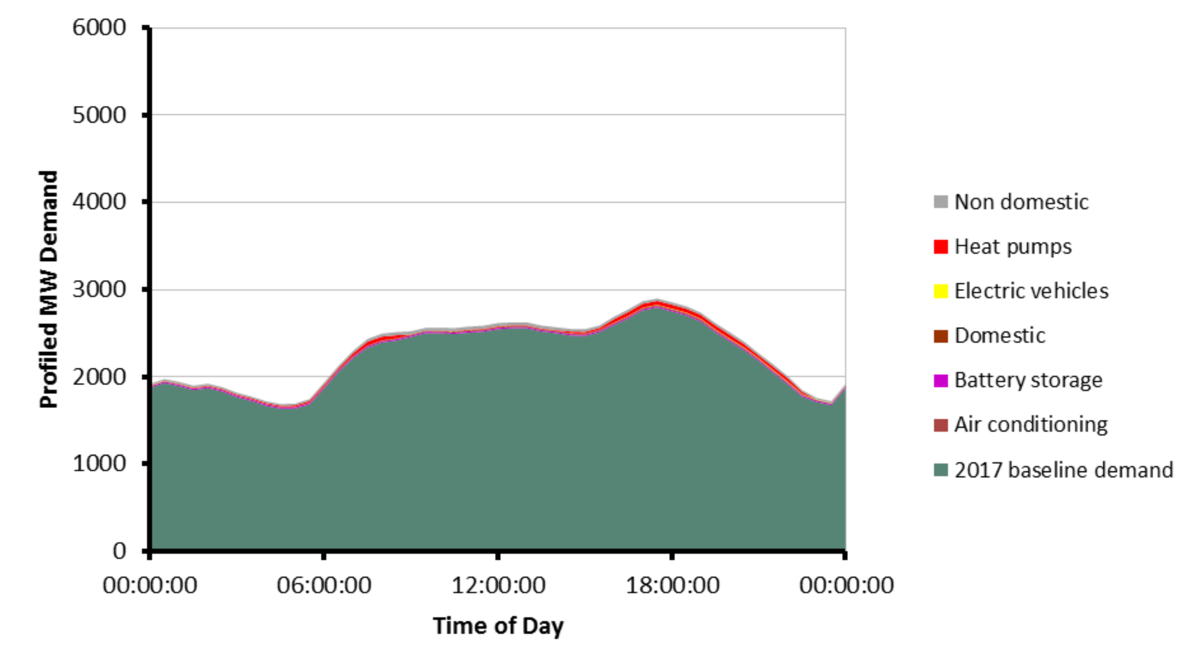

Figure 10: A half hourly demand profile of the South West licence area for a winter peak demand representative day, as used in the baseline studies

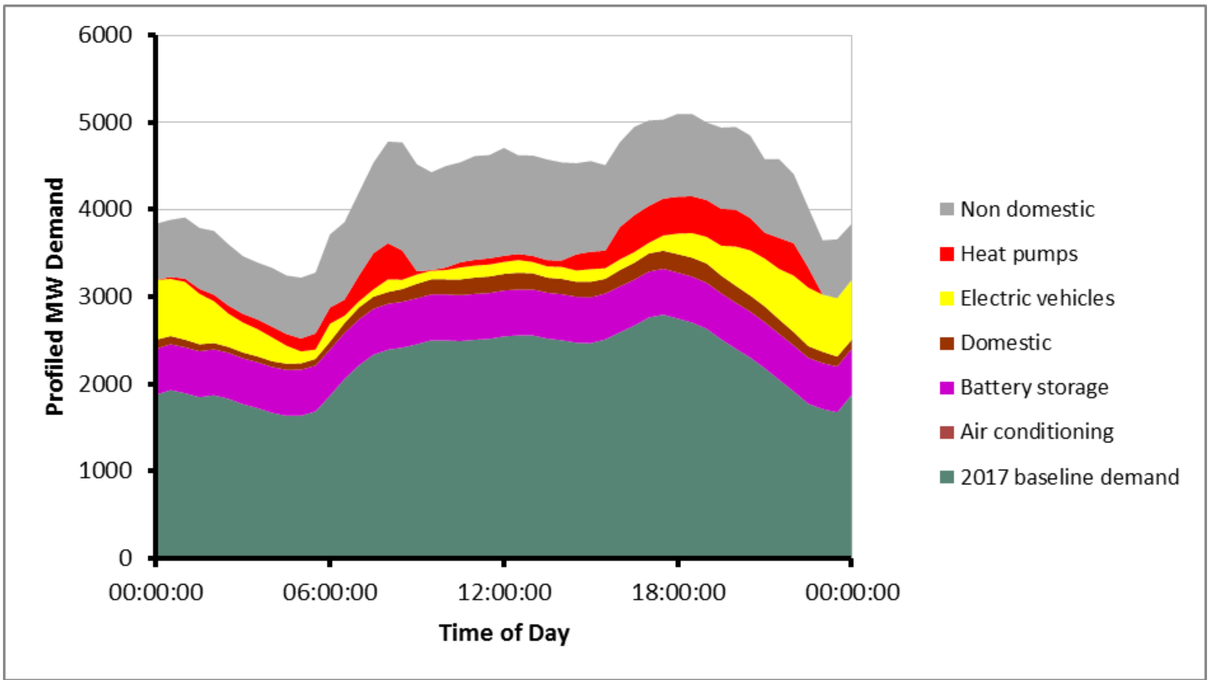

Figure 11: A half hourly demand profile of the South West licence area for a winter peak demand representative day under a Two Degrees scenario in 2030

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

5 – Network Analysis Technique and Inputs

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

Traditionally distribution networks are assessed using 'edge-case' modelling, where only the network condition which is deemed to be most onerous is analysed. As the installed capacity and behaviour of demand, generation and storage is rapidly changing, it has become difficult to predict what network condition will be most onerous. A detailed overview of modelling methodology can be found in the appendix. For this project, a broader approach was taken. The network was assessed in detail for each of the four scenarios, for 2017, 2020, and 2025.

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

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

Demand, generation and storage were aggregated by ESA to be modelled at the appropriate node(s) to assess the impact on the Subtransmission network. For BSPs this was the 33kV or 11kV busbar.

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

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

Demand, Generation and Storage Profiles

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

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

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

Some profiles were derived from measurements taken on the South West network. Date-stamped readings were reconciled to the representative days using the following seasons definition (from WPD's overhead line ratings policy, ST:SD8A/2):

- **Summer:** May-August,
- **Winter:** December-February, and

- **Spring/Autumn:** March-April and September-November.

Demand Profiles

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

Underlying Demand

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

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

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

Each BSP type was assessed for each representative day to produce twelve real and reactive power demand profiles which could be applied to the network model. Figure 12 through Figure 19 show the normalised real and reactive power demand profiles created. Because these curves are normalised, as described below in *Demand Profiles – Methodology*, a multiplying factor can be applied to them to represent the actual demand at a particular BSP.

Demand Profiles – Methodology

The BSP demand profiles are based on measured data from 2017. For each of the BSP categories (urban, rural and mixed), three BSP's from the South West licenced area were selected to form the data sample. The annual measured MW and MVAr demand data for the three BSP's, forming the sample, was aggregated by each half hourly reading. Table 4 shows the BSPs that were selected to produce the demand profiles.

Table 4: BSP category demand samples

BSP Category	BSPs in sample
Urban	- Avonmouth - Bath (Dolemeads) - Portishead
Rural	- Barnstaple - Tiverton - Woodcote
Mixed	- Exeter City - Hayle - Plympton

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

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

- **Winter Peak Demand day:** The 24 hour demand data (48 half hourly average readings) was selected from the annual demand data for the day where the peak demand occurred. Only data from the months December, January and February was considered. These months are defined as winter in WPD's overhead line ratings policy, ST:SD8A/2.
- **Summer Peak Demand day:** The 24 hour demand data was selected from the annual demand data for the day where peak demand occurred. Only data from the months May, June, July and August was considered. These months are defined as summer in WPD's overhead line ratings policy, ST:SD8A/2.
- **Summer Peak Generation day:** The 24 hour demand data was selected from the annual demand data for the day where the smallest peak demand occurred. Only data from the months May, June, July and August was considered. These months are defined as summer in WPD's overhead line ratings policy, ST:SD8A/2.
- **Autumn Peak Demand day:** The 24 hour demand data was selected from the annual demand data for the day where peak demand occurred. Only data from the months September, October and November was considered. These months are defined as autumn in WPD's overhead line ratings policy, ST:SD8A/2.

Table 5: Dates selected for underlying demand representative days

Representative Day	Dates
Winter Peak Demand	Urban – 26th January 2017 Rural – 6th February 2018 Mixed – 6th February 2017
Summer Peak Demand	Urban – 5th June 2017 Rural – 5th June 2017 Mixed – 17th May 2017
Summer Peak Generation	Urban – 2nd July 2017 Rural – 17th June 2017 Mixed – 8th July 2017
Autumn Peak Demand	Urban – 29th November 2017 Rural – 30th November 2017 Mixed – 30th November 2017

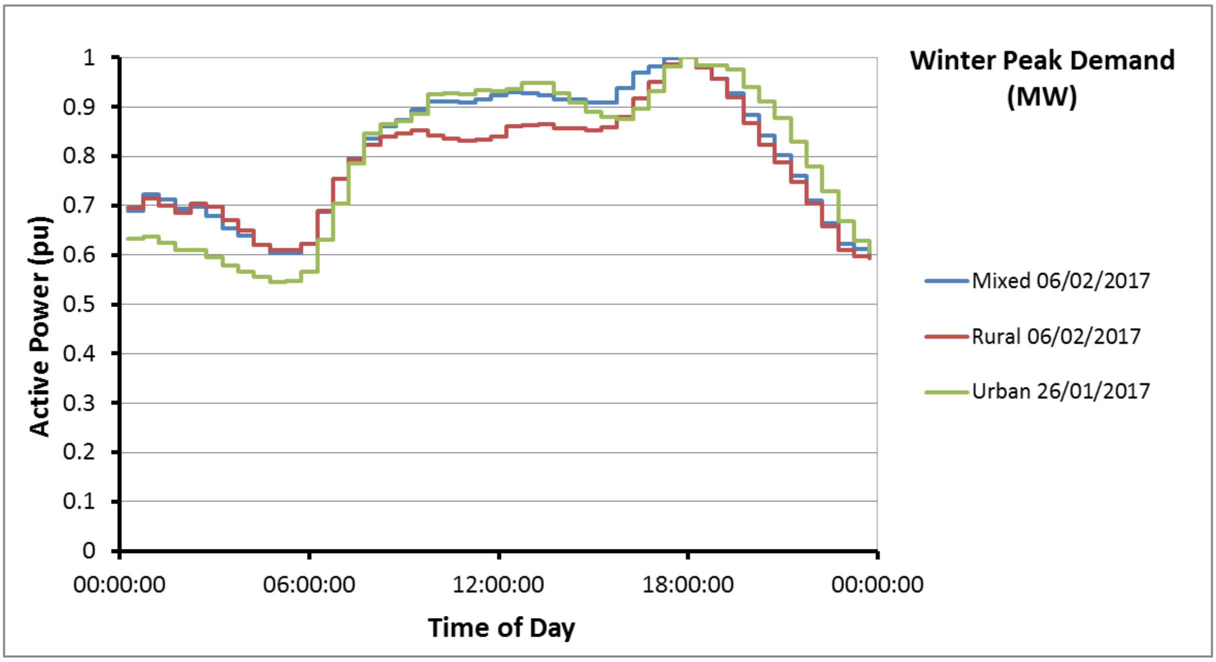

Figure 12: Real power underlying demand profiles for the Winter Peak Demand day, normalised over the peak real power annual demand

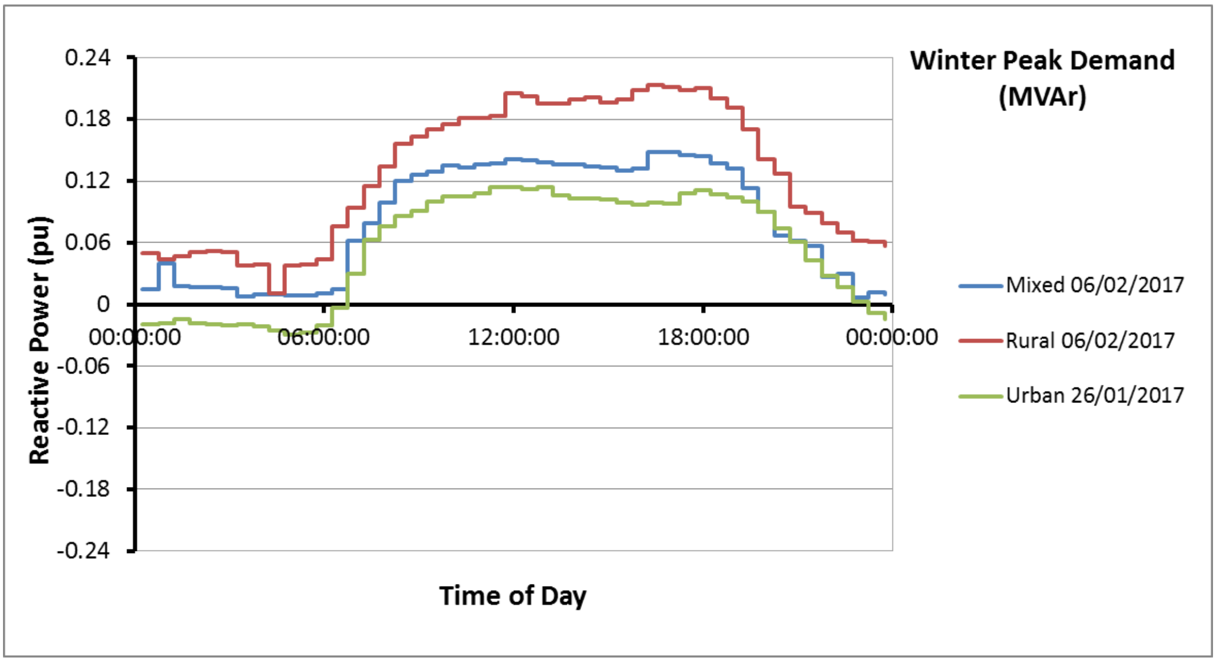

Figure 13: Reactive power underlying demand profiles for the Winter Peak Demand day, normalised over the peak real power annual demand (note: reactive power scale is not the same as the active power scale)

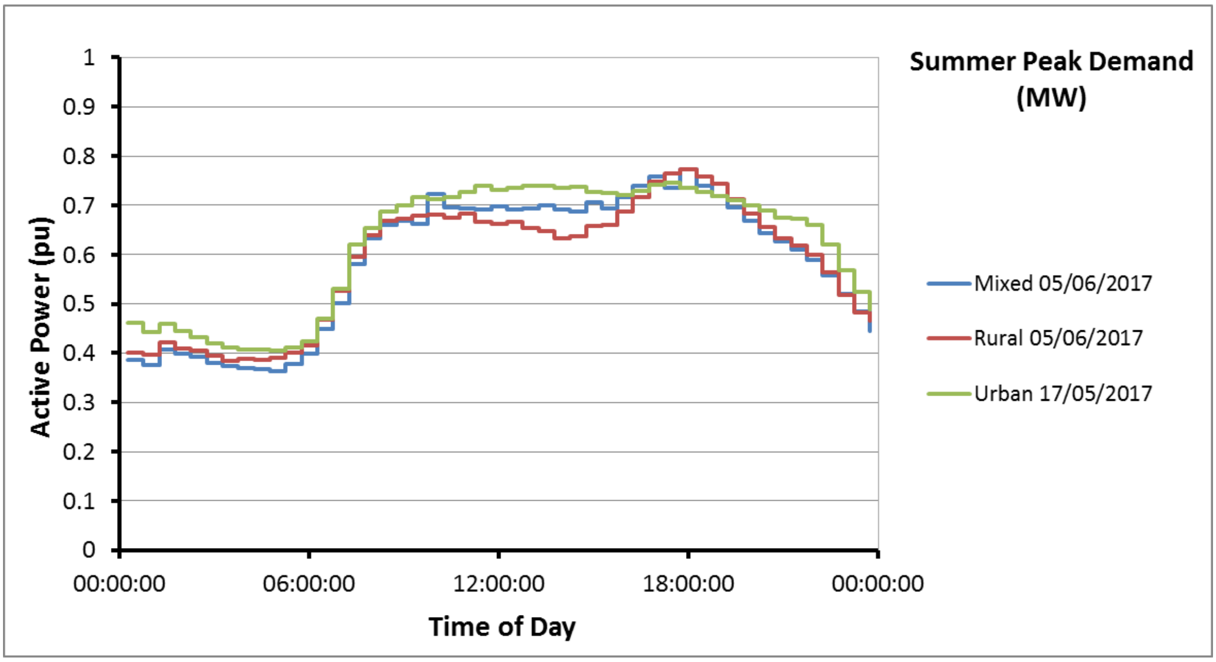

Figure 14: Real power underlying demand profiles for the Summer Peak Demand day, normalised over the peak real power annual demand

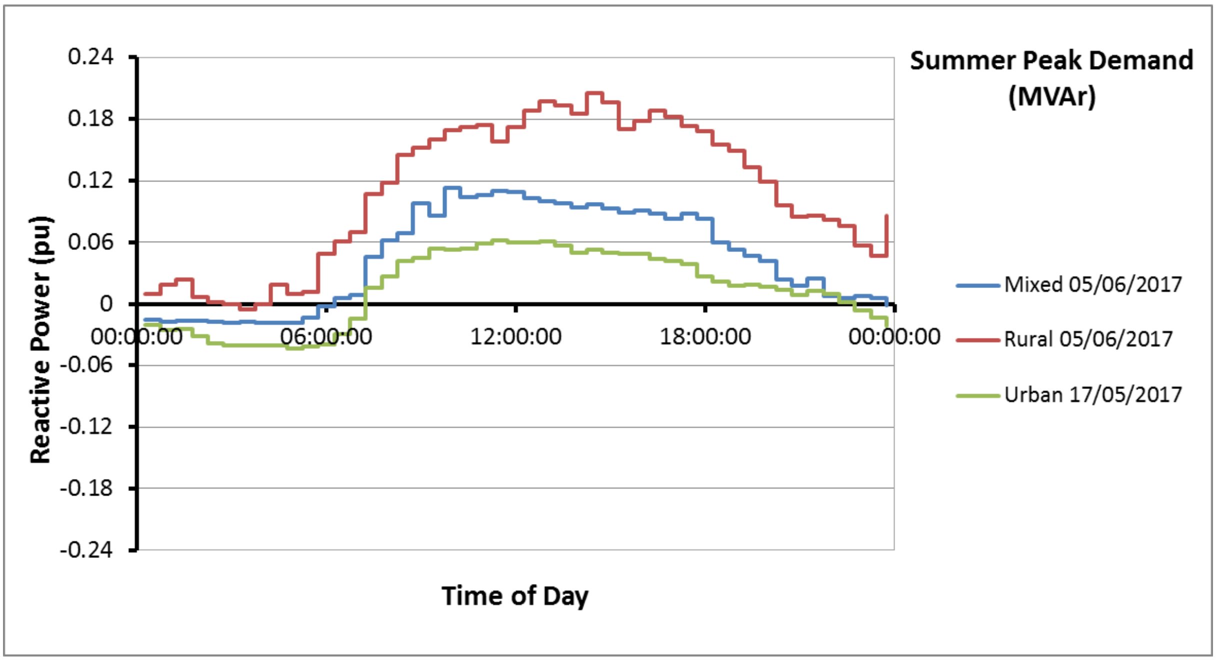

Figure 15: Reactive power underlying demand profiles for the Summer Peak Demand day, normalised over the peak real power annual demand (note: reactive power scale is not the same as the active power scale)

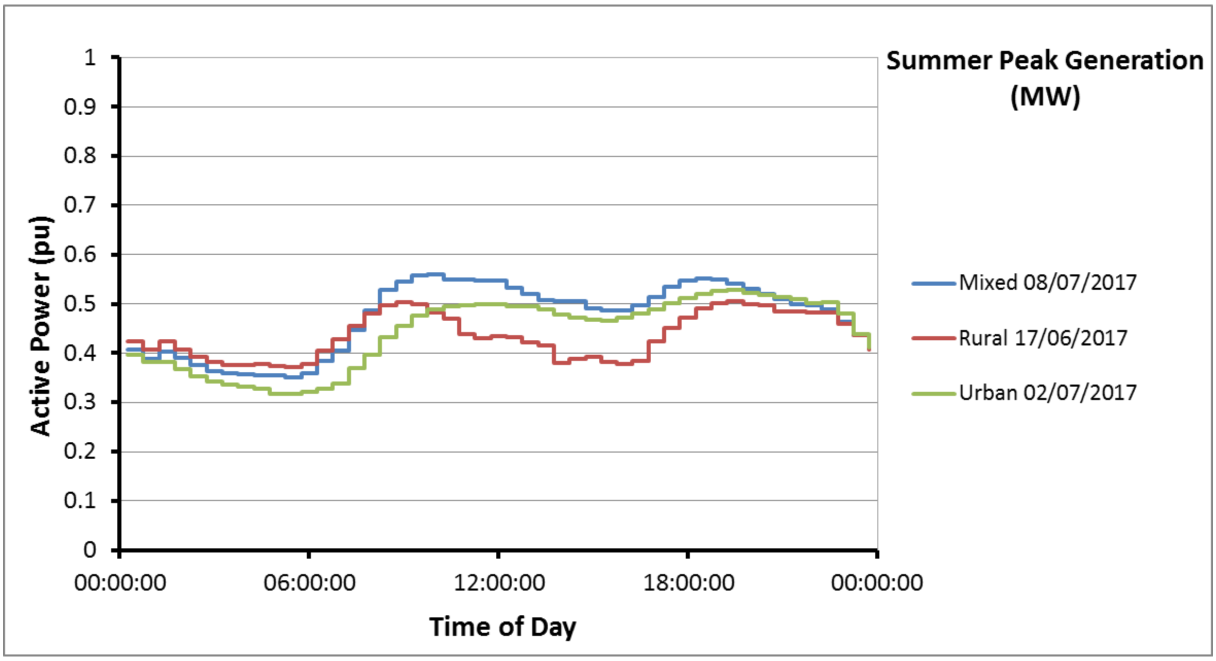

Figure 16: Real power underlying demand profiles for the Summer Peak Generation day, normalised over the peak real power annual demand

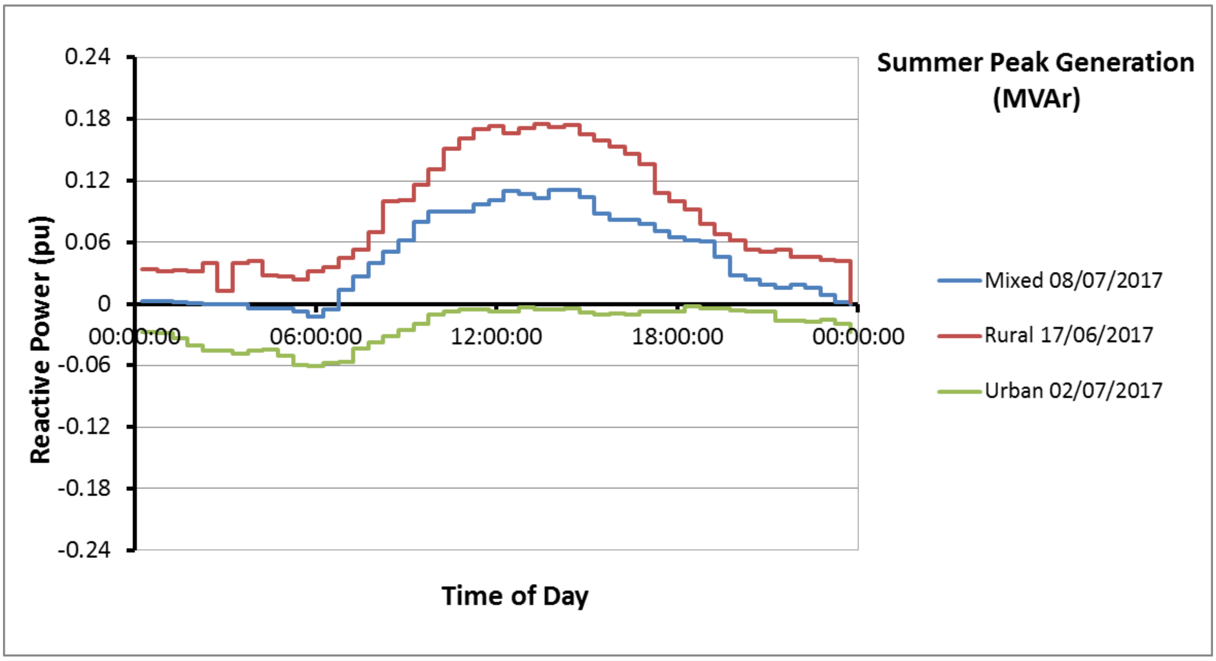

Figure 17: Reactive power underlying demand profiles for the Summer Peak Generation day, normalised over the peak real power annual demand (note: reactive power scale is not the same as the active power scale)

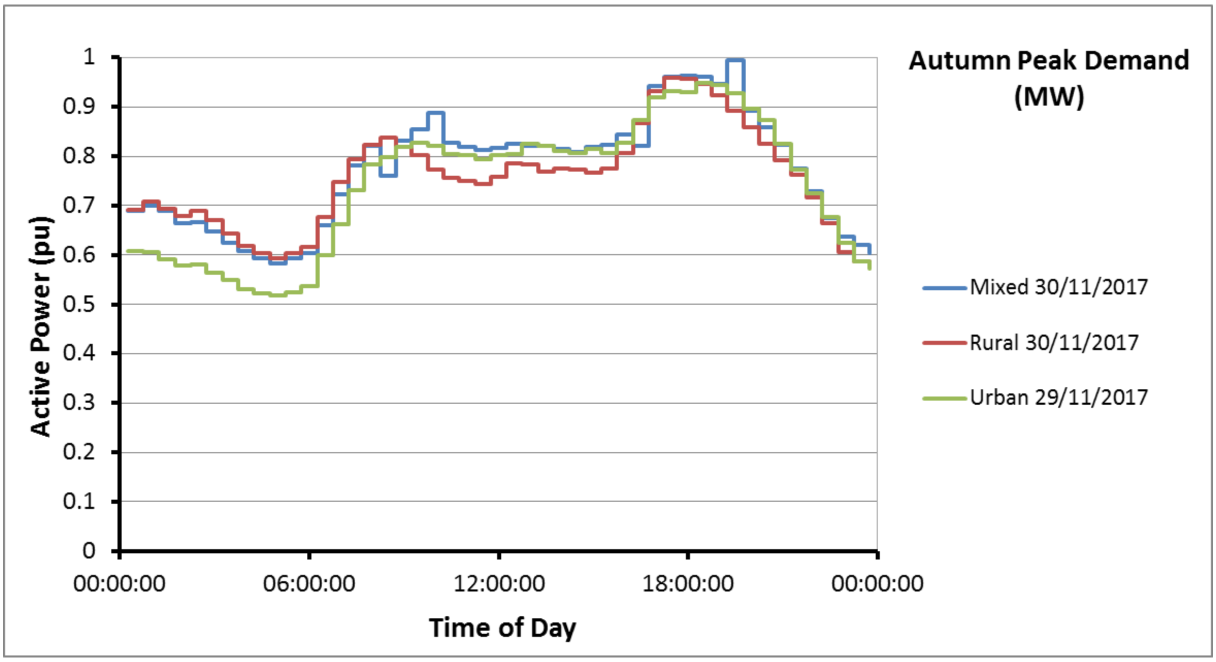

Figure 18: Real power underlying demand profiles for the Autumn Peak Demand day, normalised over the peak real power annual demand

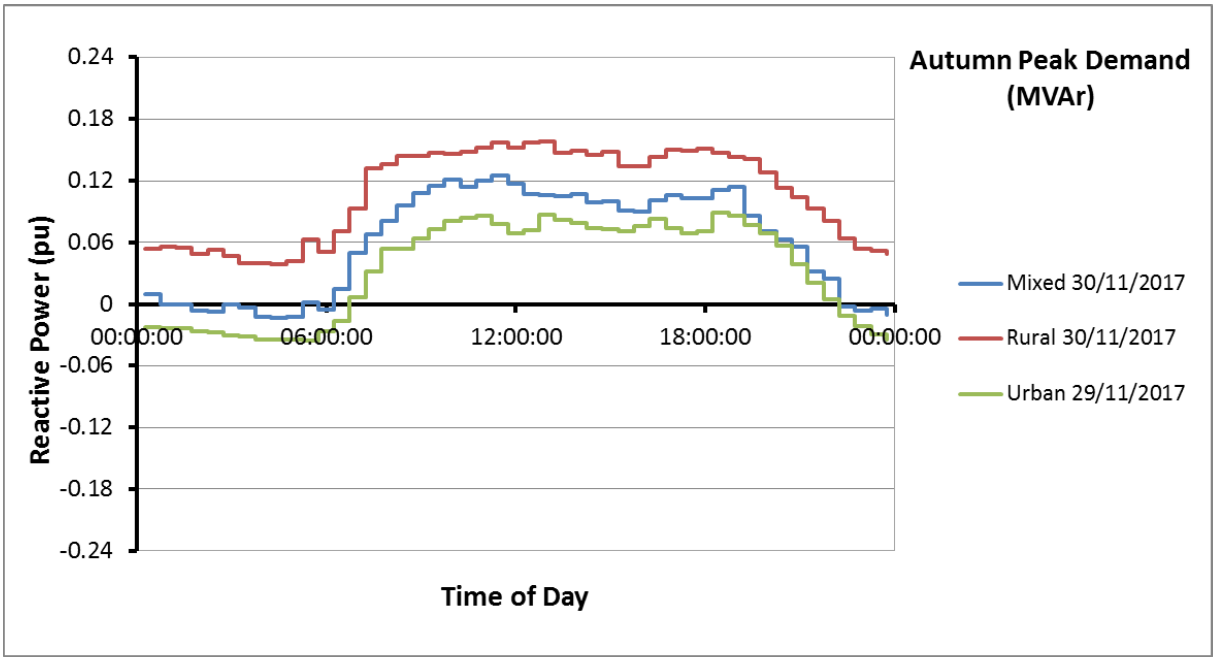

Figure 19: Reactive power underlying demand profiles for the Autumn Peak Demand day, normalised over the peak real power annual demand (note: reactive power scale is not the same as the active power scale)

Heat Pumps

The South West is a leading region for heat pumps, but due to the high-cost they have generally only been installed on off-gas houses, where an electric back-up is used at times where the heat-pump is not sufficient.

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

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

The study considered various types of heat pump as follows:

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

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

The profiles for gas and electric back-up heat pump are shown in Figure 20 and Figure 21.

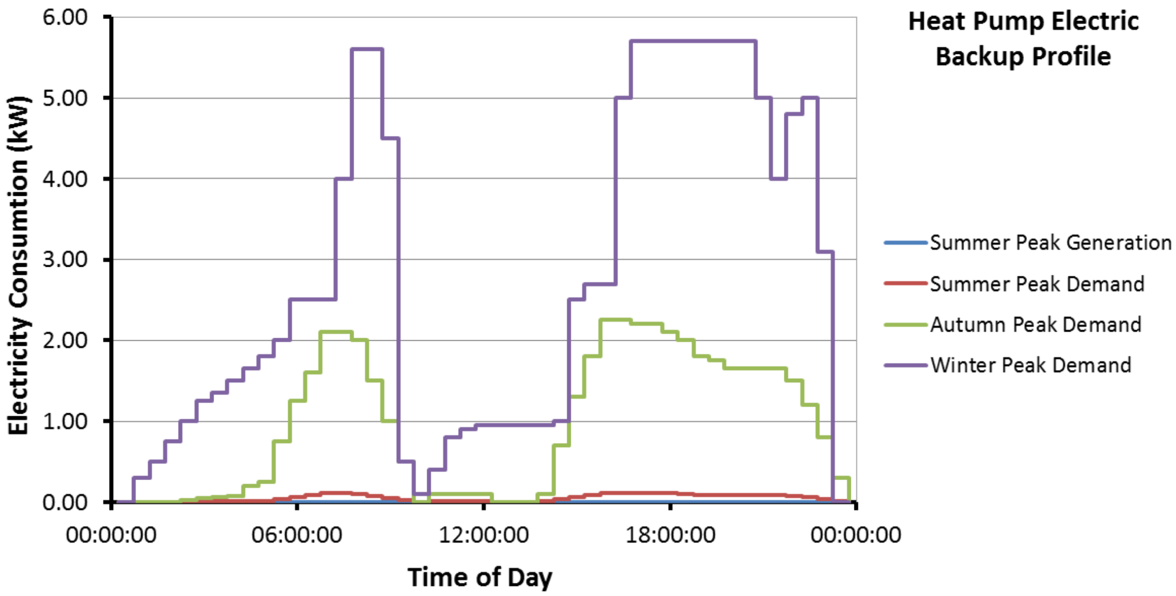

Figure 20: Electric back-up heat pump profile

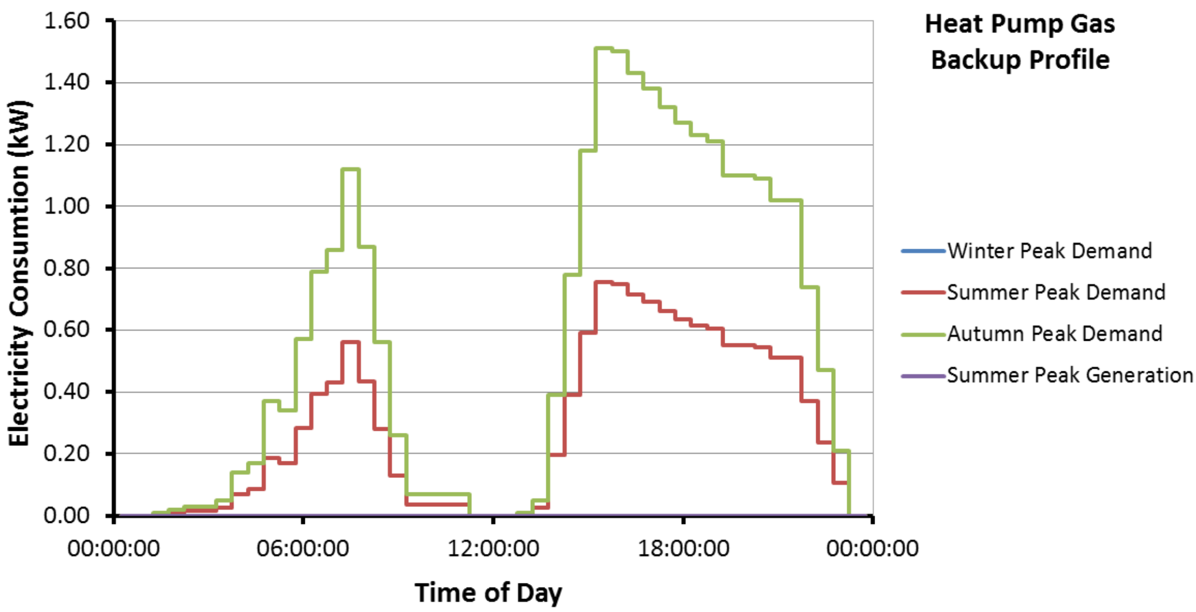

Figure 21: Gas back-up heat pump profile

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

Electric Vehicles

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

EV charging profiles were derived from the Electric Vehicles Insight Report of the Customer-Led Network Revolution project. This was based on a trial involving 143 domestic EV owners that took place in 2014. The profiles are shown in Figure 22 and Figure 23.

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

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

The Regen report considers two different charging profiles, derived from the FES report, dated July 2017. The FES report assumed that a TOUT will be applied for the Two Degrees and Slow Progression scenarios from 2020, while uninhibited charging was assumed for the Consumer Power and Steady State scenarios up to 2030. The TOUT results in a two-hour delay in peak demand, but no reduction in total energy consumption.

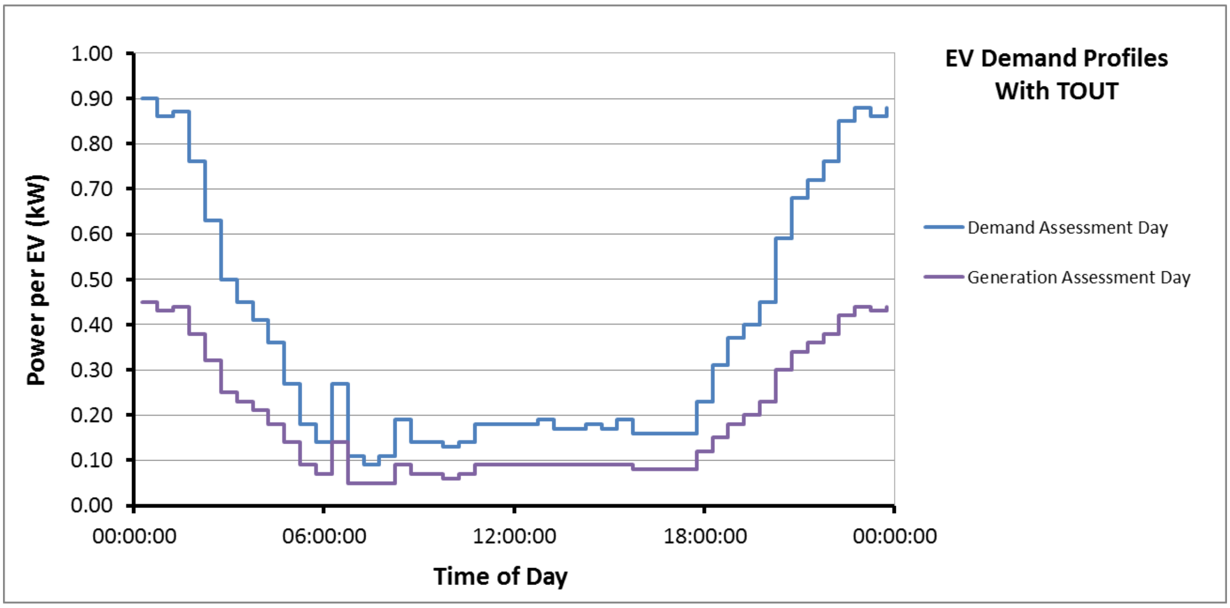

Figure 22: EV profiles with TOUT

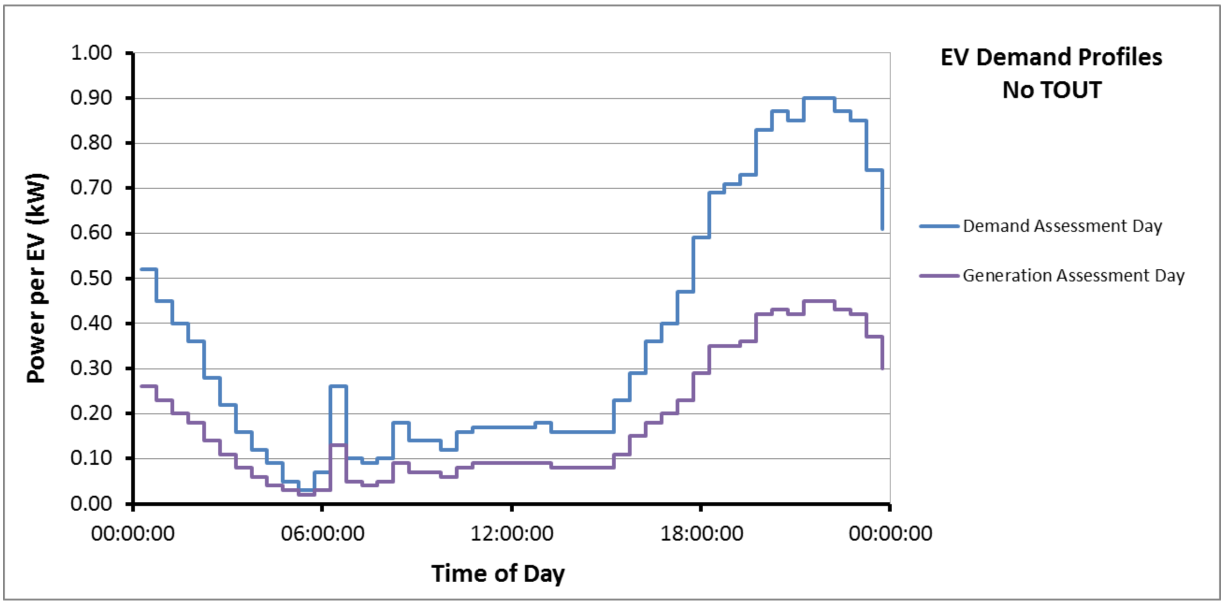

Figure 23: EV profiles without TOUT

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

Air Conditioning

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

Conventional Demand Growth

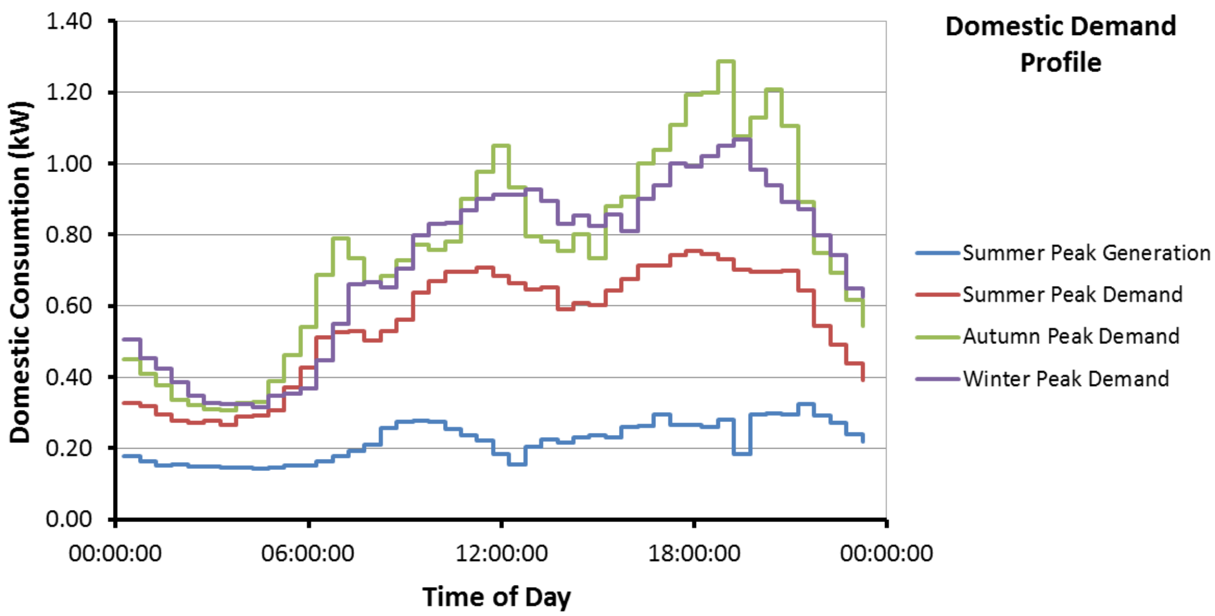

Figure 24: Diversified domestic profile (per house)

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

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

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

132kV Demand Customers

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

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

Generation Profiles

Profiles for Solar PV and Onshore Wind generation were derived from the measured output of existing generators connected South West 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 levels currently installed on WPD's distributions networks and forecasts out to 2030 under all scenarios.

Solar PV

Real power output data from all Solar PV generation sites in the South West licence area was collected and aggregated by each half hour for 2017. Only PV sites with an installed capacity greater than or equal to 1 MW were considered. The PV generator data sample comprised 207 sites, with an export capacity of 1.02GW. The geographical spread of solar PV sites in the data sample is shown Figure 25.

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

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

Figure 26 through Figure 27 show the PV generation profiles that were imposed on the network models.

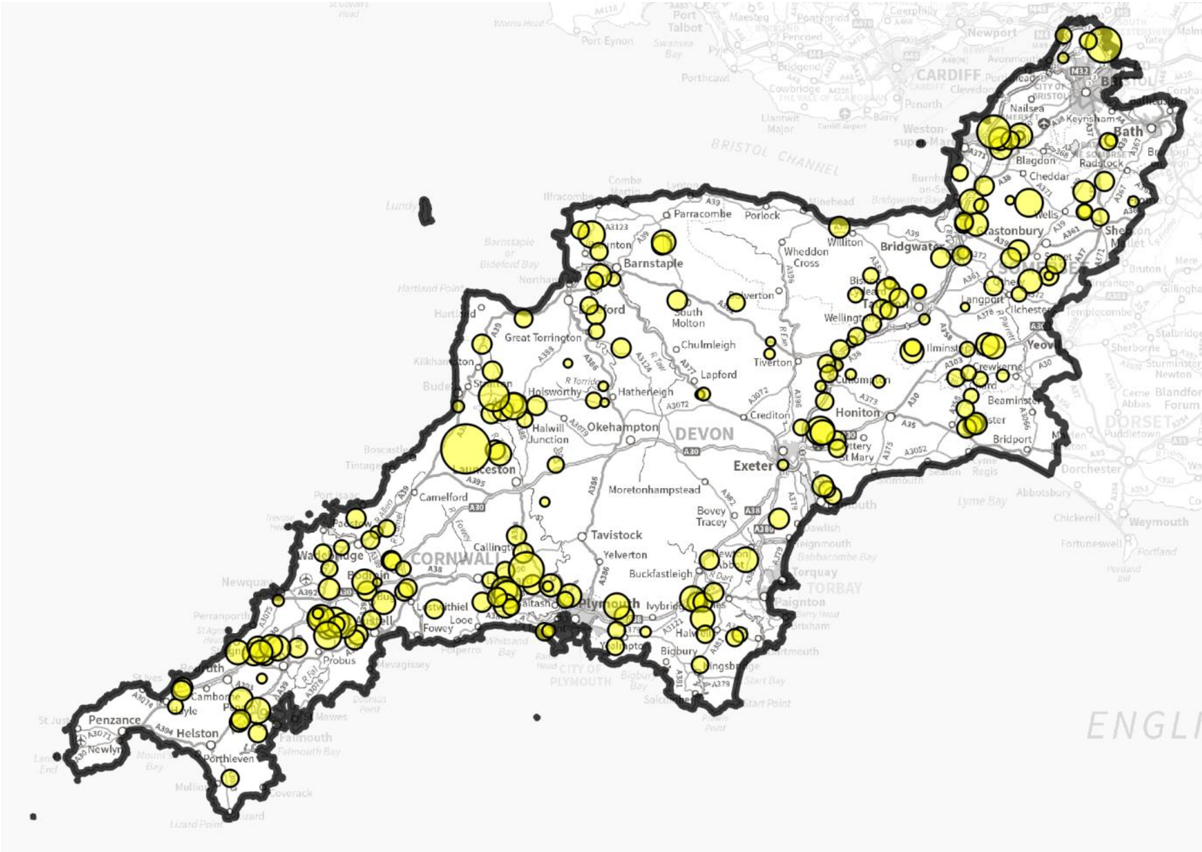

Figure 25: Map of Solar PV sites contributing to generation profiles; symbol area proportional to installed capacity [MW]

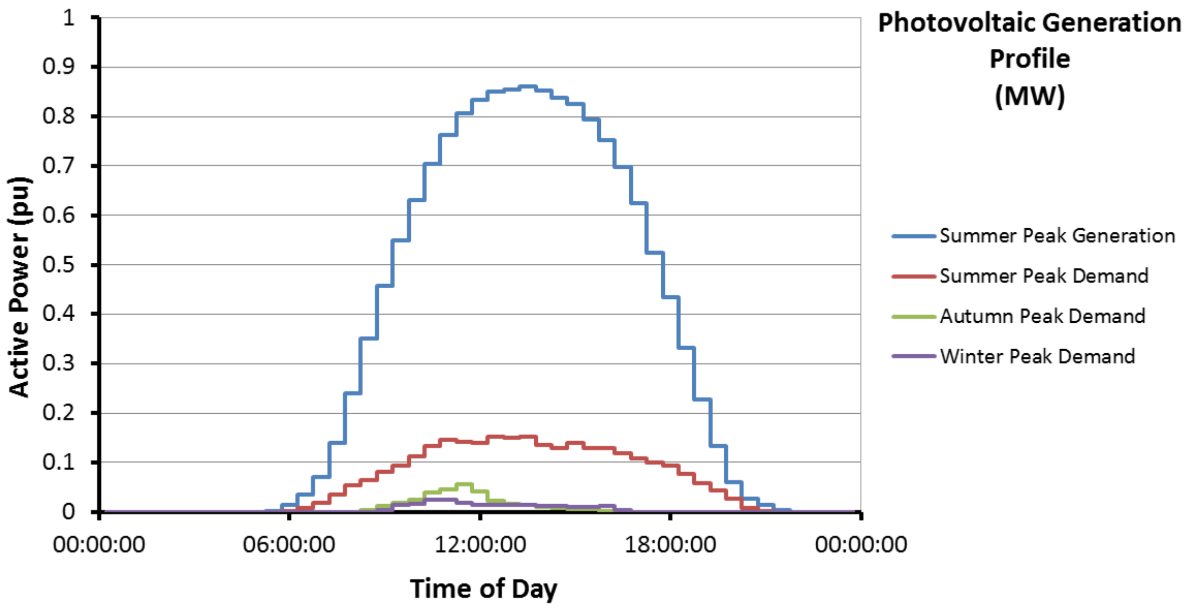

Figure 26: Normalised PV generation profile for each representative day

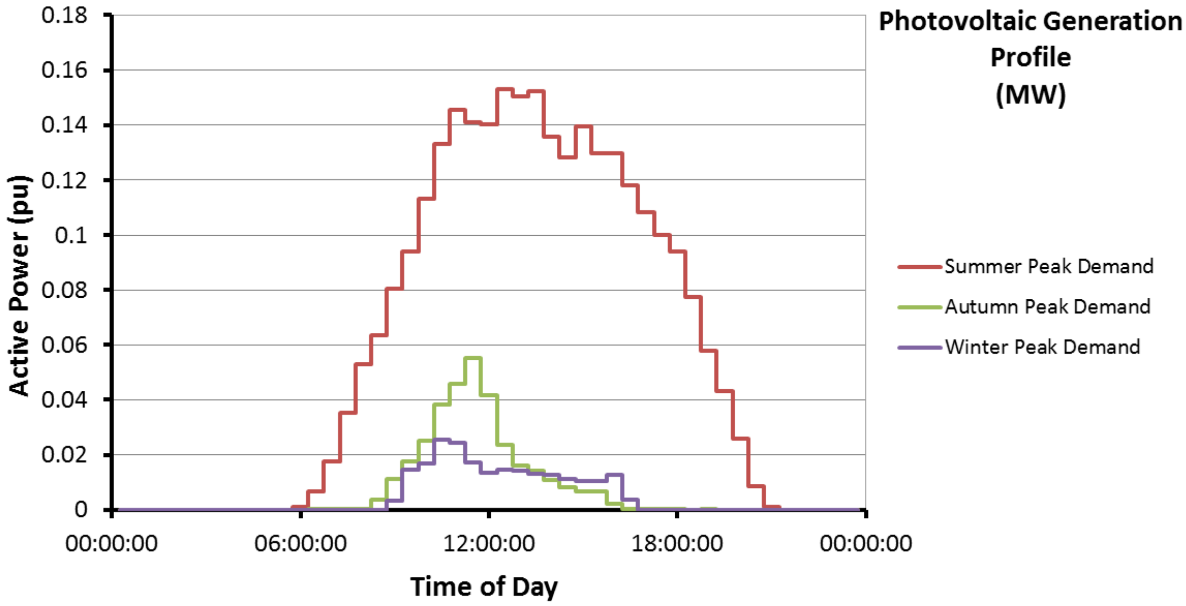

Figure 27: Detailed view of normalised PV generation profiles used for the Summer Peak, Autumn Peak and Winter Peak demand representative days

Onshore Wind

A similar process used for the PV generation profiles was used to create the Onshore Wind profiles. . The wind generator data sample comprised 27 sites, with an export capacity of 251MW. The generation output profiles are for a 24 hour period and consist of 48 data points (48 half hourly readings). A generation profile was created for each of the four representative days and only generation data from the respective representative day season was considered. Once the generation meter data had been aggregated together, an actual days' worth (48 half hourly readings) of data was selected. The data for each generation profile was selected in the following way:

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

Figure 29 through Figure 30 show the Wind generation profiles that were imposed on the network models.

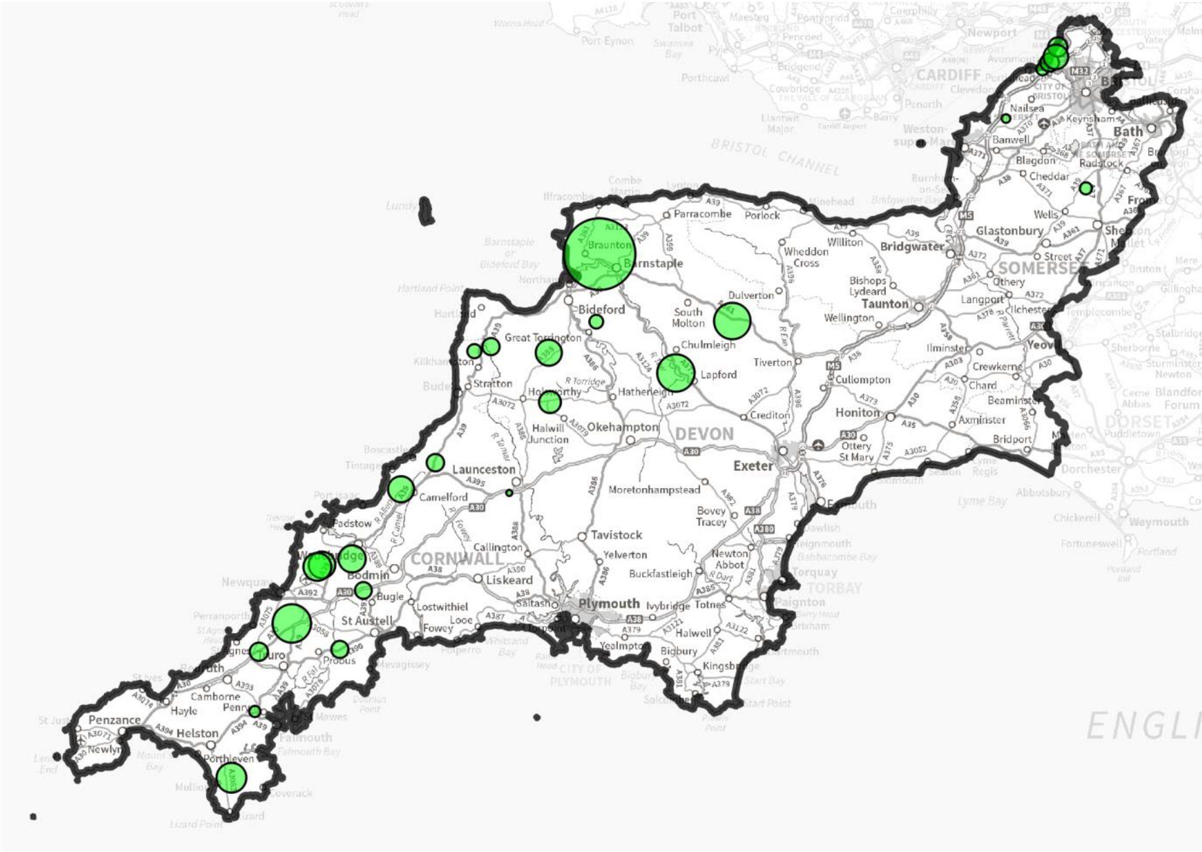

Figure 28: Map of Onshore Wind sites contributing to generation profiles; symbol area proportional to installed capacity [MW]

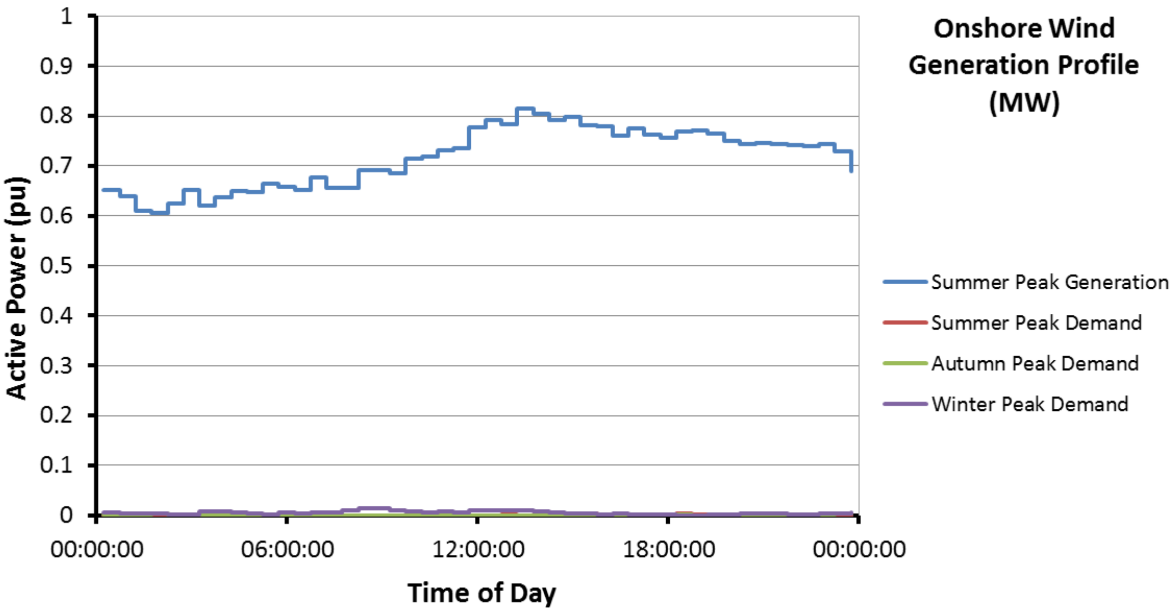

Figure 29: Normalised Onshore Wind generation profile used for each representative day. Note that due to the scale, the profiles for the demand days are shown near zero.

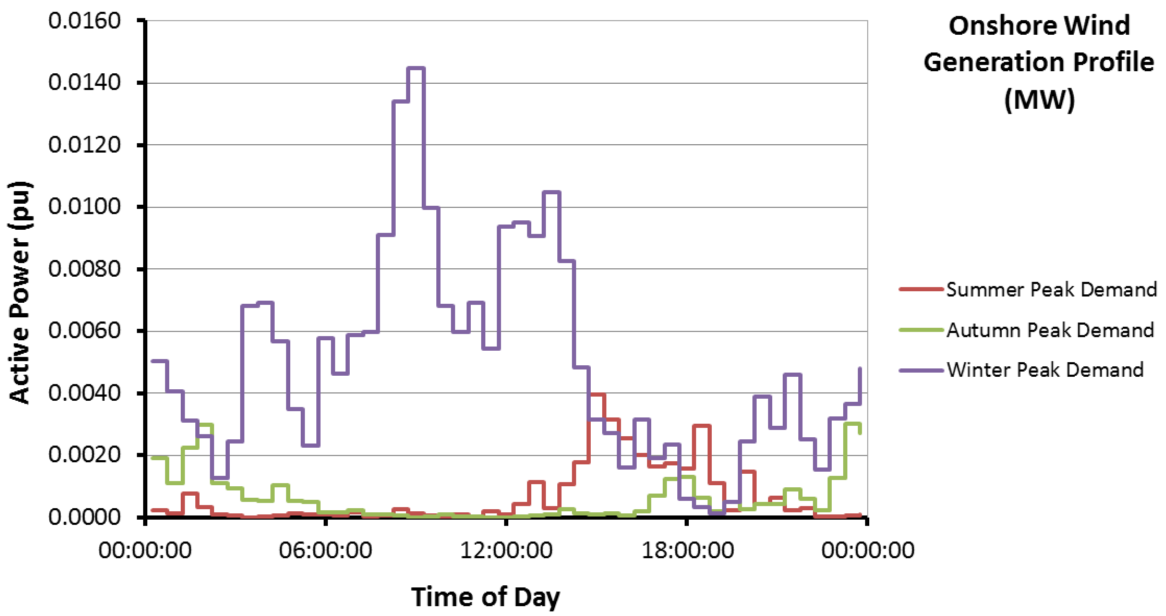

Figure 30: Detailed view of normalised Onshore Wind generation profiles used for the Summer Peak, autumn Peak and Winter Peak demand representative days

Other Generation

The remaining DG types modelled were:

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

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

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

Storage Profiles

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

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

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

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

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

6 – Results Overview

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

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

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

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

Note that under intact conditions, ONAN ratings have been assigned to transformers fitted with forced cooling. This ensures that transformers are not prematurely aged by prolonged high loading. More detail on the ratings assigned to transformers is given in Chapter 12 – Definitions and References.

Axminster GSP – collaboration with SSE

Axminster GSP supplies both WPD South West and SSE's SEPD licence area. As part of this project, we have studied the impact of the scenarios on the whole of Axminster GSP in conjunction with SSE. Results for Axminster GSP are not included in this report, but will be jointly published with SSE in an addendum later in the summer.

Demand results at a glance

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

GSP Group	2020				2025			
Melksham (WPD)								
Iron Acton	SS	SP	CP	TD	SS	SP	CP	TD
Seabank (& Sandford)	SS	SP	CP	TD	SS	SP	CP	TD
Bridgwater & Taunton	SS	SP	CP	TD	SS	SP	CP	TD
Abham, Exeter & Landulph	SS	SP	CP	TD		SP	CP	TD
Alverdiscott & Indian Queens	SS	SP	CP	TD	SS	SP	CP	TD

Generation results at a glance

Table 7: Summary of generation-driven network deficiencies by year, scenario and GSP group

GSP Group	2020				2025			
Melksham (WPD)								
Iron Acton					SS	SP	CP	TD
Seabank (& Sandford)								
Bridgwater & Taunton	SS	SP	CP	TD			CP	TD
Abham, Exeter & Landulph	SS	SP	CP	TD	SS			
Alverdiscott & Indian Queens	SS	SP	CP	TD	SS	SP	CP	TD

Assessing Network Access Requirements

There are two broad classes of network outage:

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

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

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

Case Study: Three-circuit Group

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

Consider the network shown in Figure 31. Each of the circuits A, B and C has a rating of 90MVA. The three circuits share load evenly. The seasonal peak demand at the 33kV bar of the BSP is:

- Summer peak demand: 85MW
- Spring/autumn peak demand: 105MW
- Winter peak demand: 125MW

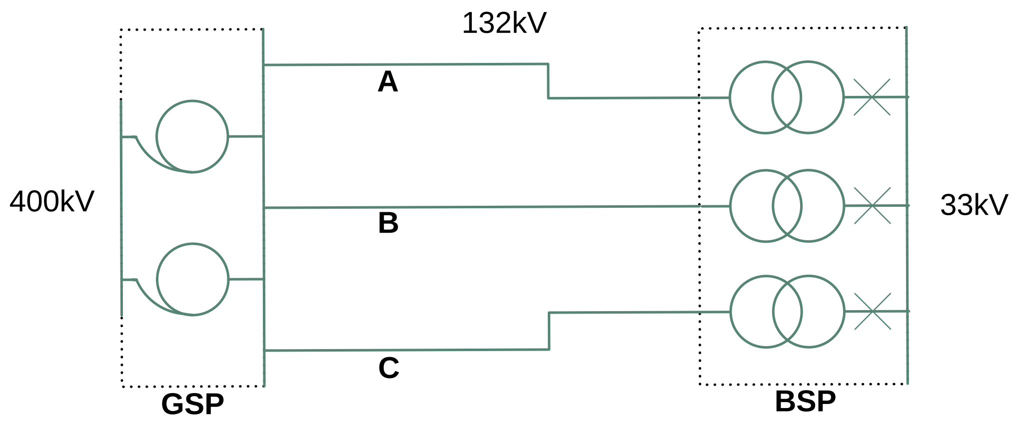

Figure 31: Three-circuit group example network

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

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

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

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

- In summer, the demand of 85MW is within the capability of the remaining circuit
- In spring or autumn, the demand of 105 MW overloads the remaining circuit
- In winter, the demand of 125MW overloads the remaining circuit

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

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

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

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

Seasonal ratings

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

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

Overhead line ratings

An NIA project to improve the accuracy of overhead line ratings, *Improved Statistical Ratings for Distribution Overhead Lines*, is approaching completion. It is intended that the results of this project are used to revise the ENA standard for overhead line ratings, ER P27. The project identified that some of the traditional seasons used for ratings do not align well with seasonal changes in network loading and ambient temperature. For example, assessment of autumn peak demand against an autumn rating compares a demand that is likely to be driven by cold weather in late November against a rating that is constrained by warm weather in September. To mitigate this effect, the project proposes new seasonal definitions, shown in Table 8. These seasons have been chosen to limit the variation in ambient temperature-related demand behavior during any one season.

Table 8: Changing seasons for overhead line ratings

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

Transformer ratings

WPD's transformer ratings standard includes ratings for summer and winter, but not for intermediate seasons. In order to assess transformers for the Autumn Peak Demand representative day, it was necessary to estimate autumn transformer ratings. Summer emergency ratings were used as a proxy to autumn cyclic ratings in the studies. Several constraints only arose as minor autumn transformer overloads, raising the question of whether the rating used is an underestimate of the true rating.

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

It is also recommended that the new seasons used in the proposed revision to ER P27 are used in the derivation of seasonal demand and generation profiles for future network studies.

7 – Baseline Results

Melksham GSP

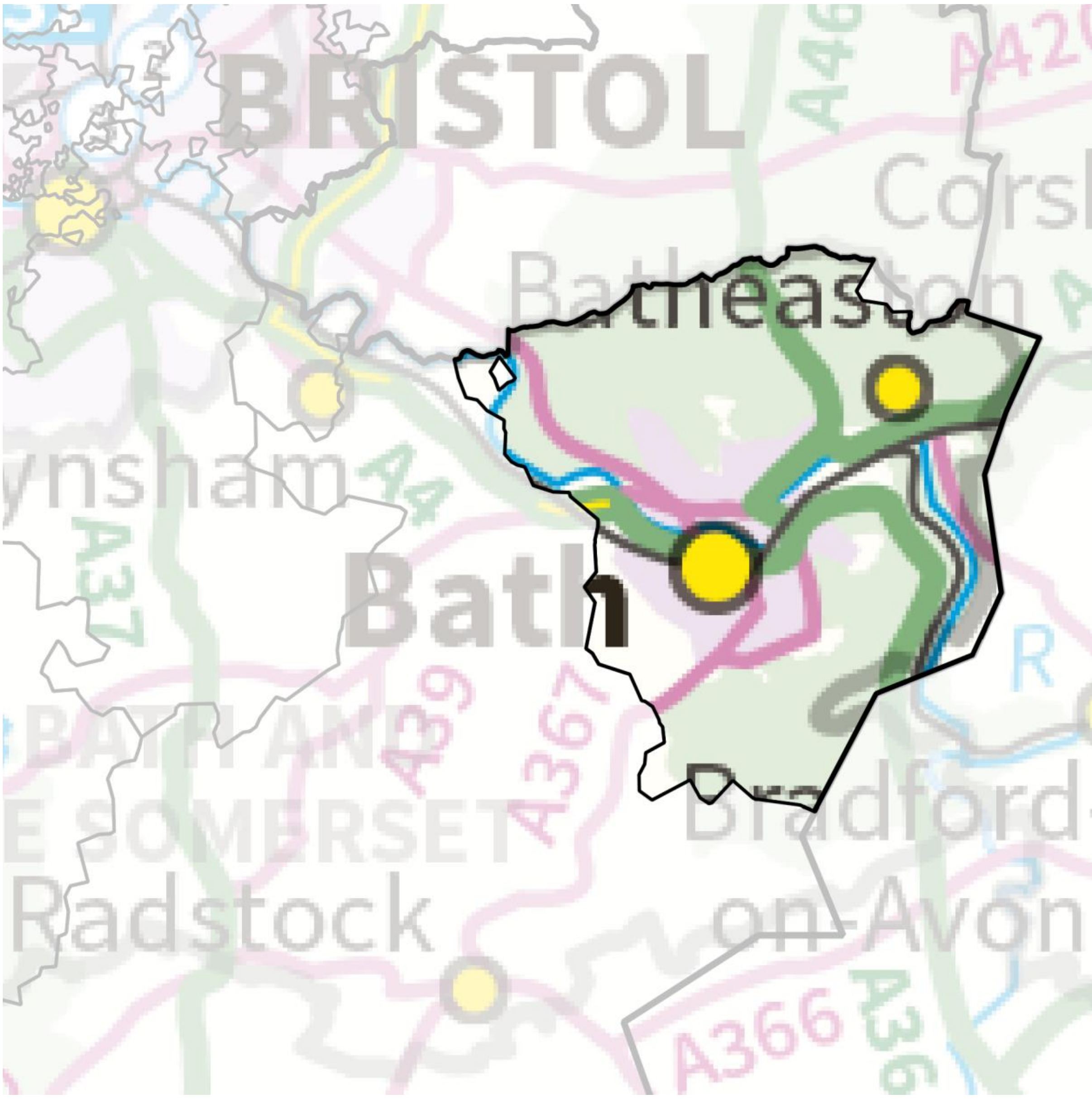

Figure 32: Area supplied by Melksham GSP. Supplies are also provided to several BSPs in SSE's SEPD licence area.

Melksham GSP is shared between WPD South West and SSE's SEPD licence area. WPD's network supplied from Melksham GSP consists of two 132kV circuits supplying a single BSP, Bath. The baseline studies did not identify any issues in WPD's network supplied from Melksham GSP.

Iron Acton GSP

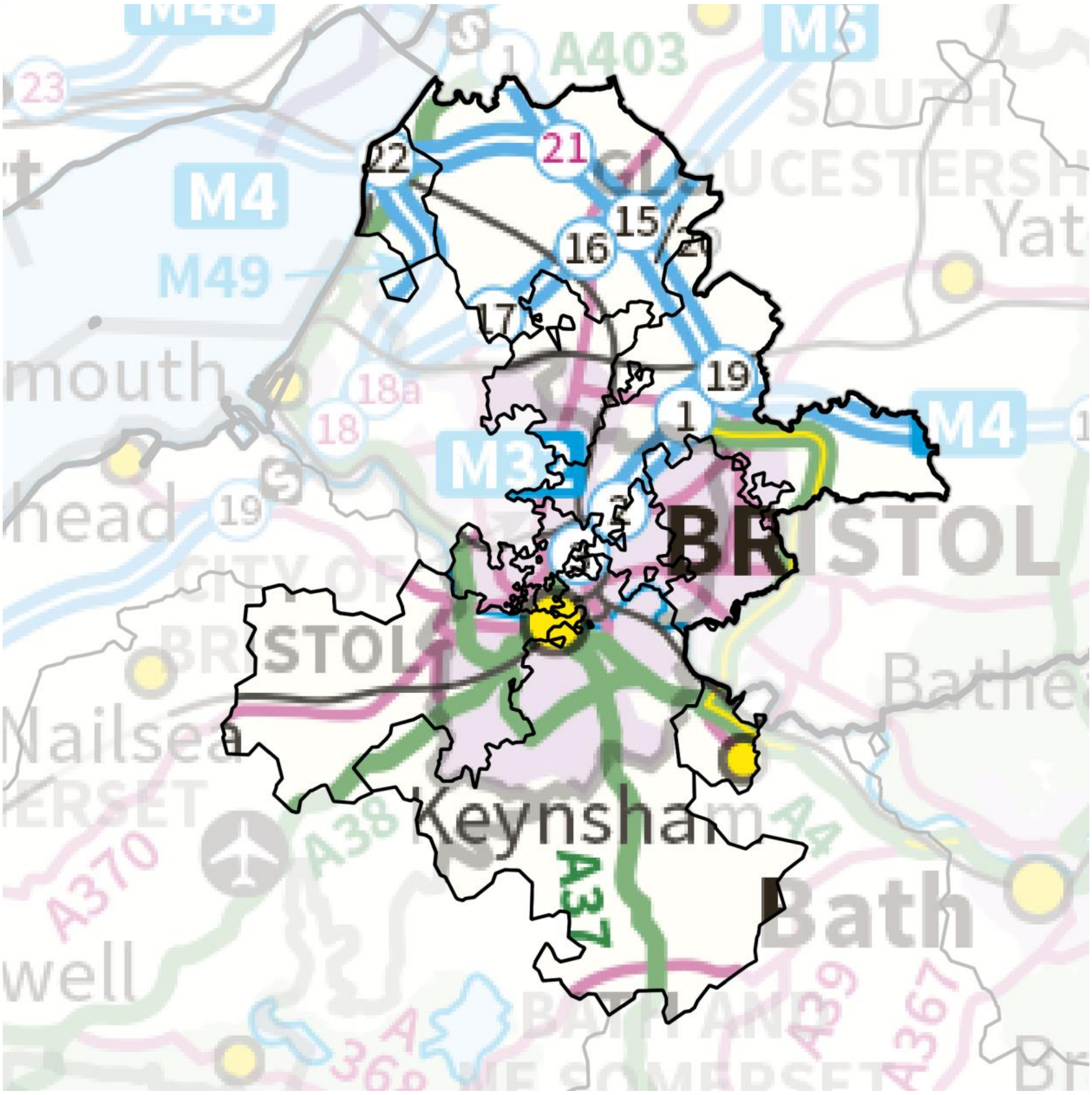

Figure 33: Area supplied by Iron Acton GSP. Supplies are also provided to several BSPs in WPD's West Midlands area, and decommissioning of the former Oldbury-on-Severn power station.

SGT capacity and fault level management

Iron Acton GSP supplies:

1. Five BSPs and two 132kV customers in WPD’s South West network;
2. Two BSPs in WPD’s West Midlands network; and
3. Decommissioning activity at the former Oldbury-on-Severn power station.

The combined WPD group demand in the Iron Acton 132kV network is 663MW.

There are six 275/132kV SGTs (four 240MVA units and two 180MVA units) supplying a two-section 132kV double busbar. Because Iron Acton is shared between multiple users, the 132kV busbars are owned and operated by National Grid. Fault level constraints combined with the limited flexibility of the 132kV switchgear mean that the bar is operated split into between two and four sections, with the exact splits frequently changing. The sections are remotely coupled at 132kV via Seabank GSP Reserve bar and Oldbury-on-Severn 132kV bar, and loose coupled at 33kV and 11kV via various WPD BSPs.

At the time of these studies, normal running arrangement is a three-way split, with an alternate two-way split available for busbar or SGT outages. This means that no SCO leaves a section of 132kV bar solely supplied via WPD's remote and/or loose couples. For various SCOs of:

- An arranged 132kV busbar or SGT outage at Iron Acton, followed by
- The fault loss of an SGT at Iron Acton,

There is a risk that one or more of the remaining SGTs at Iron Acton would overload to between 103% and 119% of nameplate rating for autumn and winter demand cases. No overload occurs for a summer peak demand case.

It is recommended that, as part of the ongoing design and operational liaison between WPD and National Grid, detailed joint studies are carried out to assess current and planned running arrangements at Iron Acton. In particular, the impact on WPD's circuits and the available capacity at Iron Acton should be considered.

Bradley Stoke/Lockleaze loose couple

Bradley Stoke BSP has two 60MVA, 132/33kV GTs, normally operated in parallel with each other.

Lockleaze BSP has four 90MVA, 132/33kV GTs. The 33kV bar is normally operated in two sections:

- One section is supplied by GT1 and GT4;
- The other section is supplied by GT2 and GT3.

Bradley Stoke 33kV is loose coupled with Lockleaze GT2 and GT3 via the 11kV bar at Abbeywood primary. For any SCO that removes 132kV infeed at Bradley Stoke BSP, the Bradley Stoke 33kV network is left back-energised by the 33/11kV T2 at Abbeywood. This would heavily overload both primary transformers at Abbeywood, and the associated 33kV circuits. Since the 33kV winding of Abbeywood T2 does not have an earthed neutral, this would also create an unearthed network.

For these studies, it was assumed that the loose couple at Abbeywood primary would be split for any arranged outage that left Bradley Stoke 33kV at next fault risk (e.g. GT or 132kV circuit outages).

It is recommended that the loose couple at Abbeywood primary is split for any outage that leaves Bradley Stoke 33kV at next fault risk.

Seabank BSP and Bradley Stoke BSP 33kV through-flow

Bradley Stoke BSP, Rolls Royce Filton, Seabank BSP and Old Green wind farm are supplied from Iron Acton GSP by a 132kV ring on the DA-route. The Reserve busbar at Seabank GSP forms part of the ring, operated split from Seabank GSP itself.

The 132kV switchgear at both Bradley Stoke and Seabank are configured such that a fault or arranged outage can remove 132kV bussing whilst leaving both GTs on load. This makes the GTs and 33kV bar at the affected BSP part of the 132kV ring.

In isolation this does not present issues, as all substations still receive direct 132kV infeed, with no overloads or unacceptable voltage conditions identified. In combination with an outage on a first leg from Iron Acton into the group, however, some of the substations on the ring are back-energised via the 33kV bar and GTs at one or other of the BSPs. This causes voltage control issues and, in some cases, overloads. These conditions are also likely to cause protection issues.

For the particular SCO of:

- an arranged outage of Bradley Stoke 220; followed by
- the fault of the 132kV circuit from Iron Acton 205 to Seabank 505 teed Old Green and Seabank BSP,

There is a risk that Bradley Stoke GT1 would overload to 111% of rating for a summer generation case. This is because the net export from both Seabank BSP and Rolls Royce Filton would feed via Bradley Stoke GT1.

It is recommended that – unless thermal, voltage and protection studies demonstrate it is acceptable to do otherwise – the following operational measures are taken for arranged outages in this group:

- **For an arranged outage splitting Bradley Stoke BSP at 132kV: offload GT1 at Bradley Stoke BSP**
- **For an arranged outage on the 132kV circuit between Iron Acton, Old Green and Seabank: offload GT1 at Bradley Stoke**
- **For an arranged outage splitting Seabank BSP at 132kV: offload GT1 at Seabank BSP**
- **For an arranged outage on the 132kV circuit between Iron Acton and Bradley Stoke: offload GT1 at Seabank BSP**

It would also be necessary to split the loose couple at Abbeywood primary for each of these arranged outages.

Seabank GSP

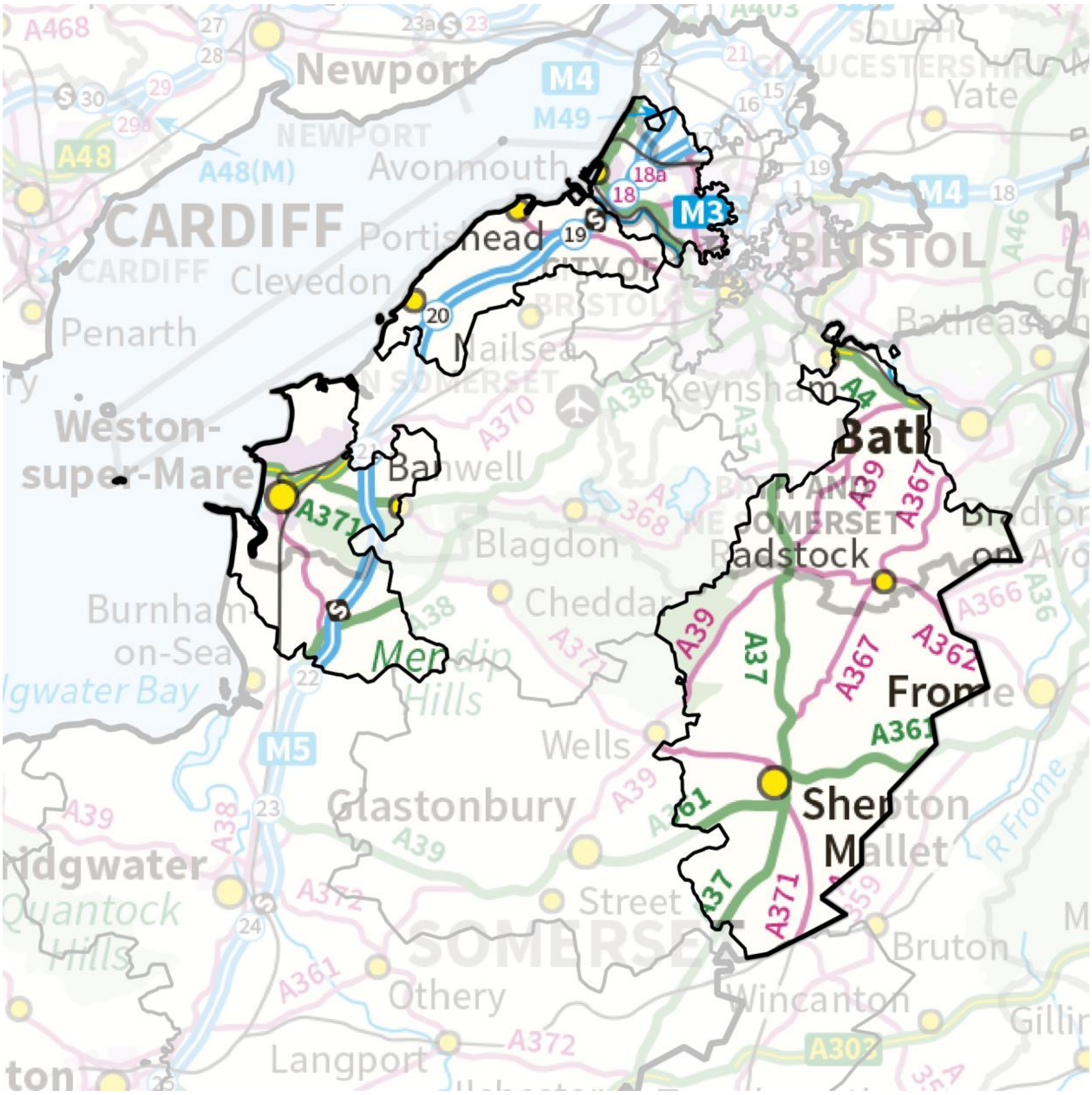

Figure 34: Areas supplied by Seabank GSP.

SGT capacity

Since the F-route split, the Seabank 132kV network is normally operated independently of the Bridgwater/Taunton 132kV network. There are three 240MVA SGTs at Seabank, but the 400kV bar supplying them is only supplied by two 400kV circuits from the wider transmission network. The group demand is 273MW.

SGT SCO

For an SCO of any two SGTs at Seabank GSP, the remaining SGT carries the group load. For autumn and winter peak demand cases, there is a risk that the remaining SGT would overload to between 105% and 123% of nameplate rating. No overload occurs for a summer peak demand case.

It is recommended that the adequacy of the available access window for the SGTs is assessed. If it is not long enough, National Grid may be able to determine short-term ratings for the SGTs which allow loading to be managed by post-fault transfers.

Transmission through-flow for 400kV busbar outage

For a fault outage of Seabank 400kV busbar Main 1, the two incoming 400kV circuits are left loose coupled by SGT2 and SGT4 via the 132kV busbar. Since Seabank 400kV is connected as a turn-in between Melksham and Whitson/Cilfynydd, it is potentially subject to considerable through-flows. Overloads of up to 105% of rating on SGT2 and SGT4 were observed for both demand and generation cases in these studies. It is likely that short-term ratings for the SGTs would allow this issue to be managed post fault, but the ratings of WPD's 132kV busbar at Seabank may present a constraint.

Seabank 400kV is near the edge of the network model used for these studies, this may limit the accuracy of contingency analysis in that area. WPD is currently implementing network models with an expanded representation of the transmission network.

It is recommended that this condition is discussed with National Grid, and reassessed once WPD's new network models are available. It should be confirmed that WPD's Seabank 132kV busbar is suitably rated for any expected through-flow.

Bridgwater & Taunton GSPs

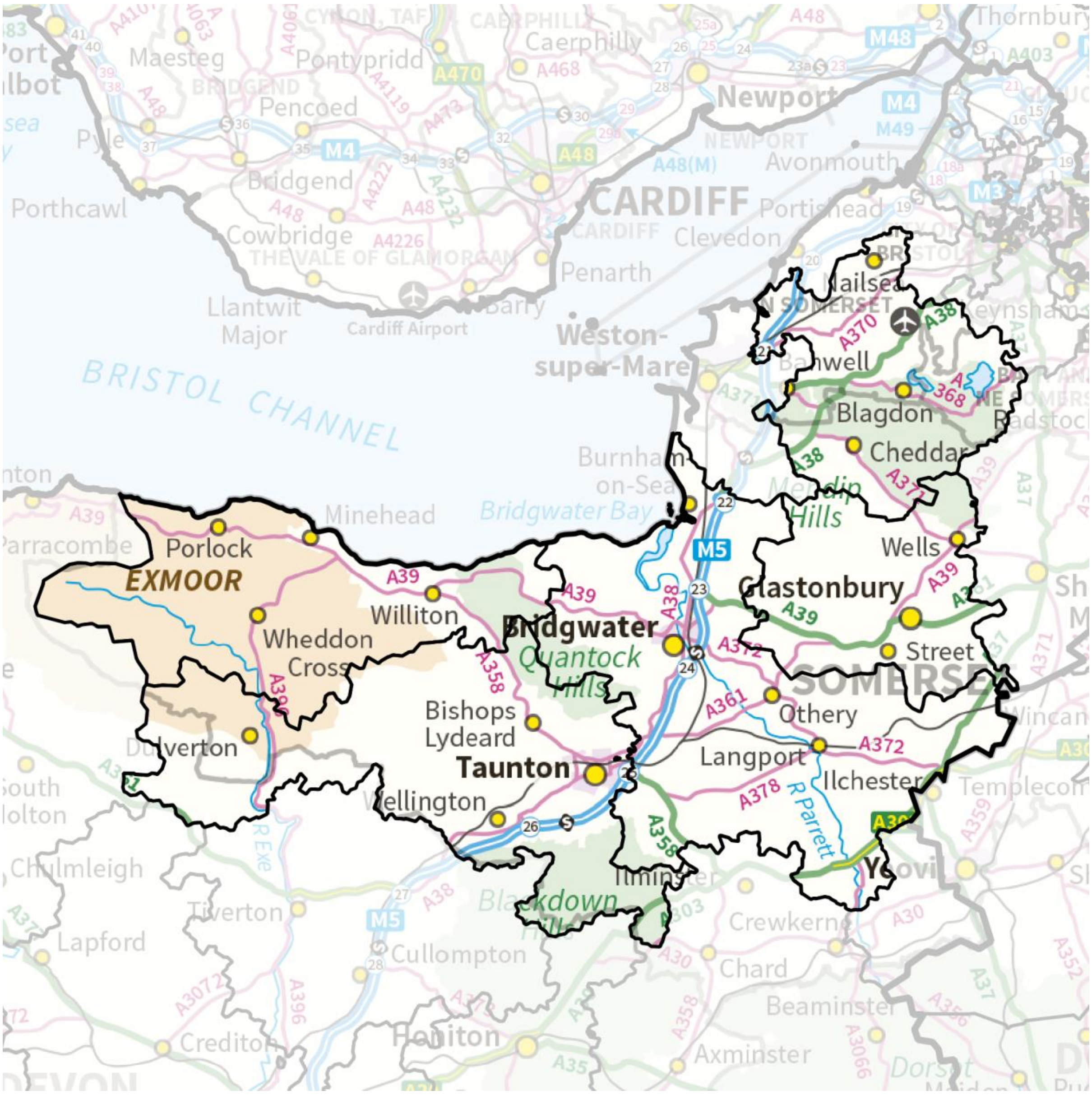

Figure 35: Area supplied by Bridgwater and Taunton GSPs.

SGT and interconnector capacity

Since the F-route split, the Bridgwater/Taunton 132kV network is normally operated independently of the Seabank 132kV network. It is supplied by two 240MVA SGTs at Bridgwater and one 240MVA SGT at Taunton, interconnected by two 132kV circuits between Bridgwater and Taunton. The group demand is 372MW.

Churchill BSP can be transferred from Bridgwater GSP onto Seabank GSP at single circuit risk; its group demand is 66MW. For protection reasons, it is also necessary to put Radstock BSP at separate single circuit risk for the duration of this transfer.

SGT SCO

For the SCO of any two SGTs in the Bridgwater/Taunton group, the group load is carried by the remaining SGT.

For the arranged outage of any one SGT in the Bridgwater/Taunton group, it was assumed that Churchill BSP would be transferred onto Seabank GSP. Despite this load transfer, for autumn and winter peak demand cases, there is a risk that the remaining SGT would overload to between 141% and 154% of nameplate rating. No overload occurs for a summer peak demand case.

It is recommended that the adequacy of the available access window for the SGTs and associated transmission circuits is assessed. If it is not long enough, alternative running arrangements, flexibility services and reinforcement should be considered as means to extend it.

Hinkley Point station demand fed via WPD network

Each SGT at Bridgwater is supplied by a 275kV transformer feeder from Hinkley Point 275kV bar. The 275kV bar is supplied by two 400/275kV SGTs (SGT5 and SGT6) from the adjacent Hinkley Point 400kV bar. The 275kV bar also supplies various demands related to Hinkley Point A, B and C power stations, with a group demand of 63MW. For various FCOs and SCOs depending on running arrangements at Hinkley Point 275kV, Hinkley Point station demand is back-energised via the Bridgwater 132kV bar and SGTs.

For an SCO of SGT5 and SGT6 at Hinkley Point, the Hinkley Point 275kV bar is solely fed via Bridgwater 132kV, and in turn from Taunton 132kV. This leaves both WPD’s Bridgwater/Taunton group and the Hinkley Point station demand fed by Taunton SGT2.

For the arranged outage of SGT5 or SGT6 at Hinkley Point, it was assumed that Churchill BSP would be transferred at single circuit risk onto Seabank GSP. Despite this load transfer, there is a risk that Taunton SGT2 would overload to between 117% and 168% of nameplate rating for all demand cases. For the autumn peak demand case, there is also a risk that both 132kV circuits from Taunton to Bridgwater (E-route and U-route) would overload to 103% of rating.

It is recommended that this is assessed in further detail with National Grid, and suitable mitigation agreed for any arranged outages of Hinkley Point SGT5 or SGT6. The overloads could be prevented by opening the 132kV interconnection between Bridgwater and Taunton for the arranged outage of either SGT at Hinkley Point.

Through-flow between Bridgwater and Taunton for 400kV outages

Together with two 400kV circuits from Exeter towards the Southampton area, the two 400kV circuits from Taunton to Hinkley Point connect the South West peninsula to the wider transmission network. The Bridgwater/Taunton 132kV network is coupled across these 400kV circuits, but sees relatively little through-flow when they are in service.

For an SCO of the two 400kV circuits between Taunton and Hinkley Point, the Bridgwater/Taunton 132kV network becomes a link between the South West peninsula and the wider transmission network.

For the particular SCO of:

- an arranged outage of the 400kV circuit from Taunton X403 to Hinkley Point X105; and
- the fault outage of the 400kV circuit from Taunton X305 to Hinkley Point X405,

On a summer generation case, there is a risk that Taunton SGT2 would overload to 206% of nameplate rating, and both 132kV circuits from Taunton to Bridgwater (E-route and U-route) are overloaded to around 202% of rating.

It is recommended that this is assessed in further detail with National Grid, and suitable mitigation agreed for any arranged outages of the 400kV circuit from Taunton X403 to Hinkley Point X105.

For these studies, the overloads were prevented by opening the 132kV interconnection between Bridgwater and Taunton for those arranged outages. This leaves Taunton BSP and Bowhays Cross BSP (group demand 121MW) at risk for the fault loss of Taunton SGT2; if this running arrangement is adopted it is recommended that an auto-close scheme is commissioned to restore Taunton BSP and Bowhays Cross BSP from Bridgwater GSP post-fault.

Depending on 400kV auto-reclose and sectionalising arrangements at Taunton, it is possible that there is a credible double circuit fault which has the same impact on the network. If this is the case, an operational intertripping scheme to split the 132kV network for applicable 400kV outages may prove more appropriate.

Impact of Hinkley Point C connection

As part of the works to connect Hinkley Point C, a second SGT (SGT1) is due to be installed at Taunton GSP in 2021. Churchill BSP is due to be transferred to Seabank GSP in 2021 to allow the removal of the southern F-route, and subsequently connected to the new Sandford GSP in 2023. Although these works will remove 132kV transfer capacity between Bridgwater and Seabank, they will increase infeed to the Bridgwater/Taunton group whilst reducing its group demand.

Bridgwater BSP and Street BSP GT capacity

The Bridgwater/Street 33kV network is supplied by three 60MVA GTs at Bridgwater and one 60MVA GT at Street, interconnected by various 33kV circuits. The group demand is 185MW.

SCO of two GTs at Bridgwater BSP

For an SCO of any two GTs at Bridgwater BSP, the group load is carried by the remaining GT at Bridgwater BSP and the GT at Street BSP. They share load unevenly, with considerably more load picked up at Bridgwater than Street.

For the arranged outage of any one GT at Bridgwater or Street, the following load transfers were simulated:

- Wells primary to Radstock BSP
- Burnham primary and Wedmore primary to Churchill BSP
- Nether Stowey primary to Bowhays Cross BSP

Despite these load transfers, for autumn and winter peak demand cases, there is a risk that the remaining GT at Bridgwater would overload to between 124% and 134% of rating. No overload occurs for a summer peak demand case.

It is recommended that the adequacy of the available access window for the GTs is assessed. If it is not long enough, short-term ratings, load management schemes, flexibility services and reinforcement should be considered as means to extend it.

132kV busbar Main 1 fault

Bridgwater 132kV is a double busbar in two sections. Bridgwater GT1, Bridgwater GT3 and Street GT1 are connected to section 1, while Bridgwater GT2 is connected to section 2. This means that – however the busbar selection of the GTs is configured – there is a credible busbar fault which can remove 132kV infeed from at least two GTs in the group.

For the current normal busbar selection, a fault on Bridgwater 132kV Main 1 disconnects Bridgwater GT3 and Street GT1. This leaves the group load on Bridgwater GT1 and GT2. For all demand cases, this overloads GT2 to between 101% and 144% of rating. For autumn and winter demand cases, it also overloads GT1 to between 113% and 120% of rating.

It is recommended that measures are taken to prevent this overload. As a temporary operational measure, all four GTs could be selected to the Reserve busbar with the Reserve section isolators closed. This would disconnect the Bridgwater/Street group for a busbar fault, so preventing the overload.

An alternative which offers better demand security would be a load management scheme that disconnects some load at 33kV in the event of a post-fault overload. This could also be configured to defer reinforcement driven by the SCO of two GTs at Bridgwater BSP.

The 2020 Results trigger a fifth GT for the group in all scenarios; if built this should be configured to resolve busbar fault overloads.

Abham, Exeter & Landulph GSPs

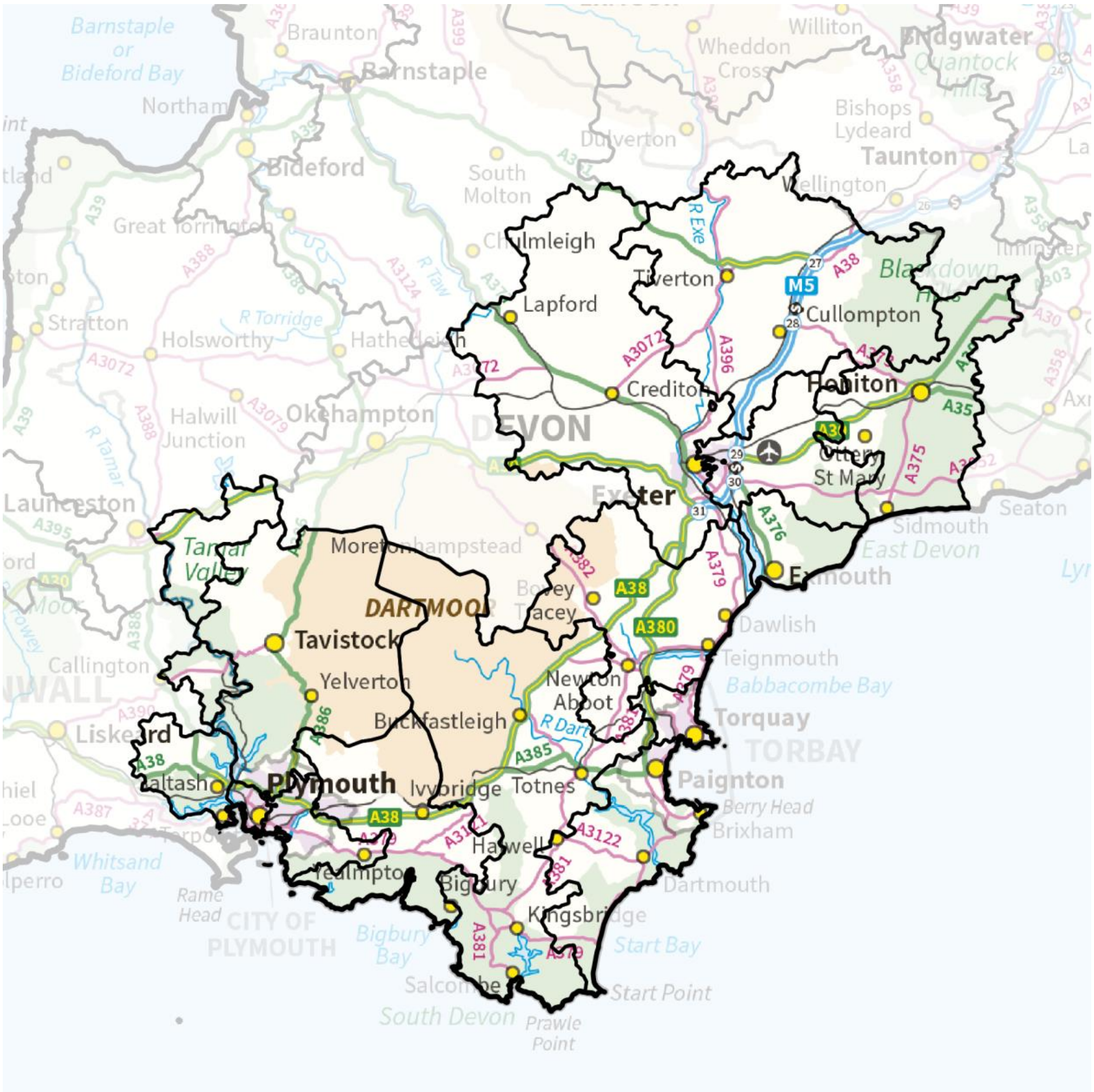

Figure 36: Area supplied by Abham, Exeter and Landulph GSPs

Abham, Exeter and Landulph GSPs are currently run in parallel on the 132kV network, with Landulph loose coupled to the Alverdiscott/Indian Queens group via the St Germans 33kV.

Landulph to Abham 132kV Network

River Dart Cables and H-route

The H-route double circuit out of Abham GSP towards Landulph GSP provides two of the four infeeds into the Totnes, Plympton, Plymouth, Milehouse and Ernesettle BSP group. The first section is a 2.3km oil filled cable that includes a section under the River Dart. The other infeed into this group is a double 132kV circuit (AA-route) fed from Landulph GSP. The group demand of these BSPs is 319MW.

The arranged outage of either 132kV AA-route circuit out of Landulph GSP towards Ernesettle BSP followed by a fault of the remaining AA-route removes the 132kV infeed from Landulph GSP and leaves Totnes, Ernesettle, Milehouse, Plymouth and Plympton supplied via Abham GSP and H-route. For this SCO combination there is a risk that the H-route would overload for all demand representative days. The magnitude of these overloads is summarised by circuit section and season in Table 9.

Table 9: H-route circuit section overloads for the described SCO combination in the baseline

Circuit section	Peak Demand Representative Day (% loading based on section rating)		
	Summer	Autumn	Winter
Abham GSP 305 – Totnes tee (River Dart crossing)	**108%**	**122%**	**117%**
Abham GSP 705 – Totnes tee (River Dart crossing)	**117%**	**129%**	**124%**
Totnes tee No 1 → Plymouth 205	**110%**	**121%**	**119%**
Totnes tee No 2 → Plympton 203	**103%**	**117%**	**113%**

The River Dart cables were previously assigned an enhanced rating for sustained post-fault loading. These ratings and their applicability should be reassessed to determine whether they can be used to resolve the studied overloads.

The existing conductor on the H-route is 175mm² ACSR (Lynx) @ 50°C; it has recently been surveyed and WPD are currently waiting on the results to determine if an increase in the maximum operating temperature can be achieved.

Moving demand from Ernesettle to Landulph and Totnes to Paignton at 33kV reduces the overload on the Dart cables to 107% and 103% on the H-route for the summer peak demand study.

Short-term ratings, load management schemes, flexibility services and reinforcement should be considered as means to ensure that a sufficient access window is available.

There is also a risk that the H-route would overload for a summer generation representative day, for the following SCO combination:

- an arranged outage of Langage 400kV main 2 busbar; and
- a subsequent fault of Abham SGT 1 and the associated 400kV circuit.

The overload is 135% of the summer rating following the fault prior to the Abham 230 auto-close scheme operating. There is currently a 35 second delay on the Abham 230 auto-close scheme. When Abham 230 closes the overload reduces to 112% of rating.

It is recommended that for the arranged outage of Langage 400kV Main 2, Abham SGT 2 is taken out of service and Abham 230 is closed. This means the subsequent fault of Abham SGT1 does not overload the Dart cable.

Ernesettle to Milehouse 132kV circuit

The Ernesettle to Milehouse 132kV cable is part of the network interconnecting Landulph and Abham GSPs at 132kV. As part of an interconnected network, flows through the cable are heavily dependent on the configuration and loading of the surrounding network.

Circuit breaker 605 at Landulph GSP feeds the 132kV circuit to Plymouth BSP 105 teed Ernesettle BSP GT2. An arranged outage can be taken to maintain Landulph 605 with the rest of the circuit left in service; this leaves Ernesettle GT2 supplied from Plymouth 105. For all peak demand representative days, taking this arranged outage would overload the Ernesettle to Milehouse 132kV cable; the peak overload is 109% of rating for autumn or summer peak demand.

It is important to note that no overload occurs for a fault or arranged outage of the whole circuit from Landulph 605 to Plymouth 105 teed Ernesettle GT2. Taking Ernesettle GT2 off load leaves the Ernesettle load on GT1, in turn this alters load share around the 132kV interconnected network sufficiently to not overload the Ernesettle to Milehouse 132kV cable.

It is recommended that when Landulph 605 is maintained the whole circuit is switched out at Ernesettle and Plymouth; this prevents the demand-driven overload. This puts Ernesettle at single circuit risk, but in the event of a subsequent fault the lost load can be recovered via the B-route from Plymouth following the fault.

Assuming that the maintenance outage of Landulph 605 is taken as recommended above, the subsequent 400kV fault of either Abham SGT and the associated 400kV network would overload the Ernesettle to Milehouse cable up to 142% for autumn, 139% for summer and 135% for winter peak demand cases.

Whilst overlaying the Ernesettle to Milehouse cable would resolve the overloads described above, it may not be the most efficient, coordinated and economical solution for the wider network. Detailed studies of this area of network should be undertaken to determine the most effective whole system solution. Short-term ratings, load management schemes, flexibility services and reinforcement should be considered as means to ensure a sufficient access window is available.

Totnes GT overload

Totnes BSP has two 22.5/45MVA transformers, with a transformer teed off either side of H-route. There is an SCO combination of the 132kV circuit between Abham 305 and Totnes GT2/Plympton GT, followed by the circuit fault between Plymouth 405 and Plympton GT1, which would result in the entire Plympton demand back fed via the 33kV bar at Totnes. Totnes GT1 would supply the entire Plympton and Totnes demand; causing significant reverse power flow on GT2. This would result in an overload of both grid transformers at Totnes for all demand and generation representative days. For this SCO combination the grid transformer GT1 at Totnes would overload, with the highest loading as much as 180% for autumn, 168% for winter and 123% for summer peak demand representative days.

It is recommended that any arranged outage that requires Abham 305 to be out of service, the circuit is also switched out so Totnes GT2 is taken off load. For the SCO fault described above, this will cause a Plympton lost load, which can be safely managed. For this scenario, there is no P2/6 requirement to restore demand following the SCO as the group demand is below 100MW.

Landulph SGT Capacity

Landulph GSP has three 240MVA SGTs, with two normally run in-service and one run on hot-standby. This running arrangement was originally due to fault level constraints but studies have shown that having all three SGTs in-service increases the SGT infeed into the Landulph and Abham group, which increases the intact loading on the Ernesettle to Milehouse cable.

For the SCO combination of:

- The arranged outage of any one of:
    - The 132kV circuit Abham → Plymouth teed Totnes, or
    - The 132kV circuit Abham → Plympton teed Totnes
- And the fault of either of the SGTs on load at Landulph,

There is a risk that the remaining SGT in service at Landulph would be loaded up to 110% of its nameplate rating for an autumn peak demand case and 107% for a winter peak demand case.

This overload does not occur for summer peak demand or peak generation cases. It is recommended that the adequacy of the available access window for the SGTs is assessed. If it is not long enough, National Grid may be able to determine short-term ratings for the SGTs which allow loading to be managed by post-fault network reconfiguration.

Exeter SGT Capacity

Exeter GSP has 3 SGTs, with one currently run on hot-standby due to fault level constraints. There is currently no auto-close scheme to switch in the hot-standby SGT for the fault of either in-service SGT.

SGT Fault

For a first circuit fault which results in the loss of an SGT at Exeter for an autumn or winter peak demand case, there is a risk that the remaining SGT would overload to between 103% of nameplate rating. No overload occurs for a summer peak demand case. National Grid has confirmed this is within the 285MVA short-term ratings of the SGTs, assuming the pre-fault loading is below 202MVA.

SGT SCO

Significantly higher loadings are seen for the arranged outage of the 132kV circuit from Abham 105 towards Paignton and Newton Abbot (R-route and CC-route) followed by a fault of either in-service Exeter SGT. This leaves the remaining SGT with a loading up to 143% (344MVA) for an autumn peak demand case and 151% (363MVA) for a winter peak demand case. This overload will only persist for the time taken for National Grid to switch in the hot-standby SGT.

The SGT overload does not occur for a summer peak demand case or summer maximum generation, so the available access window should be assessed to determine if it is sufficient for all arranged outages that can cause the overload following the subsequent SGT fault.

If a summer access window is not sufficient, it is recommended that a discussion with National Grid is had to determine if these overloads are within the short-term ratings of the Exeter SGTs or if any operational mitigation is in place to manage these overloads.

Abham to Exeter 132kV network

The 400kV network between Exeter and Langage consists of a double circuit, with an Abham SGT teed off either circuit. For the arranged outage of Exeter 400kV X305 towards Abham SGT2, Abham SGT2 is only supplied via Langage 400kV. The subsequent fault of Abham SGT1 initiates the Abham 230 auto-close scheme, coupling the Abham 132kV main and reserve bar.

Due to the reduced 400kV infeed to Abham SGT2, for a summer peak generation representative day there is a risk that the direct 132kV interconnection between Exeter GSP and Abham GSP overloads up to 106% of its seasonal rating, also the C-route between Newton Abbot and the R-route tee to 101% of rating.

It is recommended that for the arranged outage of Exeter 400kV X305, Abham SGT2 is also taken out of service and Abham 230 is closed to prevent overloads for the subsequent fault of Abham SGT1.

Tiverton BSP

Tiverton BSP is supplied via two 22.5/45MVA transformer fed on transformer feeders from Exeter Main GSP. For an FCO (arranged or fault) of either transformer, the remaining transformer would overload up to 110% of rating for an autumn representative day.

These transformers were previously assigned an enhanced rating that would resolve the studied overloads. Both transformers should be reassessed in accordance with BS IEC 60076-7 (Loading guide for oil-immersed power transformers). If a suitable enhanced rating cannot be achieved, then it is recommended that both transformers are replaced with larger units.

Landulph/St Germans BSP Group

Landulph and St Germans BSPs are normally run in parallel on the 33kV network. Landulph BSP has a single 22.5/45MVA transformer and St Germans has two 40/60MVA transformers. St Germans GT1 is fed from Indian Queens GSP and GT2 is fed from Landulph GSP; this forms a loose couple between the Alverdiscott/Indian Queens group and the Abham/Exeter/Landulph group. Landulph GT2 is fed via a transformer feeder from Landulph GSP.

FCO Overload - Generation

For the first circuit fault of either grid transformer at St Germans, the grid transformer at Landulph would overload for a summer generation case, to as much as 103% of rating.

It is recommended a detailed 33kV assessment is undertaken to determine if any generation can be moved out of group under summer intact conditions to prevent this first circuit fault overload.

The loading of Landulph GT2 under this condition is dominated by the output of solar generators. Due to this cyclic loading pattern, they are only overloaded for a few half-hours of the summer generation representative day around the time of solar peak output. It is recommended that Landulph GT2 is assessed in accordance with BS IEC 60076-7 (Loading guide for oil-immersed power transformers) to determine whether a suitable enhanced rating can be applied for solar cyclic duty.

SCO Overloads – Demand and Generation

An SCO combination of an arranged outage of a grid transformer at St Germans, followed by a fault of the other St Germans grid transformer would overload Landulph GT2 to 192% for summer peak generation, 180% for autumn peak demand, 170% for winter peak demand and 123% for summer peak demand representative days.

Transferring primaries out of group can help reduce/remove the demand-driven overloads, but was shown to exacerbate the generation-driven overload if primaries with a net demand at times of generation peak are transferred out of group. There is insufficient generation transfer out of group for the arranged outage to not cause significant overloads for the second circuit fault for a summer peak generation representative day without curtailing the output of some generators.

The SCO combination of an arranged outage of a grid transformer at St Germans, followed by a fault of the Landulph grid transformer would overload the remaining St Germans grid transformer to 145% for a summer peak generation representative day. The magnitude of this overload is lower because the St Germans grid transformers are 40/60MVA, compared with 22.5/45MVA at Landulph. This SCO combination would also overload the Indian Queens to St Austell circuit to 130% for a summer peak generation representative day.

Due to the magnitude of the SCO overloads on this network, it is recommended that for the arranged outage of either St Germans grid transformer, the 33kV network should be split pre-emptively to ensure the subsequent fault of the remaining St Germans grid transformer does not significantly overload the remaining grid transformer in service. Detailed 33kV studies will be required to determine if the 33kV split is possible.

For the arranged outage of Landulph GT2, the group cannot be practically split to mitigate the overload caused for the fault of one of the St Germans grid transformer. To enable this

arranged outage during summer, operational measures are required to mitigate the generation overload. There is no overload for a summer peak demand representative day for this SCO combination. As the majority of generation in the group is connected at 33kV, transferring primaries out of group was shown to exacerbate the problem as they are predominately net demand primaries at time of generation peak. Transferring all the 33kV generation possible out of group reduces the overload to 112%. It may be possible to achieve a summer access window through use of flexibility.

Autumn and winter peak demand representative days would also overload the remaining grid transformer for this SCO combination. Transferring primaries onto Ernesettle and St Austell at 33kV would help for the autumn peak demand case; however due to the magnitude of 33kV generation on this BSP group it is recommended that a spring or autumn peak generation case is also assessed if a summer access window is deemed insufficient.

Paignton Overload

Paignton BSP has two 60/90MVA transformers and is supplied via a double circuit (R-route) from Abham BSP; the side that supplies Paignton GT1 has a tee onto C-route supplying Newton Abbot GT2. Newton Abbot 120 is normally closed, forming one of the interconnected circuits between Abham GSP and Exeter GSP.

The arranged outage for the maintenance of line breaker 105 at Abham, followed by a subsequent fault of the Exeter GSP to Newton Abbot circuit leaves Newton Abbot BSP back-energised from the 33kV bar at Paignton. This SCO combination would overload the R-route up to 150% of seasonal rating for all representative days, as well as Paignton GT2 to as much as 180% and GT1 also marginally overloaded.

It is recommended that any arranged outage that requires Abham 305 to be maintained, Paignton GT2 is also taken off load to stop the SCO described above causing significant overloads.

Alverdiscott & Indian Queens GSPs

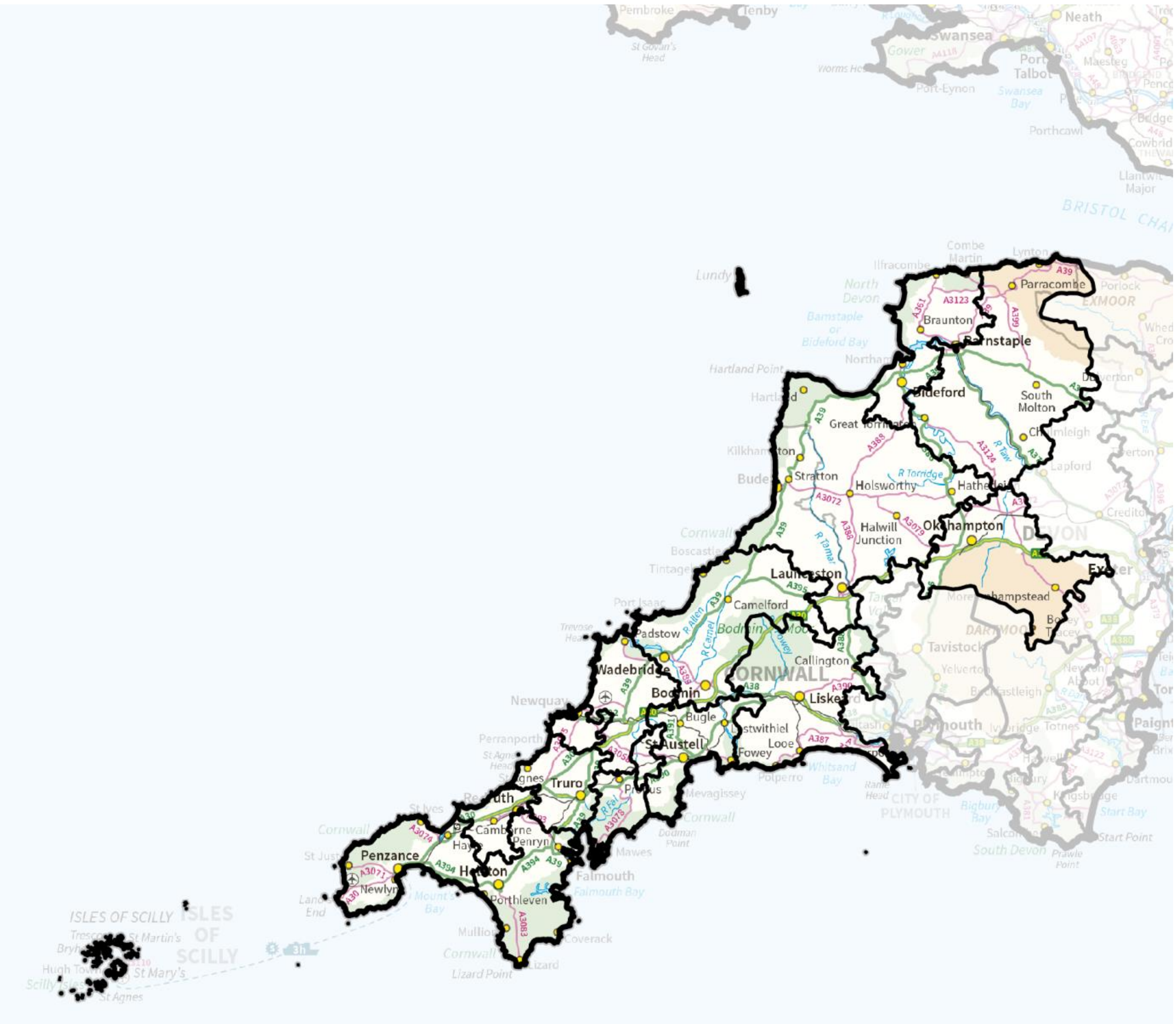

Figure 37: Area supplied by Alverdiscott and Indian Queens GSPs.

Alverdiscott GSP and Indian Queens GSP are interconnected at 132kV and take supplies from the 400kV transmission network via six 240MVA SGTs (two at Alverdiscott, four at Indian Queens). The two GSPs are interconnected at 132kV via the double circuit K-route, which includes an oil filled cable section underneath the River Torridge. The K-route has Pyworthy BSP, ST Tudy BSP and a number of 132kV generators connected.

Alverdiscott SGT Capacity

For the summer peak generation case, various SCO combinations would overload the SGTs at Alverdiscott.

The conditions causing the highest reverse power-flow loadings on Alverdiscott SGT1 are:

1. The arranged outage of Indian Queens 400kV 305 breaker towards Alverdiscott, where the 400kV circuit is left in-service, followed by the fault of Taunton SGT2 and associated 400kV

busbar (Taunton SGT2 has a HV isolator only). The overload is up to 103% of the nameplate rating.
2. The arranged outage of St Tudy main 1 busbar followed by a fault of Alverdiscott SGT2 overloads SGT1 to 102% of nameplate rating.

The conditions causing the highest reverse power-flow loadings on Alverdiscott SGT2 are:

1. The arranged outage of Indian Queens 400kV main 2 busbar and SGT2, followed by a 400kV fault of the circuit supplying Alverdiscott SGT1. This leaves SGT2 at 109% of rating.
2. The arranged outage of the Indian Queens to St Tudy 132kV circuit, followed by a 400kV fault of the circuit supplying Alverdiscott SGT1. This leaves SGT2 at 106% of rating.

It is recommended the short-term reverse power-flow ratings of both Alverdiscott SGTs are confirmed with National Grid.

K-route Overloads

North Devon Demand

An arranged outage of Alverdiscott Main 2 busbar removes one of the K-route circuit infeeds into the North Devon Group (Barnstaple, East Yelland and North Tawton). A subsequent fault of Alverdiscott SGT1 leaves Barnstaple, East Yelland and North Tawton supplied from Indian Queens via the remaining in-service K-route circuit. Currently, the thermal constraint on this circuit is the oil filled cable section underneath the River Torridge. This condition is showing as so onerous the network model did not convergence. The baseline winter peak group demand of Barnstaple, East Yelland and North Tawton is 147.5MW. The highest loading is 141.5MW for an autumn peak demand case and 121MW for a summer peak demand case. This leaves the remaining in-service River Torridge cable over 130% of its rating for all demand representative days studied.

It is recommended that for any arranged outage that takes an Alverdiscott 132kV busbar out of service, the remaining in-service K-route circuit is opened at Alverdiscott to split Indian Queens and Alverdiscott; this prevents the overload on the Torridge cable.

The fault of the remaining Alverdiscott SGT causes the lost load of East Yelland, Barnstaple and North Tawton (Main 2 arranged only), this can be picked up in stages via K-route and 33kV transfers and remains P2/6 complaint without overloading the River Torridge cable. Once the ongoing River Torridge cable reinforcement is completed this overload will no longer occur and the entire North Devon group can be supplied via a single K-route circuit.

As an alternative to splitting the network under arranged outage in anticipation of a subsequent fault, thermal overload protection could be fitted to the line circuit breakers at Alverdiscott facing towards the River Torridge cables. This could be set to automatically split the network in the event of an overload affecting the cables.

Pyworthy Area – Generation Constraints

For the arranged outage to maintain line breaker 505 at Indian Queens, Pyworthy and North Tawton are pre-emptively split on the 33kV network to mitigate the second circuit fault of the remaining 132kV infeed into Pyworthy. This arranged outage leaves Pyworthy BSP and two 132kV connected generators supplied from Alverdiscott GSP, via the K-route. This area has a high penetration of solar PV generation, as a result for a summer peak generation representative day this area is exporting real power. For this arranged outage, the oil filled cable sections of the K-route would be overloaded up to 110% for the summer peak generation representative day.

This overload does not occur for the fault condition between Indian Queens and Pyworthy because the 33kV interconnection between North Tawton is not automatically split, so more of the 33kV generation exports via North Tawton. In addition, a 132kV generator and grid transformer at Pyworthy are disconnected as part of the fault isolation which reduces the generation export. This flow is exacerbated for a SCO combination that disconnects an Indian Queens SGT and the associated 400kV network, which increase the loading on the circuit up to 120%.

The cable overlay of the oil filled section underneath the River Torridge is sanctioned and currently in progress, once complete this overload will no longer occur. Prior to work competition, careful consideration should be given whilst taking the arranged outage of the Indian Queens 505 circuit. Two options to remove the first and second circuit overloads are:

1. **Curtailing additional generation that is exporting via the Pyworthy to Torridge cable**
2. **Move more generation onto the North Tawton side of the 33kV split will remove the overload. Detailed assessment will be required to ensure that the North Tawton transformer remains within rating and 33kV thermal and voltage constraints are not exceeded.**

Indian Queens to Camborne 132kV circuit

Camborne and Hayle BSPs are supplied via a 132kV ring, with the northern infeed fed from Indian Queens 305; this circuit is also teed to Fraddon GT1. The southern side of the ring is the single circuit CC-route connecting Hayle and Rame BSP, with a tee to Fraddon GT3 and an infeed from Indian Queens 205. This complex network topology is best understood by reading the attached schematic, *South West subtransmission schematic 2018 (Devon and Cornwall)*.

The arranged busbar outage of Fraddon Main 3 removes the infeed into the Hayle and Camborne group that is teed onto CC-route between Rame and Hayle. A subsequent fault of the circuit between Rame and Truro GT1 removes another infeed into the group and disconnects Rame main 2 busbar, which leaves GT1 at Rame fed via Camborne/Hayle and GT3 via L-route. This leaves a portion of Rame supplied via the Camborne/Hayle ring.

For this SCO combination there would be a risk of overloads for an autumn peak demand representative day on the A-route. The section between Indian Queens 305 and Fraddon GT1 tee would overload to 111% of rating, the section from Fraddon GT1 tee to Camborne would overload to 108% of rating.

This overload does not occur for summer peak demand or peak generation cases. The available access window should be assessed. If it is not long enough, alternative running arrangements should be considered.

Fraddon BSP

Fraddon BSP is currently undergoing reinforcement due to the significant generation growth in the area. Prior to the reinforcement Fraddon had two grid transformers, which will not be changed as part of the reinforcement works. GT1 is a 30/60MVA transformer and is run in parallel on the 33kV with Truro BSP. GT2 is a 40/60MVA unit and is run in parallel on the 33kV with St Austell BSP.

The ongoing reinforcement works are to install a new 33kV board fed by two new 60/90MVA transformers. Demand and generation will be transferred from the existing GT1 and GT2 onto the new board to manage the growth in the area. This work is due to be completed in summer 2018; for the purposes of these studies the model is assumed as post-reinforcement, as the works are currently ongoing.

Following the reinforcement, the arranged outage of Fraddon GT2, followed by a fault of either St Austell transformer overloads the remaining St Austell transformer and circuit up to 108% for the summer generation representative day.

The arranged outage of Fraddon GT2, followed by a fault of either Truro transformer overloads the remaining Truro and circuit up to 148% for the autumn and winter peak demand representative days.

It is recommended that for the arranged outage of Fraddon GT1 or GT2, the associated 33kV interconnector with the new GT3/GT4 board is closed to mitigate the described SCO condition. Detailed studies of the 33kV network will be required to support this running arrangement.

8 – 2020 Results

The development of the scenarios to 2020 comprises:

- New generation and storage, dominated by the pipeline of Accepted-not-yet-Connected customers, and
- New demand, dominated by conventional domestic, industrial and commercial demand growth derived from local plans and similar publications.

Melksham GSP

No new reinforcement requirements were identified in the 2020 scenarios for WPD's network supplied from Melksham GSP.

Iron Acton GSP

SGT capacity

SS SP CP TD

By 2020, the combined WPD group demand in the Iron Acton 132kV network is projected to grow from 663MW to between 742MW (Slow Progression and Steady State) and 815MW (Consumer Power).

These studies highlighted several apparent demand-driven SGT overloads for various FCO and SCO conditions. Although there is sufficient SGT capacity at Iron Acton to meet demand under at least Slow Progression and Steady State, switchgear limitations may prevent appropriate load sharing and so cause overloads.

It is recommended that work is undertaken between WPD and National Grid to understand the MW capacity limits of Iron Acton GSP, and how these interact with fault level constraints. For these studies, the following reinforcement was assumed:

- **The installation of a 132kV Reserve busbar section breaker 160;**
- **Closing all 132kV section and coupler breakers to run the 132kV bar solid;**
- **Replacing the remaining 180MVA SGTs (SGT1 and SGT2) with 240MVA units.**

This resolved all SGT overloads except for some winter and autumn peak demand SCO overloads; this would leave the site with a summer-only access window. It may be possible to extend the access window through the use of short-term ratings and post-fault load transfers. Running the 132kV bar solid would require extensive fault level reinforcement – alternative reinforcement schemes may prove more economic.

Feeder Road BSP GT capacity

SS SP CP TD

By 2020, the combined group demand of the Feeder Road 33kV networks is projected to grow from 188MW to between 202MW (Slow Progression) and 210MW (Consumer Power).

Feeder Road BSP has four 132/33kV, 90MVA GTs. The 33kV bar is normally operated in two sections:

- One section is supplied by GT1 and GT3;
- The other section is supplied by GT2 and GT4.

For the arranged or fault outage of any one GT, the 33kV bar is coupled solid. For transformer faults and 132kV line faults, this is achieved by a hardwired auto-close scheme.

Iron Acton GSP has limited 132kV bussing both at the GSP and at remote sites. Because of this, load share between GTs at Feeder Road is dependent on a complex combination of conditions including busbar splits at Iron Acton and 33kV or 11kV running arrangements at other BSPs.

GT SCO

For various SCO combinations, the Feeder Road 33kV bar is left coupled solid and supplied by two GTs. For winter and autumn peak demand cases, this would overload one or both of the remaining GTs to between 101% and 108% of rating. No overload occurs for a summer peak demand case.

It is recommended that a wider suite of transformer ratings is developed, including accurate ratings for the seasons between summer and winter. This is likely to resolve the projected autumn overload in at least some scenarios.

It is recommended that the adequacy of the available access window for the GTs and associated 132kV circuits is assessed. If it is not long enough, short-term ratings, load management schemes, flexibility services and reinforcement should be considered as means to extend it. Feeder Road 33kV bar could be deloaded by commissioning 132/11kV GTs at Feeder Road BSP and transferring load from either of the existing 33/11kV primary substations on site.

Iron Acton 132kV busbar fault

A 132kV busbar fault at Iron Acton GSP will offload a GT at Feeder Road BSP without triggering the 33kV bar auto-close scheme. This leaves one section of the 33kV bar supplied by a single GT.

For an autumn peak demand case, the fault outage of 132kV busbar Reserve 1 at Iron Acton would overload Feeder Road GT3 to 103% of rating. Similarly, the fault outage of 132kV busbar Reserve 2 at Iron Acton would overload Feeder Road GT1 to 101% of rating.

It is recommended that a wider suite of transformer ratings is developed, including accurate ratings for the seasons between summer and winter. This is likely to resolve the projected overloads. If it does not, options for preventing these overloads include:

- **Extending the Feeder Road 33kV bar auto-close scheme to be triggered by 132kV busbar faults at Iron Acton GSP; or**
- **Transferring some load within the Feeder Road 33kV bar from the section supplied by GT1 and GT3 to the section supplied by GT2 and GT4.**

Seabank GSP

SGT capacity and transmission infeed

SS SP CP TD

By 2020, the group demand of the Seabank 132kV network is projected to grow from 273MW to between 304MW (Slow Progression) and 327MW (Two Degrees and Consumer Power). Under Consumer Power and Two Degrees, the proposed transfer of Kingsweston primary (see *Avonmouth GT Capacity* below) would result in a group demand of 308MW.

The growth of group demand to more than 300MW would move Seabank GSP into class E of P2/6, introducing a requirement to immediately supply all customers at prevailing demand levels for an arranged outage followed by a fault. This effectively requires three or more infeeds into the group. Since Seabank is only supplied by two 400kV circuits, this condition would not be met.

The planned development of the network to enable the connection of Hinkley Point C includes the transfer of Weston BSP onto the new Sandford GSP, and additional infeed to Seabank 132kV through parallel operation with Sandford GSP. These works, which are expected to be completed in 2023, would meet the class E condition. In that light, it is recommended that options for deferral are considered. These could include:

- **Demand transfers out of group**
- **Temporary parallel operation with Iron Acton GSP at 132kV**
- **Flexibility services**

Due to the demand growth, the SCO of any two SGTs would overload the remaining SGT in the summer peak demand case as well as the autumn and winter peak demand cases. The magnitude of the summer overload varies from 102% of nameplate rating (Slow Progression) to 114% of nameplate rating (Two Degrees).

Given the relatively small overloads, it is recommended that short-term ratings and post-fault load transfers are agreed with National Grid to manage this constraint until it is resolved by the planned development of the network to enable the connection of Hinkley Point C.

Weston BSP GT capacity

CP TD

By 2020, the group demand of the Weston 33kV network is projected to grow from 63MW to between 69MW (Steady State and Slow Progression) and 72MW (Two Degrees and Consumer Power).

Weston BSP has two 60MVA GTs. Under Two Degrees and Consumer Power, the fault loss of either GT in autumn would overload the remaining GT to between 102% of rating for an autumn peak demand case.

It is recommended that a wider suite of transformer ratings is developed, including accurate ratings for the seasons between summer and winter. This is likely to resolve this projected overload.

Avonmouth BSP GT capacity

CP TD

By 2020, the group demand of the Avonmouth 33kV network is projected to grow from 81MW to between 97MW (Slow Progression) and 110MW (Consumer Power and Two Degrees). Avonmouth BSP is dominated by industrial demand. Because of this, the demand remains high all year round.

Avonmouth BSP has two 90MVA GTs. Under Consumer Power and Two Degrees, the fault loss of either GT in summer or autumn would overload the remaining GT to between 102% and 105% of rating.

It is recommended that a reinforcement scheme is developed to transfer Kingsweston primary substation from Avonmouth BSP onto new 33kV circuits from Seabank BSP, 5km away. This reinforcement scheme should be triggered as necessary. This would also resolve the projected 132kV overloads described below in *Avonmouth/Weston 132kV ring*, and help mitigate Seabank GSP's SGT capacity and transmission infeed constraints.

Avonmouth/Weston 132kV ring

CP TD

Avonmouth BSP and Weston BSP are supplied by two 132kV circuits from Seabank GSP. Avonmouth BSP has a GT teed-off from each circuit; the circuits continue to Weston BSP where they are ringed together via circuit breaker 120 and supply two GTs. By 2020 the combined group demand of Avonmouth and Weston is projected to grow from 145MW to between 166MW (Slow Progression and Steady State) and 182MW (Consumer Power and Two Degrees).

FCO first leg overload

Under Consumer Power and Two Degrees, the fault loss of either 132kV circuit into the group would overload the remaining circuit to between 102% and 106% of rating for a summer or autumn peak demand case. The rating of each circuit is constrained by a short length of cable from the 132kV GIS switchgear at Seabank GSP to the terminal tower of the G-route tower line.

It is recommended that a reinforcement scheme is developed to transfer Kingsweston primary substation from Avonmouth BSP onto new 33kV circuits from Seabank BSP, 5km away. This reinforcement scheme should be triggered as necessary. This would also resolve the projected GT overloads described above in *Avonmouth GT Capacity*.

As part of the Hinkley Point C connection works, Weston BSP will be transferred to Sandford GSP in 2023, resolving these overloads.

SCO F-route overload

For the SCO of:

- The arranged outage of the first leg of either 132kV circuit from Seabank GSP to Avonmouth BSP; followed by
- The fault outage of the GT at Avonmouth BSP connected to the *other* 132kV circuit from Seabank GSP to Avonmouth BSP

Avonmouth BSP is left supplied via the 132kV bar at Weston BSP. Under Consumer Power and Two Degrees, this would overload part of the 132kV circuit from Avonmouth BSP to Weston BSP to as much as 118% of rating for all demand cases. This running arrangement also exacerbates the overloads described above in *FCO first leg overload.*

To prevent these overloads, it is recommended that when taking an arranged outage of a 132kV circuit between Seabank GSP and Avonmouth BSP, the associated GT at Avonmouth is taken offload.

Bridgwater & Taunton GSPs

SGT and interconnector capacity

SS SP CP TD

By 2020, the group demand of the Bridgwater/Taunton 132kV network is projected to grow from 372MW to between 398MW (Steady State) and 428MW (Two Degrees). This exacerbates the existing constraints to the extent that no access window remains for the SGTs at Bridgwater, Taunton and Hinkley Point or the 132kV circuits between Taunton and Bridgwater under any scenario.

For the SCO of any two SGTs in the Bridgwater/Taunton group, the remaining SGT would overload for all demand cases, to as much as 182% of nameplate rating.

For the SCO of both SGTs at Bridgwater or both SGTs at Hinkley Point, Taunton SGT2 would overload for all demand cases, to as much as 196% of nameplate rating. Both 132kV circuits from Taunton to Bridgwater would also overload.

For the SCO of Taunton SGT2 and either 132kV circuit from Taunton to Bridgwater, the remaining 132kV circuit from Taunton to Bridgwater would overload for all demand cases.

The growth of DG across the South West to 2020 exacerbates the issue of through-flow between Bridgwater and Taunton for 400kV outages, as described in the baseline results.

It is recommended that, if possible, the commissioning of Taunton SGT1 is brought forward from 2021 to resolve these overloads. To enable the management of busbar outages, SGT1 should be connected to section 1 of the 132kV bar at Taunton.

For these studies it was assumed that, following the commissioning of Taunton SGT1, the 132kV parallel between Bridgwater and Taunton will be split. This resolves the issues of Hinkley Point station demand fed via WPD network and through-flow between Bridgwater and Taunton for 400kV outages.

Until Churchill BSP is permanently transferred away from Bridgwater GSP, the FCO of either SGT at Bridgwater would overload the remaining SGT at up to 129% of rating. For arranged outages, this can be prevented by transferring Churchill BSP onto Seabank GSP. For fault outages, it would be necessary to agree short-term ratings and post-fault load transfers with National Grid. If this is not possible, it would be necessary to retain the 132kV parallel between Bridgwater and Taunton, with appropriate Load Management Schemes and operational measures to manage the issues of Hinkley Point station demand fed via WPD network and through-flow between Bridgwater and Taunton for 400kV outages. Maintaining the 132kV parallel may also trigger the reinforcement of both 132kV circuits from Taunton to Bridgwater.

Bridgwater BSP and Street BSP GT capacity

SS SP CP TD

By 2020, the group demand of the Bridgwater/Street 33kV network is projected to grow from 185MW to between 192MW (Steady State) and 201MW (Two Degrees). This exacerbates the existing constraints to the extent that no access window remains for the GTs at Bridgwater and Street or the associated 132kV circuits under any scenario.

For the SCO of any two GTs in the Bridgwater/Street group, one or both of the remaining GTs would overload for all demand cases, to as much as 146% of rating.

It is recommended that an additional GT is commissioned in the Bridgwater/Street group at one or both of Bridgwater BSP and Street BSP. For these studies, the following arrangement was adopted:

- **The commissioning of a 60MVA GT4 at Bridgwater BSP, supplied from section 2 of the 132kV bar;**
- **Placing Bridgwater GT3 on hot-standby to avoid breaching 33kV fault level constraints, with an auto-close scheme to put GT3 on load for the loss of any other GT in the group;**
- **Commissioning a 132kV Reserve bus section breaker 160 at Bridgwater, and selecting the four on-load GTs to separate busbars to prevent overloads for busbar faults.**

The final choice of location for the new GT(s) should be made following detailed 132kV and 33kV studies.

Although access window flexibility services may be used to defer reinforcement for the SCO condition, it is unlikely to be economic to use flexibility services year round to defer reinforcement for busbar faults. A cost-benefit analysis should be performed to determine the best combination of reinforcement and flexibility services.

The transfer of Wells primary onto Radstock BSP for the arranged outage of a GT in the Bridgwater/Street group, followed by the fault loss of either GT at Radstock would overload the remaining GT at Radstock for the autumn peak demand case to around 107% of assigned rating.

It is recommended that a wider suite of transformer ratings is developed, including accurate ratings for the seasons between summer and winter. This is likely to resolve the studied overload.

Taunton BSP GT capacity

CP TD

By 2020, the group demand of the Taunton 33kV network is projected to grow from 89MW to between 104MW (Steady State) and 121MW (Two Degrees).

By 2020, Taunton BSP will have two 90MVA GTs, GT1 and GT2. Under Consumer Power and Two Degrees, the fault loss of either GT in autumn or winter would overload the remaining GT to between 107% and 119% of rating.

It is recommended that a reinforcement scheme is developed to commission a third 90MVA GT (GT3) at Taunton, and triggered as necessary. To prevent overloads for busbar faults, the Taunton 132kV busbar should be reconfigured in three sections, with a GT on each section and infeed (SGT or 132kV circuit from Bridgwater) on at least the outer two sections. The commissioning of SGT1 onto section 1 would achieve this without further works. If GT3 is commissioned before SGT1, a bus section breaker in the Main or Reserve 132kV bar at Taunton would be required.

It may be possible to defer this reinforcement through the use of flexibility services.

Under Slow Progression and Steady State, for an autumn peak demand case only, the FCO of either GT would overload the remaining GT to around 103% of assigned rating.

It is recommended that a wider suite of transformer ratings is developed, including accurate ratings for the seasons between summer and winter. This is likely to resolve this projected overload.

Abham, Exeter & Landulph GSPs

Landulph to Abham 132kV Network

SS SP CP TD

River Dart Cables and H-route

The overloads of the River Dart cables and H-route identified in the baseline results are exacerbated in 2020 under all scenarios, as the group demand grows from 319MW in the baseline to 342MW in 2020 Two Degrees. For the SCO combination that results in the loss of both AA-route 132kV infeeds from Landulph GSP into the interconnected group of Ernesettle, Milehouse, Plymouth, Plympton and Totnes the scale of overloads are summarised in Table 10.

Table 10: H route circuit section overloads for the described SCO combination in 2020

Circuit section	Scenario	Peak Demand Representative Day (% loading based on section rating)		
		Summer	Autumn	Winter
Abham 705 → Totnes tee No 1 (River Dart crossing)	SS	**124%**	**136%**	**131%**
	SP	**124%**	**136%**	**131%**
	CP	**130%**	**142%**	**135%**
	TD	**130%**	**142%**	**135%**
Totnes tee No 1 → Plymouth 205	SS	**116%**	**127%**	**123%**
	SP	**115%**	**128%**	**124%**
	CP	**121%**	**133%**	**128%**
	TD	**121%**	**133%**	**128%**
Totnes tee No 2 → Plympton 203	SS	**108%**	**122%**	**118%**
	SP	**108%**	**122%**	**119%**
	CP	**112%**	**125%**	**121%**
	TD	**112%**	**125%**	**121%**

Ernesettle to Milehouse 132kV circuit

The arranged outage to maintain line breaker 605 at Landulph was shown to overload the Ernesettle to Milehouse cable for the autumn, summer and winter peak demand representative days under all scenarios. In the baseline this could be operationally managed by taking the circuit and Ernesettle GT2 out of service for the arranged outage; this reduced flows on the Ernesettle to Milehouse cable to within rating for all representative days.

Projected demand growth in the area would overload the Ernesettle to Milehouse cable for a first circuit fault between Landulph 605 and Ernesettle GT2 up to 107% (Two Degrees) and 103% (Consumer Power). This means that the operational mitigation of taking the circuit and Ernesettle GT2 out of service for the arranged outage is no longer effective under Two Degrees and Consumer Power.

The arranged outage described above, followed by a 400kV fault of either Abham SGT or the 400kV circuit into Landulph increases the overload on the Ernesettle to Milehouse cable from 132% in the baseline study to:

- Between 151% (Two Degrees) and 141% (Steady State) for a winter peak demand representative day
- Between 160% (Two Degrees) and 153% (Steady State) for an autumn peak demand representative day
- Between 161% (Two Degrees) and 150% (Steady State) for a summer peak demand representative day

Combined reinforcement strategy

To alleviate both sets of projected overloads, a proposed reinforcement strategy is recommended that considers the complex interconnected nature of this GSP group. For these studies, a proposed reinforcement and reconfiguration of the 132kV running arrangement at Plymouth BSP was modelled. The proposed layout is shown in Figure 38; the works include:

- **Run with circuit breaker 120 open at Plymouth, to split the 132kV interconnection between Abham GSP and Landulph GSP**
- **Double bank the Milehouse to Plymouth 132kV circuits, terminating onto line breaker 305 at Plymouth and line isolator 103 at Milehouse, this gives two 132kV circuits from Abham towards Plymouth and two 132kV circuits from Landulph to Plymouth**
- **Installation of section circuit breakers 220 and 420 to split Plymouth into 4 132kV busbars, where 220 and 420 are normally run closed**
- **Installation of a 60MVA GT4 connected to Main 4 busbar and split the 33kV demand at Plymouth BSP equally between GT1/GT4 and GT2/GT3**
- **Reconductor both H-route circuits between Plymouth and the Totnes tees with 300mm² AAAC (Upas) @ 75°C**
- **Overlay the cable sections from Totnes to Abham GSP with 1600mm² Cu XLPE, this includes the section under the River Dart**

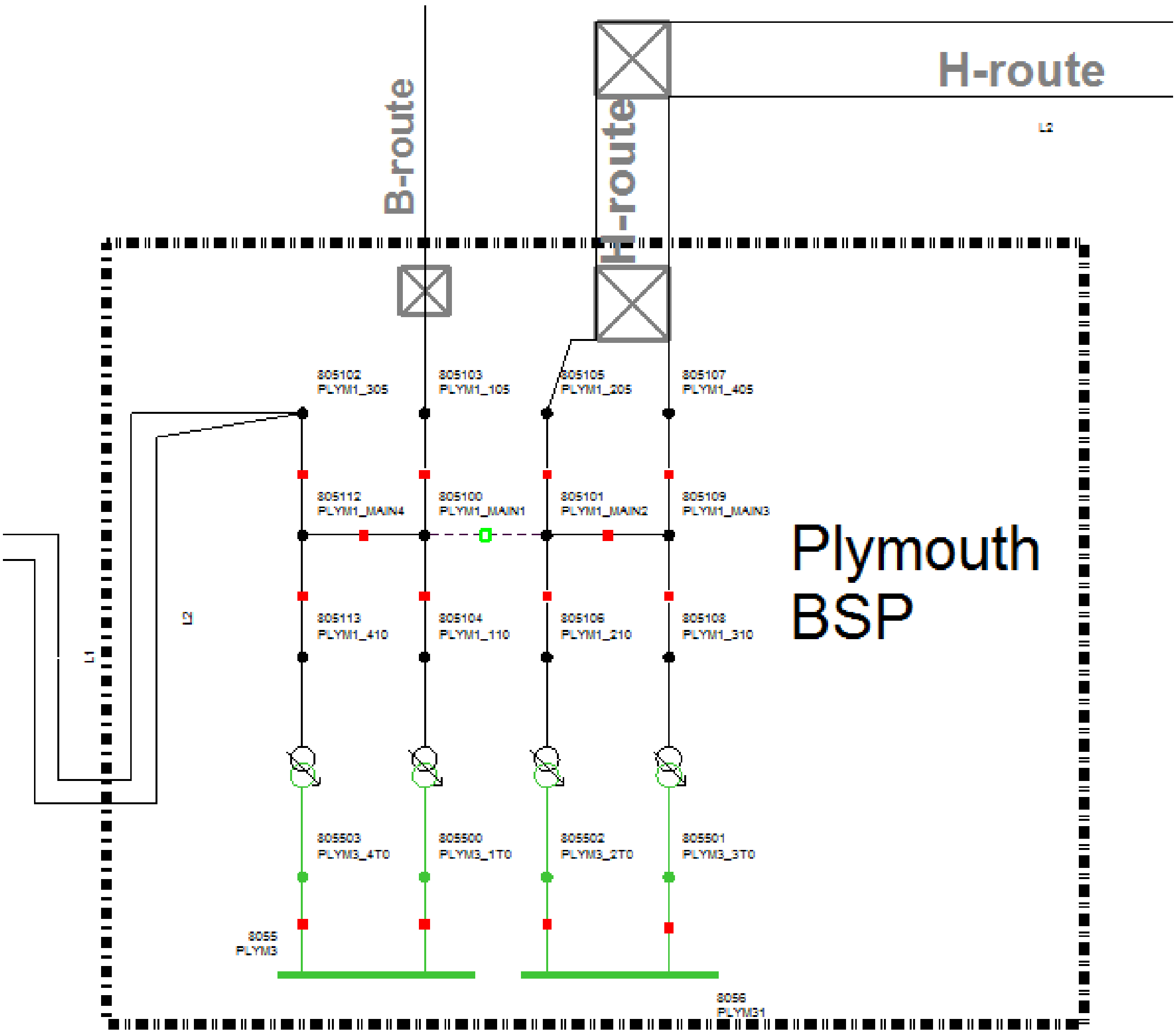

Figure 38: Proposed 132kV layout for Plymouth BSP

Although the proposed switchgear layout for Plymouth 132kV is single busbar, consideration should be given to a double busbar design that would facilitate load transfers that may allow the deferral of future reinforcement in response to further demand growth.

It may be possible to defer this reinforcement through the use of flexibility services.

Abham SGT Capacity

SS SP CP TD

Prior to the proposed Abham-Landulph Reinforcement Split

Any SCO combination that causes the loss of both AA-route circuits, as described in the Dart cables/H-route section above, would overload Abham SGT1 up to124% and Abham SGT2 up to 115% for an autumn and winter peak demand representative day. There is currently no overload for the summer peak demand case or peak generation case, so from an SGT capacity perspective there is still a summer access window before consideration must be given to the Abham SGT short-term ratings.

It is recommended the required outage for each side of AA-route is assessed. If a summer access window is not sufficient, Abham SGT short-term ratings should be confirmed with National Grid.

Following the proposed Abham-Landulph Reinforcement Split

The proposed Abham to Landulph 132kV split is described in the Landulph to Abham 132kV Network section above. This split causes a number of overloads on the Abham and Exeter interconnected network and SGTs if no reconfiguration is undertaken as part of the reinforcement works.

The Abham 230 bus coupler and 1005 direct interconnector with Exeter GSP are currently run normally open due to fault level constraints at Abham. The fault level constraint on the site is expected to be resolved by 2019, so it is recommended that Abham 230 and 1005 is run normally closed to mitigate first circuit overloads.

With Abham 1005 and 230 run normally closed, a fault of either Abham SGT overloads the remaining SGT up to 115% of the 240MVA nameplate rating during autumn and winter peak demand. Moving all of Plymouth BSP onto Landulph for this arranged outage reduces the loading on the remaining in-service SGT within nameplate rating. There are no SCO combinations identified that exacerbate the Abham SGT loadings beyond the FCO condition described above.

If the proposed split between Landulph and Abham at Plymouth BSP was implemented, careful consideration should be given to Abham SGT loadings. Migration of additional load at Plymouth onto the Landulph side of the split will reduce the Abham SGT loadings, but consideration must also be given to the loadings on the Milehouse to Ernesettle cable for the first circuit fault of the B-route.

Landulph SGT Capacity

SS SP CP TD

Demand growth in the Landulph area exacerbates the Landulph SGT overloads described in the baseline results. For the SCO combination of:

- The arranged outage of either one of:
  - The 132kV circuit Abham → Plymouth teed Totnes, or
  - The 132kV circuit Abham → Plympton teed Totnes
- And the fault of either of the SGTs in service at Landulph,

In 2020 the remaining SGT in service at Landulph would overload up to 126% for an autumn and winter peak demand representative day.

As with the baseline results, this overload does not occur for summer peak demand or peak generation representative days. The available access window should be assessed. If it is not long enough, short-term ratings should be confirmed with National Grid.

Exeter SGT Capacity

SS SP CP TD

The overloads described in the baseline results are exacerbated under all scenarios in the 2020 studies.

Prior to the proposed Abham-Landulph Reinforcement Split

SGT Fault

For a first circuit fault of an Exeter SGT, there is a risk that the remaining SGT would overload to between 148% (Two Degrees) and 130% (Steady State) of nameplate rating for an autumn or winter peak demand case. This overload is up from 103% in the baseline study, which is predominately due to the forecast conventional demand growth under all scenarios in the Exeter area.

SGT SCO

For the SCO combination of the arranged outage of Abham 105 towards Paignton and Newton Abham (R-route and CC-route) followed by a fault of either in-service Exeter SGT, the remaining SGT would overload for all peak demand representative days.

- 192% (Two Degrees) and 172% (Steady State) for a winter peak demand representative day
- 186% (Two Degrees) and 160% (Steady State) for an autumn peak demand representative day
- 147% (Two Degrees) and 122% (Steady State) for a summer peak demand representative day

These SCO overloads will only persist for the time required to switch-in the hot-standby SGT. At present, there is no auto-close scheme on the hot-standby SGT.

Combined reinforcement strategy

It is recommended a discussion is had with National Grid to determine the short-term ratings of the Exeter SGTs.

The access window for the Abham to Paignton circuit should be assessed to determine when it can be taken; ensuring the subsequent fault of the Exeter SGT does not exceed the SGT short-term rating. If the loading is within a short-term rating that permits manual switching, the hot-standby SGT at Exeter can be used to alleviate any overloads.

If the overloads for the FCO or SCO conditions are within a short-term rating that would not enable safe manual switching of the hot-standby SGT, then it is recommended an auto-close scheme is installed.

If the access window is not sufficient or the overloads exceed all short-term ratings then one of the following could be implemented:

- **Run the Exeter 132kV bars split into two sections, with two SGTs on one section and one SGT on the other section. Previous studies have shown this does not cause fault level issues and may be a viable running arrangement.**
- **Resolve the fault level constraints so all three SGTs at Exeter GSP can be run in parallel. The fault level constraints are on all site isolators, busbars and the earth grid. If no operational mitigation was available, resolving the fault level constraints, so the site could be run solid with all SGTs in-service would resolve all overloads.**

Following the proposed Abham-Landulph Reinforcement Split

Following the proposed split of Abham and Landulph GSPs at Plymouth BSP, the Exeter and Abham 132kV network would be supplied via two SGTs at Abham GSP and two SGTs at Exeter GSP, with a third at Exeter on hot-standby.

The arranged or fault outage of an Abham SGT overloads the two in-service Exeter SGTs for all demand representative days up to 108% of nameplate rating under Two Degrees and Consumer Power. No FCO overloads are seen under Slow Progression of Steady State.

Any SCO combination that causes the loss of both Abham SGTs overloads the two in-service Exeter SGTs to as much as 177% (Two Degrees) and 155% (Steady State).

It is recommended a detailed fault level study is undertaken to determine if all three Exeter SGTs can be run in parallel for the loss of one or both Abham SGTs. Running all three Exeter SGTs in parallel for the loss of both Abham SGTs and transferring Plymouth and Plympton BSP onto Landulph GSP resolves all overloads under all scenarios.

Abham to Exeter 132kV network

Significant demand growth is forecast at Newton Abbot BSP under the Consumer Power and Two Degrees scenarios. Newton Abbot is supplied via AH-route from Exeter GSP and C-route/R-route from Abham GSP. Newton Abbot BSP has two 60/90MVA transformers with the 120 breaker run normally closed, meaning the AH-route and C-route form a 132kV interconnection between Exeter GSP and Abham GSP.

Newton Abbot BSP

CP TD

For a first circuit fault of either of the grid transformers at Newton Abbot, the remaining grid transformer at Newton Abbot would overload up to 117% for autumn and 103% for a winter peak demand representative day under Two Degrees and Consumer Power only.

AH-route

SS SP CP TD

For the first circuit fault resulting in the loss of the direct infeed from Abham GSP to Newton Abbot, the Exeter GSP to Newton Abbot circuit (AH-route) is overloaded up to 112% for an autumn peak demand case, and up to 106% for a winter peak demand case. This circuit fault overload only occurs under Two Degrees and Consumer Power.

The first circuit busbar fault of Abham Main 1 exacerbates the overload as AH-route also supplies part of the demand at Paignton BSP via Newton Abbot. The overload increases to 122% (Two Degrees) and 106% (Steady State) for an autumn peak demand representative day.

It is recommended that Bradley Lane primary, normally fed out of Newton Abbot BSP is permanently transferred onto Torquay BSP at 33kV. Bradley Lane currently has a peak demand of 15MW, this transfer is sufficient to remove the transformer and circuit overloads under all scenarios without causing any overloads at Torquay or the associated 132kV circuits.

Marsh Barton to Sowton tee 132kV circuit

SP CP TD

Exeter City GT3 and Marsh Barton power station are normally fed from Exeter GSP, with Sowton teed off either side of the double circuit (AE-route). Any first circuit fault or arranged outage that takes Exeter City GT2 out of service results in all of the Exeter City BSP and Marsh Barton generation exporting through the AE-route towards Exeter GSP for a summer peak generation case. This first circuit outage would overload the AE-route between the Sowton tee and Marsh Barton power station up to 102% under Two Degrees scenario.

It is recommended the existing 175mm² ACSR (Lynx) conductors on the AE-route between the Sowton tee and Marsh Barton power station are reprofiled for 75°C operation.

Tiverton BSP

SS SP CP TD

Tiverton BSP has two 22.5/45MVA transformers fed out of Exeter GSP on transformer feeders. The first circuit fault or arranged outage of either transformer would overload the remaining in-service transformer to as much as 126% (Two Degrees) and 118% (Steady State) for an autumn and winter peak demand representative day.

It is recommended the existing 22.5/45MVA Tiverton transformers are replaced with larger units. For the purpose of these studies, two 40/60MVA transformers have been modelled.

Landulph/St Germans BSP Group

SS SP CP TD

FCO Overloads - Generation

The first circuit fault of either St Germans gird transformer exacerbates the summer generation-driven overload on the Landulph grid transformer up to as much as 109% under Two Degrees; this is compared with 103% in the baseline study.

For an arranged outage of either grid transformer at St Germans, the 33kV interconnection between Landulph and St Germans should still be pre-emptively split to protect against the next circuit fault; this will prevent the entire group being supplied from one grid transformer. For this arranged outage, the remaining grid transformer at St Germans would overload up to 104% for a summer peak generation case under Two Degrees.

SCO Overloads – Demand and Generation

For the arranged outage which removes the 132kV infeed to Landulph BSP, followed by a fault of St Germans GT2, the entire Landulph / St Germans BSP group is supplied via the AY-route and B-route from Indian Queens. The AY-route is also teed to St Austell GT2. This SCO condition would overload the AY-route section between Indian Queens and St Austell tee to:

- 129% (Two Degrees) and 118% (Steady State) for a winter peak demand representative day
- 133% (Two Degrees) and 124% (Steady State) for an autumn peak demand representative day
- 109% (Two Degrees) for a summer peak demand representative day

A similar SCO combination of an arranged outage of St Germans GT2 followed by the fault of the clean Indian Queens to St Austell Circuit causes all of St Austell BSP and St Germans BSP to be supplied via the Indian Queens to the St Austell tee. This SCO condition would overload the AY-route circuit between Indian Queens and St Austell tee up to 135% (Two Degrees) and 118% (Steady State) for a summer peak generation representative day.

The highest St Germans grid transformer overloads are demand-driven, for the arranged outage of Landulph GT2 followed by a fault of either St Germans transformer, this causes the following overloads:

- 146% (Two Degrees) and 135% (Steady State) for a winter peak demand representative day
- 155% (Two Degrees) and 145% (Steady State) for an autumn peak demand representative day

- 117% (Two Degrees) and 104% (Steady State) for a summer peak demand representative day

Combined reinforcement strategy

Due to the growth in the area and the challenges of operating a three transformer group, it is recommended that a second 40/60MVA transformer is installed at Landulph BSP on a 132kV transformer feeder from Landulph GSP. It is also recommended that the group is normally split on the 33kV to remove the challenges of operating an interconnected network. Detailed 33kV assessment will be required to determine the most appropriate split on the 33kV and if any works will be required.

The section of the AY-route from Indian Queens to St Austell/St Germans tee should also be reconductored with 300mm² AAAC (Upas) @ 75°C to resolve the overload seen for the SCO condition described above.

Sowton BSP and 132kV circuits to Exeter GSP

Sowton BSP has two 60/90MVA transformers teed off of either side of the double circuit AE-route fed out of Exeter GSP. The AE-route continues to Exeter City; one side of the AE-route is currently de-energised and the other side feeds Exeter City GT3.

Sowton GTs

CP TD

Following demand growth for the Consumer Power and Two Degrees scenarios, a first circuit fault of one of the grid transformers at Sowton overloads the remaining in-service transformer to 103% for an autumn peak demand representative day.

As part of the arranged outage of Sowton GT3, the loose couple between Exeter Main BSP and Sowton is pre-emptively broken to protect against the next circuit fault which would result in the Sowton demand supplied via the 11kV interconnection between Sowton and Exeter Main. For this arranged outage, the Sowton grid transformer overload increases to as much as 112% for an autumn peak demand case.

Although the new demand driving these overloads is within the geographic area currently supplied by Sowton BSP, it is likely to be more economic to supply 25MW of the new demand from nearby Exeter Main BSP. Modelling this demand transfer resolves the Sowton GT overloads without causing any overloads on the Exeter Main GTs.

Sowton to Exeter GSP 132kV circuits

SS SP CP TD

The fault of either grid transformer at Sowton would overload the AE-route circuit supplying the remaining in-service GT up to 103% under Consumer Power and Two Degrees. This overload is exacerbated for the arranged outage of a grid transformer at Sowton, as the loose couple between Sowton and Exeter Main BSP is pre-emptively broken for the arranged outage. For the arranged outage, the AE-route circuit supplying the remaining in-service Sowton GT would overload to as much as 112% for all peak demand representative days.

The arranged outage of the Exeter GSP to Exeter City GT2 circuit followed by the fault of Exeter to Sowton GT1 circuit leaves the entire demand of Exeter City and Sowton supplied via the remaining in-service AE-route circuit. This SCO combination would overloads the remaining AE-route circuit up to as much as 134% (Two Degrees) and 112% (Steady State) for all peak demand representative days.

Connecting 25MW of the forecasted demand growth into Exeter Main BSP rather than Sowton reduces this overload, but does not remove it. It is recommended that the 300mm² AAAC

(Upas) conductors on the AE-route between Exeter GSP 905 and the Sowton tee are reprofiled at 75°C.

Paignton to Newton Abbot 132kV circuit

SS SP CP TD

Due to the existing running arrangement at Exeter GSP, there is a credible fault of the Main 1 busbar at Exeter GSP which leaves Exeter Reserve 1 bar without an Exeter 400kV infeed. Under this fault outage, Sowton BSP and Exeter City BSP are supplied from Abham GSP via the in-service 'clean' circuit between Abham and Exeter GSPs and the 132kV interconnection via Newton Abbot.

This fault condition would overload the Paignton to Newton Abbot 132kV circuit (C-route). This circuit would overload under all scenarios and for all peak demand representative days; the overloads vary between 112% (Steady State) and 138% (Two Degrees).

It is recommended that a 160 breaker between the Reserve 1 and Reserve 2 busbars is installed at Exeter Main GSP. This will enable the reserve bars to be run normally solid without the risk of a reserve busbar fault taking both bars out of service. For the Exeter Main 1 busbar fault, the Reserve 1 bar still has a direct 400kV infeed, removing the overloads on the Abham to Exeter 132kV network.

Exeter City BSP

CP TD

Exeter City has two 45/90MVA transformers fed out of Exeter GSP. The first circuit fault or arranged outage of either transformer would overload the remaining in-service transformer to as much as 105% for an autumn peak demand representative day. This overload only occurs for the Consumer Power and Two Degrees scenarios.

It is recommended that a wider suite of transformer ratings is developed, including accurate ratings for the seasons between summer and winter. This is likely to resolve this projected overload.

Alverdiscott & Indian Queens GSPs

Alverdiscott SGT Capacity

SS SP CP TD

For both summer peak generation and peak demand cases, various SCO combinations would overload the SGTs at Alverdiscott.

Generation Overloads

For the summer peak generation case, various SCO combinations would overload the SGTs at Alverdiscott. The same SCO conditions described in the baseline results which would cause reverse power flow overloads would also cause overloads of a similar magnitude under all scenarios in 2020.

The conditions causing the highest reverse power-flow loadings on SGT1 are:

3. The arranged outage of Indian Queens 400kV 305 breaker towards Alverdiscott, where the 400kV circuit is left in-service, followed by the fault of Taunton SGT2 and associated 400kV busbar (Taunton SGT2 has a HV isolator only). The overload is up to 109% of the nameplate rating.
4. The arranged outage of St Tudy main 1 busbar followed by a fault of Alverdiscott SGT2 overloads SGT1 to 106% of nameplate rating.

The condition which causes the highest reverse power flow loadings on SGT2 is the SCO combination of the arranged outage of Indian Queens 400kV Main 3 busbar, followed by a circuit fault of Taunton SGT1. This removes two of the four 400kV infeeds into Alverdiscott GSP and leaves Alverdiscott SGT1 fed via Indian Queens and Alverdiscott SGT2 fed via Taunton. This SCO combination would overload SGT2 at Alverdiscott up to 131% (Two Degrees) and 127% (Steady State) for a summer peak generation case.

Following the Statement of Works process, Modification Applications to National Grid have led to the development of an ANM solution to manage flows on the Alverdiscott SGTs. It is intended that this ANM system will utilise short-term post-fault ratings for the SGTs to minimise pre-fault curtailment of generators.

Demand Overloads

The SCO combination of an arranged outage of the Main 1 busbar at St Tudy, followed by an SGT fault at Alverdiscott would overload the remaining SGT in-service up to 112% (Two Degrees) and 101% (Steady State) for an autumn and winter peak demand representative day.

It is recommended that the adequacy of the available access window for the SGTs and associated transmission circuits is assessed. If it is not long enough, alternative running arrangements, flexibility services and reinforcement should be considered as means to extend it.

Indian Queens SGT Capacity

SS SP CP TD

For the SCO combination which takes two SGTs at Indian Queens out of service, the remaining two SGTs in service would overload above the nameplate rating under all scenarios. These overloads would occur for an autumn and winter peak demand representative day up to as much as 112% (Steady State) and 117% (Two Degrees). These overloads also occur for a busbar fault of either of the Indian Queens Reserve 1 or Reserve 2 bars, as this also disconnects two SGTs.

The access window should be assessed to determine if a summer access window is sufficient, if a longer access window is required then Indian Queens short-term ratings should be confirmed with National Grid.

East Yelland BSP

SS SP CP TD

East Yelland BSP is fed out of Alverdiscott GSP and has two 30/60MVA transformers. For the first circuit fault outage of either grid transformer at East Yelland, the remaining in-service grid transformer would overload to as much as 129% for all peak demand representative days under Consumer Power and Two Degrees. Under Steady State and Slow progression, the remaining in-service grid transformer at East Yelland would overload to as much as 114%; however only for an autumn and winter peak demand representative day.

It is recommended the existing 30/60MVA transformers are replaced with 60/90MVA transformers under all 2020 scenarios.

Barnstaple BSP

TD

Barnstaple BSP is fed out of Alverdiscott GSP and has two 30/60MVA transformers. For the first circuit fault outage of either grid transformer at Barnstaple, the remaining in-service grid transformer would overload to as much as 112% for an autumn peak demand representative day under a Two Degrees scenario.

It is recommended that a wider suite of transformer ratings is developed, including accurate ratings for the seasons between summer and winter. This is likely to resolve this projected overload.

K-route Overloads

SS SP CP TD

North Devon Demand

This overload on K-route was identified in the baseline study for the arranged outage of Alverdiscott Main 2 busbar followed by a fault of the remaining Alverdiscott SGT. This leaves East Yelland, Barnstaple and North Tawton supplied via a single K-route circuit. In the baseline study this caused significant overloads on the River Torridge cables, to the point where the model did not converge under some demand representative days. It was recommended that Alverdiscott and Indian Queens are split for the arranged outage to mitigate the subsequent fault.

In 2020 the Torridge cable reinforcement is completed, meaning this overload would not be seen with the baseline demand. The demand growth at all three BSPs under all scenarios means this SCO condition will still overload the remaining K-route circuit on the overhead section between Alverdiscott and St Tudy BSP. This circuit is currently ACSR 175mm² (Lynx) @ 75°C, so would require reconductoring with 300mm² AAAC (Upas) @ 75°C to remove this overload.

It is recommended that despite the reinforcement of the Torridge cables, the pre-emptive K-route split for the arranged outage of either Alverdiscott 132kV busbar is still taken to mitigate this SCO condition.

Pyworthy Area – Generation and Demand Constraints

The SCO combination of an arranged outage of an SGT at Alverdiscott, followed by the second circuit fault of the other SGT at Alverdiscott would result in overloads on the K-route in 2020 for both peak generation and peak demand representative days.

For a summer peak generation representative day, the aforementioned SCO combination would overload the K-route section between Pyworthy and the tower opposite St Tudy BSP. This section is currently ACSR 175mm² (Lynx) @ 75°C, with the section from St Tudy to Indian Queens being AAAC 300mm² (Upas) @ 75°C. The generation overloads occur under all scenarios, with the highest overload being 106% under a Two Degrees scenario.

The demand overloads only occur for an autumn and winter peak demand representative day. The highest overload is 119% under a Two Degrees scenario and 106% under a Steady State scenario.

From a demand perspective, there is an access window in summer where a demand-driven overload will not occur. If a summer access window was sufficient then curtailment of generation during the arranged outage of either Alverdiscott SGT could be sufficient to defer reinforcement. For the purposes of these studies the overloaded section has been reinforced by reconductoring with 300mm² AAAC (Upas) @ 75°C.

Camborne/Hayle BSP Group

SS SP CP TD

The Camborne/Hayle group demand increases from 106MW in the baseline to 116MW under a Two Degrees scenario in 2020. The group remains in Class D of P2/6, which requires the group demand less 100MW to be restored within 3 hours for a second circuit outage. Initial studies have shown there is insufficient 33kV transfer capacity currently available to transfer the required demand out of the Camborne and Hayle group for the Consumer Power and Two Degrees scenarios in 2020.

For a first circuit fault of the A-route circuit between Indian Queens and Camborne BSP, there would be marginal overloads on the CC-route circuit between Hayle and Rame up to as much as 104% under a Two Degrees and Consumer Power scenario.

It is recommended that a third 132kV circuit into the Camborne/Hayle group is built to resolve these constraints. For these studies, the following arrangement was adopted:

- **Extending Camborne 132kV bar from the Main 1 end with a second section breaker 420 to a new Main 4. The works associated with Camborne are shown in Figure 39;**
- **Establishing a new 132kV route (assumed to be a wood pole line) from a line isolator on Camborne Main 4 to a tee-off from the northern circuit of the BM-route tower line, approximate circuit length 8km;**
- **Extending the Rame 132kV bar to form a four-corner closed mesh. The works associated with Rame are shown in Figure 40;**
- **Laying a 600m 132kV cable from a line isolator on Rame BSP Main 4 to the northern circuit at tower BM118 to separate the existing Rame/Hayle/Fraddon circuit into:**
    - **A Rame/Hayle circuit, and**
    - **A Rame/Camborne/Fraddon circuit.**

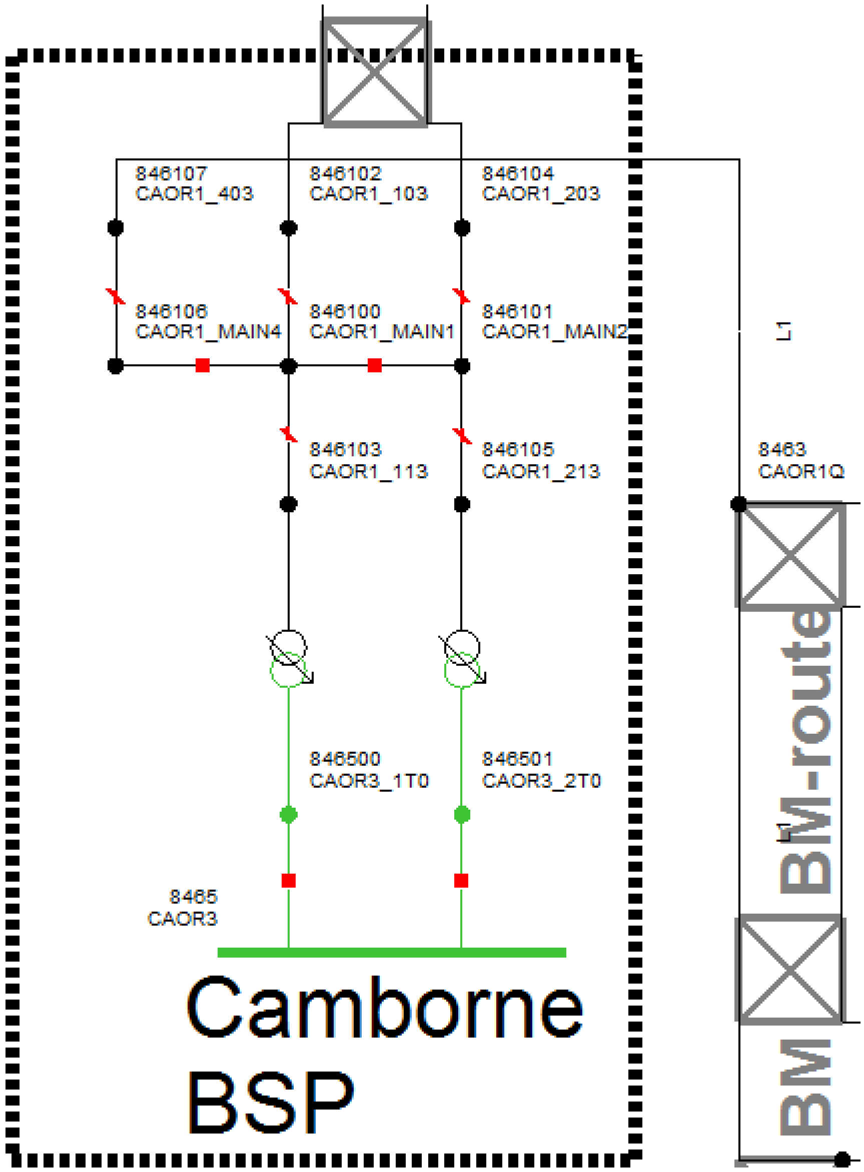

Figure 39: Proposed extension to Camborne BSP and new circuit teed from BM-route

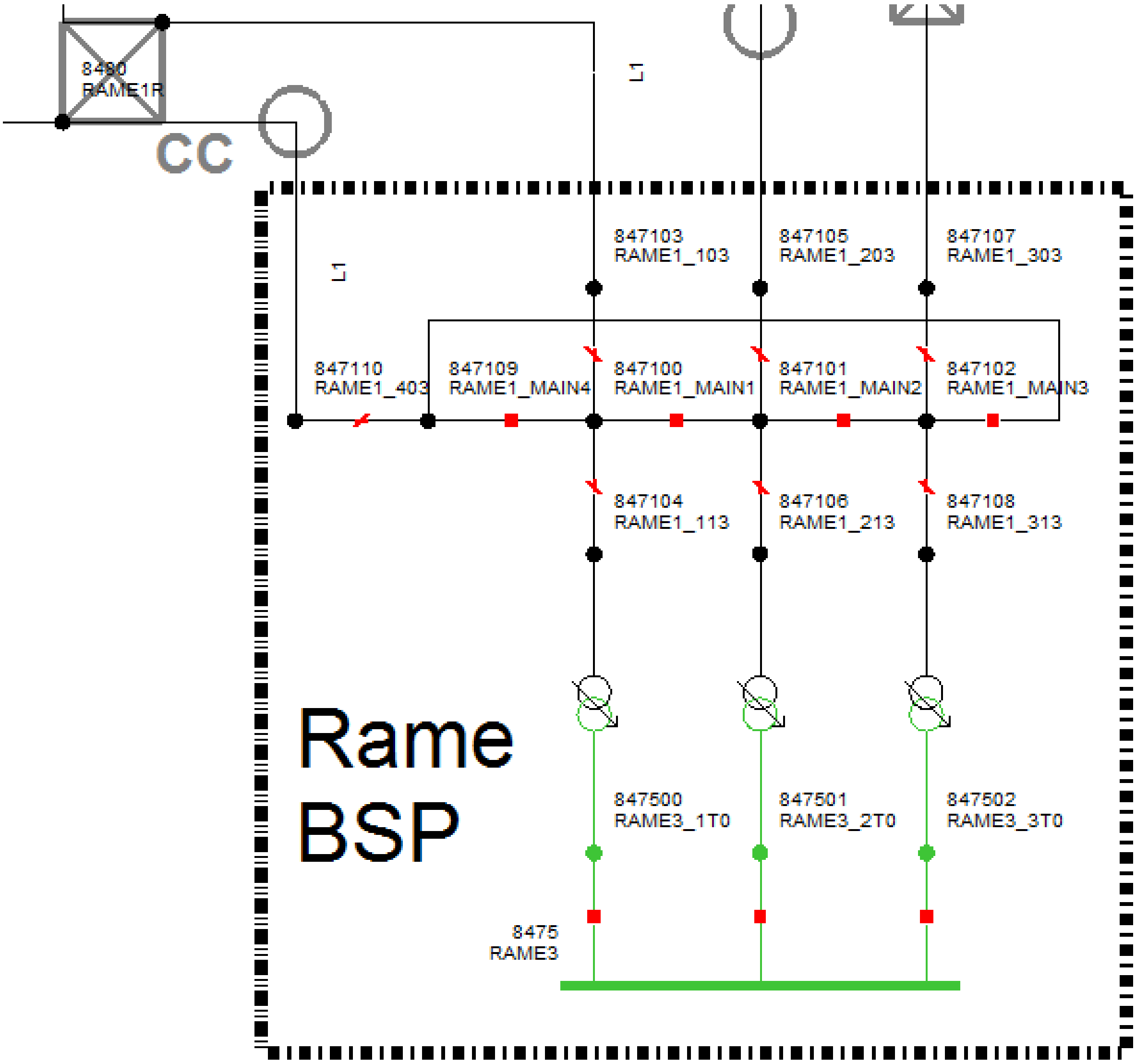

Figure 40: Proposed extension to Rame BSP

To reduce interdependence between Camborne and Hayle BSPs, the existing Camborne GT1 could be reconnected at 132kV to Camborne Main 4 instead of Camborne Main 1.

9 – Hinkley Point C connection works

By the end of 2024, it is expected that the works on WPD's network to enable the connection of Hinkley Point C nuclear power station will be complete. These works entail a major reconfiguration of the 132kV networks in Somerset and the Severnside area to make way for a new 400kV route from Hinkley Point to Seabank. Works affecting WPD's network include:

- The removal of the 132kV F-route and G-route from Bridgwater GSP to Avonmouth BSP;
- The undergrounding of parts of various other 132kV routes in the area;
- Reconfiguration of the 132kV circuits at Churchill BSP;
- The commissioning of a second SGT at Taunton GSP;
- The addition of a third independent 400kV circuit and removal of one SGT from Seabank GSP, leaving two SGTs;
- The commissioning of a new GSP at Sandford (4km south west of Churchill BSP) with two SGTs, to be operated in parallel with Seabank GSP at 132kV;
- The conversion of Bridgwater GSP from 275kV infeed to 400kV infeed. This reconfiguration will resolve the issue of Hinkley Point station demand fed via WPD network; and
- The replacement of switchgear at several substations to prevent fault level overstressing.

These works have been designed to provide comparable capacity and security to the existing network. To validate the proposed network design, a study was run on the post-Hinkley Point C network with baseline (2017/18) demand and generation. This study identified one issue which may influence the design of WPD's post-Hinkley Point C network, described below.

Through-flow between Sandford and Seabank for 400kV outages

Sandford GSP is due to be connected to the 400kV network as a single-side turn-in from the Hinkley Point to Seabank route. The Sandford / Seabank 132kV network is due to be coupled across the 400kV network, but should see relatively little through-flow when the 400kV network is intact.

For an outage of the Sandford/Seabank/Melksham 400kV circuit, the Sandford/Seabank 132kV becomes a link between the South West peninsula and the wider transmission network.

For a summer peak generation case, this risks overloading the 132kV interconnecting circuits between Sandford and Seabank. A coincident outage of the Hinkley Point/Seabank 400kV circuit exacerbates these overloads, and also overloads the SGTs at Sandford and Seabank.

Circuit loading for these running arrangements is heavily dependent on the demand and generation conditions around the wider GB network. The studied overloads might be removed by modifying the representation of the wider GB network in the network model, but this does not guarantee that the overloads would not occur.

It is recommended that the 132kV circuit connection design at Churchill BSP is modified to allow Sandford GSP and Seabank GSP to be operated independently of each other without compromising security of supply. For these studies, it has been assumed that Sandford GSP and Seabank GSP will be operated independently of each other, split on 132kV circuit breakers at Churchill BSP.

If it is intended to operate Sandford GSP and Seabank GSP in parallel with each other, it is recommended that more detailed studies are carried out in conjunction with other network operators to ensure that there is no risk of overload for 400kV outages.

10 – 2025 Results

The focus of the scenarios shifts from 2020 to 2025, as new technologies such as EVs, HPs and battery storage come to dominate growth. A significant fraction of the forecast demand growth is battery storage importing energy coincident with network peak demand. If the operating model of battery storage does not rely on the ability to import energy at times of network peak demand, it may be possible to defer some reinforcement by curtailing battery storage imports.

In the 2020 results, several constraints only arose as minor autumn transformer overloads. This theme continues through the 2025 results; individual sites where this is the only constraint have not been written up in detail.

Melksham GSP

No new reinforcement requirements were identified in the 2025 scenarios for WPD's network supplied from Melksham GSP.

Iron Acton GSP

SGT capacity

SS SP CP TD

By 2025, the group demand of Iron Acton GSP is projected to grow to between 850MW (Steady State) and 1.01GW (Consumer Power).

The 2025 studies highlighted several further demand-driven SGT overloads for various FCO and SCO conditions.

The 2025 scenarios should be considered as part of any joint studies between WPD and National Grid regarding the development of Iron Acton GSP. The projected demand growth may exceed practical limits on capacity at a single GSP. Reinforcement options that could be used to deload the Iron Acton 132kV bar include:

- **Additional SGT infeed at Seabank GSP, to allow the transfer of the DA-route (Bradley Stoke BSP, Rolls Royce Filton, Seabank BSP and Old Green wind farm) from Iron Acton GSP to Seabank GSP;**
- **Uprating the YXA- or YXB-route from Iron Acton to Oldbury-on-Severn from 132kV to 275kV or 400kV operation. This would allow a new GSP to be established at Oldbury-on-Severn to supply Ryeford BSP and potentially Lydney BSP;**
- **Establishing a second GSP near to Iron Acton, supplied by the 400kV circuits from Melksham to South Wales, and transferring some 132kV circuits from Iron Acton to the new GSP;**
- **Establishing GSPs in Bristol at Feeder Road and Lockleaze. Some of the 132kV routes to these substations were constructed suitable for future uprating to 275kV, but this capability has not been maintained in more recent diversionary work.**

DA-route

CP TD

Bradley Stoke BSP, Rolls Royce Filton, Seabank BSP and Old Green wind farm are supplied from Iron Acton GSP by a 132kV ring on the DA-route. Following demand growth to 2025 under Consumer Power and Two Degrees, there is a risk that the outage of either first leg from Iron Acton would marginally overload the other (to no more than 101% of rating) for a summer peak demand case.

Both first legs from Iron Acton are overhead, with 400mm² ACSR (Zebra) conductors, profiled for operation at 50°C.

Reprofiling the existing conductors for operation at a higher temperature would alleviate the projected overloads. If this proves impractical, the lines could be reconductored with 500mm² AAAC (Rubus) as an alternative.

Seabank BSP GT capacity

SS SP CP TD

Seabank BSP has two 60MVA, 132/33kV GTs.

By 2025, the group demand is projected to grow to between 53MW (Steady State) and 69MW (Consumer Power and Two Degrees). This is augmented by between 19MW and 24MW transferred from Avonmouth BSP via Kingsweston primary substation.

The outage of either GT at Seabank would overload the remaining GT in all scenarios. Under Slow Progression and Steady State, overloads are seen for summer and autumn peak demand cases, to as much as 111% of rating. Under Consumer Power and Two Degrees, overloads are seen for all peak demand cases, to as much as 149% of rating.

Generation growth in the area also triggers overloads for the same running arrangement in all scenarios, to between 121% and 130% of rating.

Under all scenarios, the replacement of both GTs at Seabank with 90MVA units would resolve the projected overloads.

Given the constraints identified at Avonmouth BSP (in part triggering this reinforcement at Seabank BSP), a coordinated approach should be taken to subtransmission reinforcement in north-west Bristol.

Lockleaze BSP GT capacity

CP TD

Lockleaze BSP has four 90MVA, 132/33kV GTs. The 33kV bar is normally operated in two sections:

- One section is supplied by GT1 and GT4. By 2025, the group demand of this section is projected to grow to between 106MW (Steady State) and 118MW (Consumer Power).
- The other section is supplied by GT2 and GT3. By 2025, the group demand of this section is projected to grow to between 85MW (Steady State) and 96MW (Consumer Power).

Under Consumer Power and Two Degrees, the outage of GT1 or GT4 for an autumn or winter peak demand case would overload the other to as much as 117% of rating.

It is expected that major reinforcement can be deferred by transferring load between the two sections of 33kV bar at Lockleaze BSP. Beyond that, reinforcement options that could be used to deload the Lockleaze 33kV bar include:

- **Commissioning 132/11kV GTs at Lockleaze BSP and transferring load from the existing 33/11kV primary substation on site; or**
- **Establishing a new BSP in north-east Bristol and transferring primary substations in the area from Lockleaze BSP to the new BSP.**

Either of these reinforcement schemes is likely to trigger the construction of a 132kV busbar at Lockleaze or Feeder Road BSP.

St Pauls BSP GT capacity

CP TD

St Pauls BSP has two 60MVA, 132/11kV GTs: GT2 and GT3. Each GT has two 11kV windings (A and B), each of which is rated at 30MVA. The 11kV bar is normally operated in two sections:

- One section is supplied by GT2's A-winding and GT3's A-winding;
- The other section is supplied by GT2's B-winding and GT3's B-winding.

Load is balanced between the A-windings and B-windings by 11kV transfers as necessary. The current split has more demand allocated to the A-windings than the B-windings.

By 2025, the combined group demand of the two sections of 11kV bar is projected to grow to between 57MW (Steady State and Slow Progression) and 66MW (Consumer Power and Two Degrees).

For the arranged or fault outage of either GT, the remaining GT carries the group load. Under Consumer Power and Two Degrees, this would overload the A-winding of the remaining GT to as much as 112% of rating for an autumn peak demand case.

It is expected that major reinforcement can be deferred by rebalancing load between the two sections of 11kV bar at St Pauls BSP. Beyond that, reinforcement options include:

- **A third 132/11kV GT at St Pauls BSP. This is likely to trigger the construction of a 132kV busbar at Feeder Road BSP; or**
- **Further 11kV infeed at other sites in the central Bristol area. Transferring load to 33/11kV substations would exacerbate constraints at the surrounding 132/33kV substations (Feeder Road, Lockleaze and Avonmouth).**

Feeder Road BSP GT capacity

SS SP CP TD

By 2025, the combined group demand of the Feeder Road 33kV networks is projected to grow to between 219MW (Slow Progression) and 246MW (Consumer Power).

This demand growth exacerbates the constraints identified in the 2020 results: *GT SCO* and *Iron Acton 132kV busbar fault*. Depending on the scenario, GTs would overload to as much as 129% of rating.

Reinforcement options that could be used to deload the Feeder Road 33kV bar include:

- **Commissioning 132/11kV GTs at Feeder Road BSP and transferring load from one or both of the existing 33/11kV primary substations on site; or**
- **Establishing a new BSP in south-east Bristol and transferring primary substations in the area from Feeder Road BSP to the new BSP.**

Either of these reinforcement schemes is likely to trigger the construction of a 132kV busbar at Feeder Road BSP.

Wider reinforcement requirements in the area should also be considered. In particular, the transfer of Keynsham East primary substation from Radstock BSP would help to resolve projected GT overloads at Radstock.

Seabank & Sandford GSPs

SGT and interconnector capacity

SS SP CP TD

In light of the risk of through-flow between Sandford and Seabank for 400kV outages identified above, Seabank and Sandford GSPs were modelled as operating split at 132kV.

Seabank GSP is planned to have two 240MVA SGTs following the completion of Hinkley Point C connection works. It was assumed that Seabank GSP would supply Avonmouth BSP, Portishead BSP and Radstock BSP. Following demand growth to 2025, this gives a group demand ranging from 258MW (Steady State) to 311MW (Consumer Power).

Under all scenarios, the outage of either SGT at Seabank would overload the remaining SGT. Under Consumer Power and Two Degrees, overloads occur for all peak demand cases, up to 140% of nameplate rating. Under Steady State and Slow Progression, overloads occur for the autumn and winter peak demand cases, up to 114% of nameplate rating.

A third SGT at Seabank GSP could be used to prevent these overloads.

It is recommended that, when planning the redevelopment of Seabank GSP as part of the Hinkley Point C connection works, consideration is given to the potential retention or future reinstatement of SGT4.

Sandford GSP is planned to have two 240MVA SGTs. It was assumed that Sandford GSP would supply Weston BSP and Churchill BSP. Following demand growth to 2025, this gives a group demand ranging from 160MW (Steady State) to 191MW (Consumer Power).

Under some scenarios it may be possible to defer the third SGT at Seabank GSP by improving the split of demand between Seabank GSP and Sandford GSP. This would require the reconfiguration of 132kV circuits, and potentially a new BSP.

Weston BSP GT capacity

SS SP CP TD

By 2025, the group demand of the Weston 33kV network is projected to grow to between 87MW (Steady State) and 107MW (Two Degrees and Consumer Power).

Weston BSP has two 60MVA GTs. Under all scenarios, the outage of either GT would the remaining GT for all peak demand cases. Peak overloads range from 124% of rating (Steady State) to 155% of rating (Consumer Power).

The replacement of both GTs at Weston BSP with 90MVA units should resolve the projected overloads.

Radstock BSP GT capacity

CP TD

By 2025, the group demand of the Radstock 33kV network is projected to grow to between 93MW (Steady State) and 114MW (Consumer Power).

Radstock BSP has two 90MVA GTs, supplied by two 132kV circuits. Under Consumer Power and Two Degrees, the outage of either GT would overload the remaining GT for an autumn or winter peak demand case, to as much as 117% of rating.

Although additional GTs at Radstock BSP or a nearby new BSP could be used to resolve the projected overloads, wider reinforcement requirements in the area should also be considered. Keynsham East primary substation, on the outskirts of south-east Bristol, is currently supplied

from Radstock BSP. Reinforcement to resolve constraints at Feeder Road BSP could incorporate the transfer of Keynsham East either to Feeder Road BSP or to a new BSP in south-east Bristol.

Avonmouth BSP GT capacity

SS SP CP TD

By 2025, the group demand of the Avonmouth 33kV network is projected to grow to between 112MW (Steady State and Slow Progression) and 139MW (Consumer Power).

Under all scenarios, the outage of either GT would overload the remaining GT to as much as 110% of rating for a summer or autumn peak demand case.

Under Steady State and Slow Progression, the transfer of Kingsweston primary substation to Seabank BSP (as proposed in 2020 for Consumer Power and Two Degrees) would resolve the projected overloads.

Under Consumer Power and Two Degrees, a new 132/11kV BSP in the Avonmouth area could be used to deload existing primary substations fed from the Avonmouth BSP 33kV bar.

Given the constraints identified at Seabank BSP (in part triggered by the transfer of Kingsweston from Avonmouth), a coordinated approach should be taken to subtransmission reinforcement in north-west Bristol.

Bridgwater GSP

SGT capacity

SS SP CP TD

As part of the works to connect Hinkley Point C, Churchill BSP will be permanently transferred away from Bridgwater GSP. With Bridgwater GSP and Taunton GSP operating split at 132kV, this will leave Bridgwater GSP with two 240MVA SGTs supplying Bridgwater BSP and Street BSP.

Despite supplying a smaller area, by 2025 group demand is projected to grow to around 272MW (Consumer Power and Two Degrees) or around 221MW (Steady State and Slow Progression).

Under Steady State and Slow Progression, the outage of either SGT at Bridgwater would overload the remaining SGT to between 101% and 105% of nameplate rating for a winter peak demand case.

Given the marginal nature of the projected overloads, it is likely that they can be resolved through a combination of short-term ratings, minor demand transfers, and improved reactive compensation.

Under Consumer Power and Two Degrees, the outage of either SGT at Bridgwater would overload the remaining SGT to between 120% and 133% of nameplate rating for a winter or autumn peak demand case.

Although a third SGT at Bridgwater GSP could resolve the projected overloads, Bridgwater GSP is only supplied by two transmission circuits, so a third SGT would only support further demand growth up to the P2/6 Class E threshold of 300MW.

Nearby Taunton GSP is a bussing point for several transmission circuits. In this light, a third SGT at Taunton GSP with demand transferred from Bridgwater GSP may prove more appropriate.

Bridgwater BSP and Street BSP GT capacity

CP TD

Following proposed reinforcement in 2020, Bridgwater/Street 33kV network is supplied by five 60MVA GTs. By 2025 group demand is projected to grow to around 272MW (Consumer Power and Two Degrees) or around 221MW (Steady State and Slow Progression).

The group can be left supplied by two GTs at Bridgwater and one at Street for either:

- The SCO of two GTs at Bridgwater; or
- The fault outage of Bridgwater 132kV Main 1 busbar.

Under Consumer Power and Two Degrees, this would overload one or both of the remaining GTs at Bridgwater for all demand cases, to as much as 131% of rating.

A potential reinforcement scheme to prevent these overloads would entail:

- **Commissioning a second 60MVA GT at Street BSP and splitting the 33kV interconnection between Bridgwater and Street; and**
- **Establishing 132kV circuits to a new BSP to the north of Bridgwater. This BSP could be a 132/33kV site with part of the Bridgwater 33kV network transferred to it, or a 132/11kV site to replace or augment existing primary substations.**

Taunton GSP

SGT capacity

CP TD

Following the commissioning of SGT1 and the split from Bridgwater GSP, Taunton GSP will have two 240MVA SGTs supplying Taunton BSP and Bowhays Cross BSP.

By 2025 group demand is projected to grow to around 174MW (Steady State), 182MW (Slow Progression) or 235MW (Consumer Power and Two Degrees).

Under Consumer Power and Two Degrees, the outage of either SGT at Taunton would overload the remaining SGT to between 104% and 111% of nameplate rating for a winter or autumn peak demand case.

Commissioning a third SGT at Taunton GSP would alleviate the projected overloads. It would also allow the transfer of some demand from Bridgwater GSP, which would alleviate projected SGT overloads there.

Taunton BSP GT capacity

SS SP CP TD

Slow Progression and Steady State

Under Slow Progression and Steady State, Taunton BSP has two 90MVA GTs.

By 2025 group demand is projected to grow to around 137MW (Steady State) or 144MW (Slow Progression). The outage of either GT at Taunton would overload the remaining GT for all demand cases, to as much as 131% of rating (Slow Progression) or 124% of rating (Steady State).

To prevent these overloads, a new BSP could be established in the area to deload Taunton BSP. Depending on the location of demand growth, one option would be a 132/11kV BSP connected to the existing 132kV circuits between Taunton and Bridgwater.

Consumer Power and Two Degrees

Under Consumer Power and Two Degrees, following reinforcement proposed in 2020, Taunton BSP has three 90MVA GTs.

By 2025, group demand is projected to grow to around 192MW. The SCO of any two GTs at Taunton would overload the remaining GT for all demand cases, to as much as 165% of rating.

Generation growth in the area also triggers overloads for the same running arrangement, to around 114% of rating.

In 2020, for the arranged outage of a GT at Taunton, some demand was transferred to Bridgwater BSP to prevent overloads for the subsequent fault loss of a second GT at Taunton. By 2025, this exacerbates the projected overloads at both Bridgwater BSP and Bridgwater GSP. Reducing these transfers would exacerbate some of the projected overloads at Taunton BSP.

To prevent these overloads, one or more new BSPs could be established in the area to deload Taunton BSP. Depending on the location of demand growth, one option would be a 132/11kV BSP connected to the existing 132kV circuits between Taunton and Bridgwater.

Abham and Exeter GSPs

Abham to Plymouth 132kV Network

River Dart Cables and H-route

No overloads are seen on the River Dart cables and H-route under any scenario following the reinforcements proposed in 2020.

Abham and Exeter SGT Capacity

SS SP CP TD

All 2025 studies have assumed the split of Abham and Landulph GSPs on the 132kV at Plymouth BSP.

Abham GSP is modelled with the 230 bus coupler breaker closed and the 1005 direct interconnector with Exeter GSP run normally closed; this assumes that the existing fault level constraints at Abham are resolved by planned asset replacement works.

Exeter GSP is modelled with two SGTs on load and one SGT on hot-standby for fault level control.

Intact

Both Abham SGTs are at 96% (Two Degrees) and 80% (Steady State) of nameplate rating under intact running.

Both in-service Exeter SGTs are over their nameplate rating for all demand representative day under Two Degrees and Consumer Power; the highest loading is 117% for the winter peak demand representative day.

Abham SGT Fault

A first circuit fault of either Abham SGTs overloads the remaining in-service SGT for all demand representative days up to between 149% (Two Degrees) and 120% (Steady State) of nameplate rating.

A busbar fault of Abham Reserve bar increases this overload to 160% under Two Degrees, as Abham SGT1 and two of the three interconnectors with Exeter GSP are lost, meaning Abham SGT2 picks up more of the group.

Exeter SGT Fault

For a first circuit fault which results in the loss of an SGT at Exeter, for an autumn or winter peak demand case, there is a risk that the remaining SGT would overload to between 148% (Two Degrees) and 130% (Steady State) of nameplate rating. This is marginally lower than 2020 overloads due to the change in running arrangement at Abham GSP.

SCO constraints

For the SCO combination of either Abham SGT followed by the fault of the Exeter to Newton Abbot circuit the remaining in-service SGT at Abham is over nameplate rating for all demand representative days up to 166% (Two Degrees) and 132% (Steady State) of rating for winter peak demand. This loading is reduced to 140% (Two Degrees) and 101% (Steady State) for summer peak demand.

For the SCO combination of an Abham SGT followed by a subsequent fault of the remaining in-service Abham SGT, both Exeter SGTs are overloaded to in excess of 190% of rating for all demand representative days. Studies of the winter and autumn representative days did not converge for this SCO condition due to the magnitude of the overloads.

This analysis assumed only two SGTs are in service at Exeter due to existing fault level constraints. The existing fault level constraint assumes Landulph, Abham and Exeter are normally run in parallel on the 132kV. With the split between Landulph and Abham and this SCO fault condition the fault infeed from the other GSP may have reduced to the point where all 3 SGTs can be run in parallel. If all 3 Exeter SGTs can be run in parallel the overload reduces to 130% on all SGTs for summer peak demand under Two Degrees.

Abham to Exeter 132kV Network

CP TD

Exeter and Abham GSPs are mutually dependent on infeed via interconnecting 132kV circuits. Demand growth to 2025, particularly under Consumer Power and Two Degrees, triggers overloads of all three interconnecting 132kV circuits for various FCO and SCO conditions. The worst studied overloads are to as much as 184% of rating for the SCO of both Abham SGTs.

Newton Abbot BSP

CP TD

Overloads were seen on both Newton Abbot GTs in 2020 for a FCO of the other transformer under Two Degrees and Consumer Power. The proposed reinforcement was to move Bradley Lane primary from Newton Abbot BSP onto Torquay BSP under normal running. This resolved all overloads on Newton Abbot in 2020 without causing any additional issues on Torquay.

In 2025 the continued growth at Newton Abbot BSP overloads both GTs for the same FCO condition up to 133% for the autumn peak demand representative day under Two Degrees and Consumer Power.

Depending on the location demand growth, options to deload the Newton Abbot 33kV bar include:

- **Commissioning a pair of 132/11kV GTs at Newton Abbot BSP to augment or replace the nearby primary substation; or**
- **Building a new BSP on the H- or AH-route to the north of Newton Abbot.**

Combined SGT and 132kV circuit reinforcement strategy

The significant demand growth across the Abham and Exeter 132kV network would trigger major reinforcement in all scenarios. This would include multiple new SGTs, with potential for a new GSP close to Plympton BSP to supply the area to the east of Plymouth.

Continued parallel operation at 132kV between Exeter and Abham is unlikely to be sustainable. Given the pre-existing fault level constraints in the area, the development of a viable reinforcement scheme will require integrated load flow and fault level analysis.

Finding a running arrangement that allows all three SGTs at Exeter to be on load simultaneously without breaching fault level constraints and agreeing short-term ratings for the SGTs at Exeter and Abham may allow some reinforcement to be deferred.

Reinforcement should be coordinated between this network and Landulph GSP – load transfer facilities at Plymouth BSP may allow reinforcement in one group to be deferred whilst making best use of reinforcement in the other group.

Newton Abbot BSP is connected at 132kV across one of the interconnecting circuits between Exeter and Abham GSPs. Reinforcement of either is likely to trigger some works on the other.

Tiverton BSP

CP TD

Tiverton BSP was identified as requiring reinforcement in 2020 under all scenarios due to demand growth in the area. The proposed reinforcement was to replace the existing 22.5/45MVA transformers with 40/60MVA transformers.

By 2025, the group demand of Tiverton 33kV network grows to 81MW under Two Degrees and Consumer Power.

Under Consumer Power and Two Degrees, the fault loss of either GT for autumn or winter peak demand would overload the remaining GT to between 110% and 122% of rating.

It may be possible to defer reinforcement through the use of flexibility services. When the reinforcement recommended in the 2020 results is triggered, consideration should be given to installing 60/90MVA GTs rather than 40/60MVA GTs.

Exeter Main BSP

SS SP CP TD

Exeter Main has one 30/60MVA transformer and one 40/60MVA transformer fed out of Exeter GSP. No overloads were identified out to 2020 on either GT. By 2025, the demand growth overloads either GT for the first circuit fault of the other transformer under Two Degrees and Consumer Power.

A first circuit fault of either GT causes an overload to as much as 140% of rating in autumn under Two Degrees and Consumer Power. Overloads are also seen for the summer representative day up to 132% of rating. These overloads are exacerbated for an Exeter GSP Main 1 busbar fault, as this causes the loss of infeed to Exeter Main GT1, and energises part of the 132kV via GT2. The overloads are up to 159% under Two Degrees and Consumer Power.

The only overloads seen under Slow Progression and Steady state are for the Exeter Main 1 busbar fault. The magnitudes of these overloads are up to 116% for the autumn peak demand representative day.

Replacing the existing 60MVA transformers with 60/90MVA units under Consumer Power and Two Degrees would resolve the circuit fault overloads.

The fault of Exeter GSP Main 1 busbar overload should be assessed to determine if there is a running arrangement that mitigates this overload.

Sowton BSP, Exeter City BSP and associated 132kV circuits

Exeter City BSP

SS SP CP TD

Exeter City has two 45/90MVA transformers fed out of Exeter GSP. In 2020, for the arranged outage of a GT at Exeter City, the remaining GT was overloaded to as much as 105% for an autumn peak demand representative day under Consumer Power and Two Degrees.

By 2025, this overload is seen for all demand representative days under all scenarios. The overload reaches 129% for the autumn representative day under Two Degrees.

Due to Exeter City BSP being located in a densely populated area, there are significant challenges associated with getting a third circuit into the site. Exeter City BSP is currently supplied via a triple circuit tower line, where the centre phase is de-energised, as it does have sufficient clearances to allow the centre circuit to be maintained without de-energising all three circuits. The Exeter City transformers are already 90MVA units, which is the largest transformer installed as standard, so an additional transformer would be required. This would mean the BSP would become a three transformer group, which has a number of operational challenges associated with it.

For these reasons, serious consideration should be given to a new BSP in south west Exeter to de-load Exeter City BSP; this would primarily be to supply the new demand. This BSP can be ringed into the southern side of AB-route, which is one of the two clean interconnectors between Abham and Exeter GSPs.

Sowton BSP

CP TD

Sowton BSP is supplied via BJ-route, which is teed of either side of AE-route fed out of Exeter GSP.

Initial 2020 studies showed the Sowton GT overloading for autumn peak demand under Consumer Power and Two Degrees. Detailed investigation identified that the majority of the forecast demand growth was within the Sowton ESA, but was actually connecting into Exeter Main; due to the spare capacity available. This removed all 2020 overloads seen on the Sowton transformers.

By 2025, continued demand growth at Sowton causes overloads on both Sowton GTs to as much as 122% of rating for the loss of the other GT for all demand representative days under Consumer Power and Two Degrees. This is reduced to 112% for the summer peak demand representative day.

Both sides of the BJ-route are also overloaded for the FCO causing the loss of one of the Sowton GTs. This overloads the circuit to as much as 124% for summer peak demand.

It is recommended that the group demand of Sowton BSP is limited by moving demand onto Exeter Main BSP where spare capacity will be available if the proposed reinforcement of installing 60/90MVA transformers was carried out. This will resolve the Sowton GT overloads under all scenarios. If Exeter Main BSP was to reach capacity there is scope to create a new BSP at Ottery St Mary, to further deload Exeter Main BSP. Detailed 33kV studies would be required to determine how much demand can be moved.

132kV Network – Generation Overloads

SS

The Marsh Barton to Sowton tee overloaded in 2020 under all scenarios except Steady State. This overload was for any first circuit fault or arranged outage that takes Exeter City GT2 out of service resulting in all of the Exeter City BSP and Marsh Barton generation exporting through the AE-route towards Exeter GSP for a summer peak generation case. Following generation growth to 2025, this overload also occurs in Steady State.

It is recommended the existing 175mm² ACSR (Lynx) conductors on the AE-route between the Sowton tee and Marsh Barton power station is reprofiled to 75°C.

132kV Network – Demand Overloads

SP CP TD

The arranged outage of Exeter City GT2 leaves all of Exeter City supplied via the AE-route and D-route. The AE-route between Marsh Barton power station and the Sowton GT3 tee was reprofiled to 75°C due to generation-driven overloads scenarios under all scenarios except Steady State in 2020. The Exeter City to Marsh Barton circuit (D-route) is currently 175mm² ACSR (Lynx) @ 50°C.

The proposal of a new BSP in south west Exeter to de-load Exeter City would resolve this overload, but an interim solution would be to reprofile the existing 175mm² ACSR (Lynx) conductor on the D-route between Exeter City GT3 and the Marsh Barton power station tee to 75°C.

The arranged or fault outage of Sowton GT3 leaves all of Sowton supplied via the eastern side of AE-route. This was not identified as requiring reinforcement in 2020, but the continued demand growth at Sowton means overloads are seen up to 118% for summer and autumn peak demand representative days.

It is recommended the existing 175mm² ACSR (Lynx) conductors on the western side of AE-route between Exeter GSP and the tee to Sowton GT1 is reprofiled to 75°C.

The western side of AE-route feeds Sowton GT3 and Exeter City GT3. For the arranged outage of Exeter City GT2 followed by a fault of Exeter GSP to Sowton GT1 circuit, the AE-route is overloaded to as much as 121% for autumn peak demand and 112% for summer peak demand. This circuit was reinforced in 2020 for this SCO condition, but the continued demand growth is showing overloads beyond the rating of the 300mm² AAAC (Upas) @ 75°C.

The proposal of a new BSP in south west Exeter to de-load Exeter City and migration of new demand from Sowton BSP to Exeter Main BSP is expected to resolve this overload under all scenarios. Alternatively, it may be possible to resolve this overload by transferring either Sowton GT3 or Exeter City GT3 onto one of the interconnecting circuits between Exeter GSP and Abham GSP.

Torquay BSP

CP

Torquay BSP has two 45/90MVA transformers and is fed out of Abham GSP on a double circuit (AW-route). The first circuit fault of either transformer overloads the remaining transformer up to 103% for the autumn representative day under Consumer Power only.

It may be possible to defer this reinforcement through the use of flexibility services.

It is recommended that a wider suite of transformer ratings is developed, including accurate ratings for the seasons between summer and winter. This is likely to resolve this projected overload.

Landulph GSP

As part of the proposed reinforcement to resolve overloads identified in the 2020 studies, the 132kV parallel between Landulph GSP and Abham GSP was split at Plymouth BSP.

SGT Capacity

SS SP CP TD

No loadings above SGT nameplate ratings are seen for any FCO condition.

For the SCO combination of either normally in-service Landulph SGT, the hot-standby SGT is switched in. The subsequent fault of either SGT leaves the remaining Landulph SGT 149% over nameplate rating for winter and autumn peak demand representative days under Two Degrees and Consumer Power. The highest loading for this SCO condition in summer peak demand is 115%. There are no summer generation-driven overloads.

It is recommended that the adequacy of the available access window for the SGTs and associated transmission circuits is assessed. If it is not long enough, alternative running arrangements, flexibility services and reinforcement should be considered as means to extend it. It may be possible to agree short-term ratings for the SGTs at Landulph GSP with National Grid.

Depending on the expansion of SGT capacity in the Exeter/Abham group, it may be possible to manage Landulph SGT outages by transferring demand out of group at Plymouth BSP.

Landulph to Plymouth 132kV Network

SS SP CP TD

The 132kV split at Plymouth leaves Milehouse, Ernesettle and half of Plymouth with a group demand of 210MW under Two Degrees. This group is fed out of Landulph GSP on the AA-route double circuit. Totnes, Plympton and the other half of Plymouth is separately fed out of Abham GSP on the H-route double circuit and has a group demand up to 145MW under Two Degrees.

Ernesettle to Milehouse 132kV circuit

The demand growth at Ernesettle, Milehouse and Plymouth means that a first circuit fault of the Landulph 605 circuit to Ernesettle and Plymouth leaves the Ernesettle to Milehouse cable overloaded for all demand representative days, to as much as 106% of rating under Two Degrees and Consumer Power. This overload is not seen under Slow Progression and Steady State.

The projected overloads of the Ernesettle to Milehouse cable could be resolved by:

- **Overlaying the Ernesettle to Milehouse 132kV cable with a new, larger cable; or**
- **Building a third 132kV circuit from Landulph GSP into the group, to Milehouse or Plymouth BSP.**

Depending on the expansion of SGT capacity in the Exeter/Abham group, it may be possible to defer this 132kV circuit reinforcement by transferring demand out of the Landulph to Plymouth 132kV network at Plymouth BSP. It is unlikely that flexibility would be a viable option, as the overload occurs for a first circuit fault in all seasons.

The arranged outage to maintain Landulph 132kV bus coupler 130 splits the 132kV bar into two nodes. The subsequent fault of Landulph SGT3 leaves one node without direct infeed, so that parts of Landulph BSP and St Germans BSP are supplied via the Plymouth 132kV ring.

This overload increases for a SCO condition where there is an arranged outage of Landulph 130 bus coupler, followed by a fault of Landulph SGT 3. No auto-close scheme is currently installed on the hot-standby SGT for the loss of one of the in-service SGTs. This means the reserve bar has no SGT infeed, so is supplied via Plymouth 132kV ring. This overloads the Ernesettle to Milehouse cable up to 150% under Two Degrees and 124% under Steady State.

This onerous running arrangement could be avoided by:

- **Installation of a second bus coupler 230 at Landulph to avoid the busbar split for the arranged outage of 130; or**
- **For the arranged outage of bus coupler 130, transferring all circuits onto the Main busbars, putting SGT1 on load, and putting SGT3 on hot-standby.**

A busbar fault of Landulph GSP Reserve 1 and 2 opens Landulph 605, but leaves Ernesettle GT2 on load via Plymouth BSP and, in turn, the Ernesettle to Milehouse cable. This overloads the Ernesettle to Milehouse cable to 135% for all demand representative days under Two Degrees and Consumer Power. This overload reduces to 117% under Slow Progression and Steady State.

This overload could be prevented by intertripping from Landulph 605 to Ernesettle 2T0.

Ernesettle BSP

CP TD

Ernesettle BSP has two 60/90MVA transformers fed out of Landulph GSP on the AA-route. A first circuit fault of either transformer leaves the remaining transformer overloaded up to 110% for autumn and winter peak demand representative days.

The projected overloads could be resolved by establishing a new BSP to the north of Plymouth supplied from the B-route, and transferring demand from Ernesettle BSP. Although it may be possible to defer reinforcement through demand transfers to other BSPs, this is likely to exacerbate other constraints including the overload of the Ernesettle to Milehouse 132kV cable.

Landulph/St Germans BSP Group

As part of the proposed 2020 reinforcements for the St Germans/Landulph BSP group, a second 40/60MVA transformer is installed at Landulph BSP on a 132kV transformer feeder from Landulph GSP. For the 2025 studies, the group was split at 33kV to remove the challenges of operating an interconnected network, with a proposed split of demand and generation to make best use of the transformer and circuit ratings.

Detailed 33kV studies should be undertaken to determine the most appropriate split on the 33kV network.

Generation

CP TD

Generation growth in the Landulph and St Germans interconnected group is forecast to grow to between 129MW (Steady State) and 166MW (Two Degrees) in 2025.

For a first circuit outage (arranged or fault) which results in the loss of GT1 at Landulph, the remaining GT2 would overload up to as much as 144% under a Two Degrees scenario. For a first circuit outage which results in the loss of GT2 at Landulph, the remaining GT1 in service would overload up to as much as 108% under a Two Degrees scenario.

Similarly, for a first circuit outage (arranged or fault) which results in the loss of 132kV infeed to GT1 at St Germans, the remaining GT2 in-service would overload up to as much as 107% under a Two Degrees scenario. For a first circuit outage which results in the loss of 132kV infeed to GT2 at Landulph, the remaining GT1 in service would overload up to as much as 106% under a Two Degrees scenario.

Uprating the smaller GT2 at Landulph BSP would help to alleviate the generation related overloads. These studies suggested that a 33kV split between Landulph and St Germans would be beneficial to the group for a peak generation case. Care must be given to where the split is made, as considerably more generation is forecast in the St Germans area.

Demand

Under normally 33kV running there are no demand-driven overloads on either Landulph GT for the FCO (arranged or fault) of the other Landulph GT. For the arranged out of either AA-route circuits that supplies Ernesettle BSP, there is 33kV interconnection to Landulph BSP that can be used to transfer load onto Landulph. Under this condition the subsequent fault Landulph GT1 overloads GT2 up to 157% for winter peak demand under Consumer Power and Two Degrees. Not making the transfer for the arranged outage would result in the overload of the in-service Ernesettle GT.

At St Germans, a first circuit outage (arranged or fault) which results in the loss of 132kV infeed and a grid transformer at St Germans would overload the remaining in-service grid transformer up to as much as 118% for an autumn peak demand case and up to as much as 111% for a winter peak demand scenario. The overloads would occur under a Two Degrees scenario.

To ensure the capability to transfer load from Ernesettle to Landulph, GT2 at Landulph BSP would need to be uprated to alleviate the demand related overloads under Consumer Power and Two Degrees. Alternatively, Ernesettle BSP could be reinforced through the establishment of a new BSP to the north of Plymouth.

Similarly, upgrading the GTs at St Germans to 60/90MVA units would alleviate the projected demand and generation issues.

Alverdiscott and Indian Queens GSPs

North Devon

Generation Overloads

SP CP TD

A first circuit outage (arranged or fault) which results in the loss of the 132kV circuit between Alverdiscott, Barnstaple GT1 and East Yelland 103 would overload the J-route circuit between Barnstaple GT1 and East Yelland 303 up to 105% (Slow Progression), 107% (Consumer Power) and 124% (Two Degrees).

The J-route circuit between East Yelland 303 and Barnstaple GT2 has recently been recrimped to remove the rating restriction; there are plans to reprofile this circuit for 75°C operation. These reprofiling works would alleviate the projected overloads on this circuit for 2025.

Demand Overloads

CP TD

A first circuit outage (arranged or fault) which results in the loss of the Main 2 busbar at Alverdiscott would result in the loss of two of the three 132kV circuits into the East Yelland and Barnstaple group. This leaves the entire Barnstaple and East Yelland demand fed via one of the northern K-route circuits between Alverdiscott and East Yelland and Alverdiscott SGT1, with the J-route circuit between East Yelland 303 and Barnstaple GT2 feeding the demand at Barnstaple. This FCO condition would overload the K-route circuit between Alverdiscott and East Yelland up to as much as 110% for summer, 121% for an autumn and 116% for a winter peak demand case under the Consumer Power and Two Degrees scenarios. This FCO condition would also overload the J-route circuit from East Yelland to Barnstaple GT2 up to 111% for an autumn peak demand case.

For an arranged outage of the northern K-route circuit between East Yelland 403 and Alverdiscott 105, the bus coupler breaker 130 at East Yelland is closed so as not to leave Barnstaple BSP at single circuit risk. If this FCO is followed by the circuit fault of the T-route/J-route circuit between Alverdiscott and Barnstaple GT1, this would result in the loss of two of the three 132kV circuits into the Barnstaple and East Yelland group. Similar to the above overload, this leaves the entire

Barnstaple and East Yelland demand fed via one of the northern K-route circuits between Alverdiscott and East Yelland, with the J-route circuit between East Yelland 303 and Barnstaple GT2 feeding the demand at Barnstaple. This condition would overload the K-route circuit between Alverdiscott 405 and East Yelland 203, up to as much as 108% for a summer, 117% for an autumn and 111% for a winter peak demand case under the Consumer Power and Two Degrees scenarios. This FCO condition would also overload the J-route circuit from East Yelland to Barnstaple GT2 up to 106% for an autumn peak demand case.

The J-route circuit between East Yelland 303 and Barnstaple GT2 has recently been recrimped to remove the rating restriction; there are plans to reprofile this circuit for 75°C operation. These reprofiling works would alleviate the projected overloads on this circuit for 2025.

A first circuit outage (arranged or fault) which results in the loss of the J-route circuit between East Yelland 303 and Barnstaple GT2 would leave the group demand at Barnstaple fed via GT1 and the J-route teed to the T-route from Alverdiscott. Currently this circuit is 175mm² ACSR (Lynx) which has a restricted rating. The FCO condition would overload the circuit between Barnstaple and the tee point up to 110% (Consumer Power) and 108% (Two Degrees) for an autumn peak demand scenario.

Recrimping and reprofiling the other J-route circuit for 75°C operation between the tee point and Barnstaple GT1 would alleviate the projected overloads. With the group demand of Barnstaple BSP forecasted to exceed 100MW, re-profiling the J-route circuits into Barnstaple to match the cyclic rating of a 60/90MVA transformer should be considered.

East Yelland BSP

CP TD

The peak demand for East Yelland BSP is forecasted to grow to between 87MW (Steady State) and 111MW (Two Degrees) in 2025. Currently East Yelland is fed via two 60/90MVA grid transformers. The first circuit outage (arranged or fault) which results in the loss of one of the 132kV K-route circuits between Alverdiscott and East Yelland and a grid transformer at East Yelland would overload the remaining in-service grid transformer at East Yelland up to 113% (Two Degrees) and 115% (Consumer Power) for an autumn peak demand representative day. The overload would also occur up to 103% (Two Degrees) and 104% (Consumer Power) for a winter peak demand representative day.

One option to resolve the overload seen from the demand growth at East Yelland BSP is to establish a new BSP at Alverdiscott to transfer load from both Barnstaple and East Yelland, the group demand of both East Yelland and Barnstaple is forecasted to grow to as much as 250MW in 2025.

Barnstaple BSP Capacity

Generation Overloads

SP CP TD

The peak generation in Barnstaple BSP is forecasted to grow to between 71MW (Steady State) and 103MW (Two Degrees) in 2025.

The first circuit outage (arranged or fault) which takes a grid transformer at Barnstaple out of service would overload the remaining in-service grid transformer up to 124% under a Two Degrees scenario. For a first circuit outage (arranged or fault) which results in the loss of the J-route circuit between East Yelland and Barnstaple GT2 would overload Barnstaple GT1 up to 124% under a Two Degrees scenario.

The arranged outage to maintain circuit breaker 120 at Alverdiscott GSP, followed by a fault of SGT1 at Alverdiscott, would overload GT1 at Barnstaple up to 103% (Slow Progression), 106% (Consumer

Power) and 130% (Two Degrees). As the circuit breaker 130 is not closed for this arranged outage, the vast majority of the generation exports through GT1.

Creation of an Alverdiscott BSP with load transferred from Barnstaple BSP would resolve the GT overloads identified.

Demand Overloads

SS SP CP TD

The peak demand in Barnstaple BSP is forecasted to grow to between 75MW (Steady State) and 103MW (Two Degrees) in 2025.

The first circuit outage (arranged or fault) which takes a grid transformer at Barnstaple out of service would overload the remaining in-service grid transformer up to 117% (Steady State) and 162% (Two Degrees) for an autumn peak demand case under all scenarios. The FCO condition would also overload the GT at Barnstaple up to 104% (Steady State) and 144% (Two Degrees) for a winter peak demand case under all scenarios. Under the Two Degrees and Consumer Power scenarios, the overloads also occur for a summer peak demand case, up to as much as 149%.

Creation of an Alverdiscott BSP with load transferred from Barnstaple BSP would resolve the GT overloads identified.

Alverdiscott GSP and K-route

Alverdiscott SGT Capacity

Generation Overloads

SS SP CP TD

Due to high generation growth in the area, for the fault of an SGT at Alverdiscott the remaining SGT in service would overload up to 145% (Two Degrees), 122% (Consumer Power) and 116% (Slow Progression) for a summer peak generation day under all scenarios. The overloads also occur for an arranged outage on one of the 400kV circuits between Taunton and Indian Queens, which disconnects one of the SGTs at Alverdiscott and cause overloads of a similar magnitude.

For the summer peak generation case, various SCO combinations would overload the SGTs at Alverdiscott. The overloads described in the baseline and 2020 results are exacerbated under all scenarios in 2020. The condition which causes the highest reverse power flow loadings on SGT2 is the SCO combination of the arranged outage which results in the loss of 132kV infeed from Indian Queens to St Tudy, followed by a 400kV fault of the circuit between Indian Queens and Taunton. This would result in the loss of an SGT at Alverdiscott and one of the 132kV interconnecting circuits between Indian Queens and Alverdiscott. This SCO combination would overload the remaining in-service SGT up to as much as 191% (Two Degrees), 147% (Consumer Power), 140% (Slow Progression) and 119% (Steady State).

Demand Overloads

SS SP CP TD

The first circuit fault which results in the loss of an SGT at Alverdiscott would overload the remaining in-service SGT up to as much as 136% under Two Degrees and Consumer Power for an autumn peak demand representative day. These overloads would also occur up to as much as 137% (Two Degrees and Consumer Power) and 104% (Slow Progression) for a winter peak demand representative day. This overload would also occur for an arranged outage which results in the loss of an SGT at Alverdiscott under the Two Degrees and Consumer Power scenarios.

The SCO combination of the arranged outage which results in the loss of 132kV infeed from Indian Queens to St Tudy, followed by a 400kV fault of the circuit between Indian Queens and Taunton would result in the loss of an SGT at Alverdiscott and one of the 132kV interconnecting circuits between Indian Queens and Alverdiscott. This SCO condition would overload the remaining in-service SGT at Alverdiscott up to as much as 154% (Two Degrees) and 112% (Steady State) for a winter peak demand case. The overloads also occur for an autumn peak demand case (146% in Two Degrees and 107% in Steady State) and also for a summer peak demand case (117% in Two Degrees and 123% in Consumer Power).

K-route

As part of the reinforcements for the 2020 model, the north western side of the K-route from Pyworthy 305 to the tower opposite St Tudy BSP was reconductored with 300mm² AAAC (Upas) @ 75°C.

Generation

SP CP TD

For a first circuit outage (arranged or fault) which results in the loss of 132kV infeed from Indian Queens 505 to Pyworthy 305 would result in all of the generation export from Pyworthy BSP and up to two 132kV connected generators being fed towards Alverdiscott. For this FCO, this would overload the 132kV circuit between Pyworthy 105 and Alverdiscott GSP up to as much as 135% (Two Degrees), 107% (Consumer Power) and 104% (Slow Progression).

There are multiple SCO combinations which would overload parts of the K-route for a summer peak generation representative day:

- The SCO combination which results in the loss of two SGTs at Alverdiscott would leave all of the generation export from the BSPs in North Devon being fed through the K-route to Indian Queens. This SCO condition would overload the 132kV circuits between Pyworthy 305 to Indian Queens and also from Canworthy 132kV generator to Indian Queens up to as much as 134% (Two Degrees), 108% (Consumer Power) and 104% (Slow Progression). This SCO condition would also overload the SGTs at Indian Queens up to as much as 121%.
- The arranged outage of Main 1 busbar at St Tudy, followed by a fault of an SGT at Alverdiscott, would leave all of the generation export from St Tudy BSP and two 132kV connected generators being fed towards Alverdiscott. This SCO combination would overload the K-route circuit between Northmoor 132kV generator and Alverdiscott GSP up to 102% under a Two Degrees scenario only. This SCO combination would also heavily overload the remaining SGT in-service at Alverdiscott, up to as much as 192%.
- The 400kV SCO combination which results in the loss of two SGTs at Indian Queens would result in all of the generation export from Pyworthy BSP and two 132kV connected generators being fed towards Alverdiscott. This SCO condition would overload the 132kV circuits between Pyworthy 105 to up to as much as 142% (Two Degrees), 118% (Consumer Power) and 113% (Slow Progression). This SCO condition would also overload both SGTs at Alverdiscott up to as much as 119%.

Demand

SP CP TD

The group demand for North Devon and the ESAs as fed by the K-route (which encompasses North Tawton, East Yelland, Barnstaple, Pyworthy and St Tudy) is forecasted to grow to between 322MW (Steady State) and 411MW (Two Degrees). The overloads described in the 2020 results are exacerbated in 2025 under the Consumer Power and Two Degrees scenarios, to the extent that a summer outage window is no longer available. In the higher demand growth scenarios for 2025, the significant demand growth limits the accuracy of study work.

Pyworthy and North Tawton BSPs

Generation

SS SP CP TD

There is high generation growth forecast in the Pyworthy and North Tawton BSP group, which is operated interconnected at 33kV. For various SCO combinations there are grid transformers at Pyworthy and North Tawton which would overload under all scenarios for a peak generation:

- An arranged outage of Main 1 busbar at Alverdiscott GSP, followed by a fault of GT4 at Pyworthy would result in the loss of the GT at North Tawton and Pyworthy GT4, which would overload Pyworthy GT3 up to 104% under a Two Degrees scenario.
- The SCO combination which results in the loss of two grid transformers at Pyworthy would overload the remaining in-service grid transformer, up to as much as 154% (Two Degrees), 165% (Consumer Power), 156% (Slow Progression) and 133% (Steady State)

St Tudy BSP

Generation Overloads

SP CP TD

The generation in St Tudy is forecasted to grow to between 74MW (Steady State) and 115MW (Two Degrees) in 2025. For a first circuit outage (arranged or fault) which results in the loss of one of the two grid transformers at St Tudy, the remaining grid transformer in-service would overload up to 156% (Two Degrees), 116% (Consumer Power) and 111% (Slow Progression).

Demand Overloads

CP TD

The peak demand in St Tudy is forecasted to grow to between 59MW (Steady State) and 73MW (Two Degrees) in 2025. For a first circuit outage (arranged or fault) which results in the loss of one of the two grid transformers at St Tudy, the remaining grid transformer in-service would overload up to 113% (Two Degrees) and 116% (Consumer Power) for an autumn peak demand representative day. The same FCO would also overload the remaining in-service GT at St Tudy up to 105% (Two Degrees) and 107% (Consumer Power) for a winter peak demand representative day.

Combined SGT and 132kV circuit reinforcement strategy

The East Yelland, Barnstaple, Pyworthy, North Tawton and St Tudy BSP group sees a generation increase from 306MW in the baseline up to 531MW (Two Degrees) and 360MW (Steady State) in 2025. This is compared with a baseline demand of 261MW up to 410MW (Two Degrees) and 322MW (Steady State) in 2025.

The significant demand and generation growth across the North Devon 132kV network would trigger major reinforcement in all scenarios. This would include multiple new SGTs at Alverdiscott or establishing a new GSP in close proximity to the existing K-route.

The generation growth on the Pyworthy/North Tawton BSP under all scenarios will require significant levels of curtailment, or an additional GT infeed into group. In 2025 under Two Degrees the generation growth is predominately located at Pyworthy; with Pyworthy having 200MW of generation, compared with 30MW at North Tawton. If a new GSP was to be built then locating it near Pyworthy BSP to support the generation growth would likely reduce the 132kV works required to resolve the identified overloads.

Given the projected demand and generation growth at both Pyworthy and St Tudy BSPs, a new two-transformer BSP between Pyworthy and St Tudy on the K-route is likely to be an appropriate reinforcement.

Continued parallel operation of Indian Queens and Alverdiscott GSPs is unlikely to be sustainable with additional SGTs, due to fault level constraints and the increasing complexity of operating a highly interconnected 132kV network. If K-route was split, it should be done in a way that gives flexibility to transfer demand and generation between GSPs.

If Pyworthy was fed out of Indian Queens GSP following a K-route split (normally or abnormally), there would be a 33kV loose couple between Alverdiscott and Indian Queens GSPs via the Pyworthy and North Tawton 33kV network. For this running arrangement, it may be possible to move the North Tawton 33kV parallel onto Barnstaple BSP, which is normally fed out of Alverdiscott; removing the loose couple with Pyworthy.

A wider system approach will be required when determining the best reinforcement for the North Devon and K-route network and any reinforcement should be coordinated with the Indian Queens GSP.

Indian Queens SGT Capacity

Generation Overloads

SP CP TD

For the SCO combination or busbar fault which takes two SGTs at Indian Queens out of service would overload the remaining two SGTs in service for a summer peak generation representative day, up to as much as 103% (Slow Progression), 108% (Consumer Power) and 135% (Two Degrees).

Demand Overloads

SS SP CP TD

For the SCO combination which takes two SGTs at Indian Queens out of service, the remaining two SGTs in service would overload above the nameplate rating under all scenarios. These overloads would occur for an autumn and winter peak demand representative day up to as much as 116% (Steady State) and 141% (Two Degrees). These overloads also occur for a busbar fault of either of the Indian Queens Reserve 1 or Reserve 2 bars, as this also disconnects two SGTs. The SGT overloads would not occur for a summer peak demand representative day.

The outage window should be assessed to determine if a summer outage window is sufficient and short-term ratings of SGTs can be utilised. If this is not sufficient, alternative running arrangements, flexibility services and reinforcement should be considered as means to extend it.

Fraddon BSP

Generation

For a first circuit fault which results in the loss of either AY-route circuit between Indian Queens and St Austell, grid transformer GT2 at Fraddon would overload up to 120% (Two Degrees) and 103% (Consumer Power and Slow Progression). For the first circuit arranged which also results in the loss of the AY-route circuit to St Austell, the interconnected Fraddon GT2 and St Austell group is split. For the arranged outage, grid transformer GT2 at Fraddon would overload up to 112% (Two Degrees) and 101% (Consumer Power and Slow Progression).

For the arranged outage of GT2 at Fraddon, the 33kV interconnection between Fraddon and St Austell is pre-emptively split and the interconnector between Fraddon GT2 and Fraddon GT3/GT4 is closed. A subsequent fault of either GT3 or GT4 at Fraddon would leave all of the generation export from Fraddon GT2, GT3 and GT4 exporting via the remaining grid transformer. This SCO condition would overload the remaining in-service GT at Fraddon up to 168% (Two Degrees), 115% (Consumer Power and Slow Progression). This SCO condition would also overload the circuit from Indian Queens to the remaining in-service Fraddon GT up to 115% under a Two Degrees scenario. A similar magnitude overload also occurs for an arranged outage of Fraddon GT1, which initiates a 33kV split between Fraddon and Truro and closes the interconnector between Fraddon GT1 and Fraddon GT3/GT4.

The SCO condition which results in the loss of both of the AU-route circuits from Indian Queens to Fraddon would overload the A-route circuit between Indian Queens and Camborne up to 116% under a Two Degrees scenario.

Many of these complex SCO issues could be avoided by reconfiguring the 33kV networks in the area to form separate groups, each fed by two GTs at a BSP. This would require 33kV works to:

- **Split the 33kV parallel between Fraddon GT1 and Truro BSP; and**
- **Split the 33kV parallel between Fraddon GT2 and St Austell BSP.**

These works would allow Fraddon GT1 and GT2 to be operated in parallel with each other. It is recommended that detailed 33kV studies are carried out to assess the practicality of these proposals.

West Cornwall 132kV Network

The 132kV network in West Cornwall is fed via four 132kV circuits from Indian Queens, the AU-route and the A-route. Both double circuit routes feed into Fraddon BSP; there are teed circuits to supply the wider Truro, Rame, Hayle and Camborne groups. In 2025, the group demand of the West Cornwall network is forecasted to grow to between 360MW (Steady State) and 418MW (Two Degrees). For the SCO condition which results in the loss of both of the AU-route circuits between Indian Queens and Fraddon, the remaining A-route circuits supplying the West Cornwall group would overload. The circuit with smaller rating feeding Fraddon GT1 would overload up to up to as much as 154% for an autumn peak demand case under all scenarios. The overloads also occur up to as much as 153% for a winter peak demand case under all scenarios, and up to as much as 118% for a summer peak demand case under the Two Degrees and Consumer Power scenarios. The A-route circuit with the larger rating feeding Fraddon GT2 would also overload up to as much as 108% for an autumn peak demand and case up to as much as 106% for a winter peak demand case under a Two Degrees and Consumer Power scenario.

Given the projected demand growth in the West Cornwall 132kV network, the A-route circuit from Indian Queens 305 to Fraddon would need to be reconductored with 300mm² AAAC (Upas) @ 75°C. These reconductoring works would enable a summer access window; however it should be noted that further demand growth would require further 132kV infeed into the group.

Truro BSP

Generation Overloads

SP CP TD

The peak generation at Truro BSP is forecasted to grow to between 86MW (Steady State) and 109MW (Two Degrees) in 2025. For an arranged outage which deloads one of the grid transformers at Truro, this condition would overload the remaining grid transformer to as much as 128% (Two Degrees), 113% (Consumer Power) and 105% (Slow Progression).

Demand Overloads

CP TD

The peak demand at Truro BSP is forecasted to grow to between 66MW (Steady State) and 74MW (Two Degrees) in 2025. For an arranged outage which deloads one of the grid transformers at Truro, this condition would overload the remaining grid transformer to as much as 106% (Two Degrees) and 109% (Consumer Power) for an autumn peak demand case.

The 2025 studies for the Truro and Fraddon network included a pre-emptive split of the 33kV network for the loss of a grid transformer at Truro, to mitigate the next fault loss of another grid transformer. For the arranged outage to main circuit breaker 120 at Truro, this pre-emptive split is not triggered as both GTs at Truro remain in service, albeit with a poor load share as GT1 is fed via Rame and GT2 via Fraddon. For a subsequent fault of the Rame GT1 to Fraddon GT3 (teed to Camborne main 4 busbar) circuit, this leaves all of the demand at Fraddon GT1 fed via the grid transformers at Truro. This SCO condition would overload Truro GT2 up to 113% (Two Degrees) and115% (Consumer Power) for an autumn peak demand case, and up to 108% (Two Degrees) and 110% (Consumer Power) for a winter peak demand case.

It is recommended that a wider suite of transformer ratings is developed, including accurate spring and autumn ratings. This is likely to resolve the projected autumn demand-driven overload.

The demand SCO condition can be managed operationally by splitting the 33kV network for the maintenance of 120 at Truro, either to lose the Fraddon GT1 demand as a lost load or close the interconnector to the Fraddon new board.

It may be possible to resolve the generation overloads through the use of flexibility. Alternatively, replacing the existing 30/60MVA Truro transformers with 60/90MVA units would resolve all overloads.

Hayle BSP

CP TD

For a first circuit outage (arranged or fault) which results in the loss of one of the 132kV infeed into Hayle BSP and opens the 120 circuit breaker, would overload the remaining in-service grid transformer for an autumn or winter peak demand representative day under the Two Degrees and Consumer Power scenarios. This FCO condition would overload the remaining grid transformer to as much as 116% for an autumn peak demand case and up to as much as 110% for a winter peak demand case. This overload is exacerbated when followed by a fault of one of the circuits into the wider 132kV connected Camborne and Hayle group, which would overload the remaining in-service grid transformer up to 123% for an autumn peak demand case and 117% for a winter peak demand case.

Replacing the existing 30/60MVA Hayle transformers with 60/90MVA would resolve the overload under Two Degrees and Consumer Power.

Hayle/Camborne

SS SP CP TD

As part of the 2020 reinforcements to secure the Hayle and Camborne group against a lost load for a second circuit outage, the following reinforcement works were modelled:

- Extension of the 132kV busbar at Rame to accommodate a 4 corner mesh arrangement
- Removal of the tee point on the CC-route and BM-route to terminate both circuits onto separate 132kV isolators at Rame
- Installation of a new 420 breaker at Camborne to accommodate a new 132kV interconnecting circuit between Camborne and the BM-route from Rame to Fraddon

The peak demand in the Hayle and Camborne group is forecasted to grow to between 118MW (Steady State) and 138MW (Two Degrees) in 2025. For the arranged outage of Main 2 busbar at Camborne, followed by a fault of the BM-route circuit between Fraddon and Rame (also teed to Camborne 403), this would remove two 132kV infeeds into the Hayle and Camborne group. This SCO combination would overload the CC-route circuit between Rame and Hayle up to as much as 106% (Steady State) and 125% (Two Degrees) under all scenarios for an autumn peak demand case. The overloads would also occur for a winter peak demand case (up to as much as 103% in Steady State and 123% in Two Degrees) under all scenarios and for a summer peak demand case (up to as much as 103% in Two Degrees and 109% in Consumer Power only).

Overloads of similar magnitude would also occur on the A-route circuit between Camborne and Indian Queens teed Fraddon GT1 for the SCO combination of the circuit between Rame and Hayle, followed by a fault of the BM-route circuit between Fraddon and Rame (also teed to Camborne 403). This would also result in the loss of two 132kV infeeds into the Hayle and Camborne group, leaving the group supplied via the A-route circuit from Fraddon to Camborne.

Reprofiling the existing 175mm² ACSR (Lynx) conductors on the CC-route from Rame to Hayle and the A-route from Camborne to Fraddon for operation at 75°C would resolve the projected overloads.

11 – Next Steps

Baseline Constraints

It is recommended that the operability constraints identified in the baseline studies are assessed in further detail, and mitigated where necessary. Constraints involving transmission outages or SGT capacity should be assessed in conjunction with National Grid.

Comparing Investment Options for 2020

This study has identified some areas of the network which would require reinforcement under the forecasted demand, generation and storage scenarios. It is recommended that for each of the reinforcement requirements identified in the 2020 studies, a preferred solution is developed and triggered as necessary. Each preferred solution could comprise conventional network build, novel technologies, flexibility services, or a combination of those tools. Each solution should be chosen through technical and cost-benefit assessment, to ensure the efficient, co-ordinated and economic development of the network. The timing of planned asset replacement should be taken into account when choosing and coordinating options. The affected networks are:

- Iron Acton GSP SGTs
- Feeder Road BSP GTs
- Seabank GSP SGTs and transmission infeed
- Weston BSP GTs
- Avonmouth/Weston 132kV ring
- Bridgwater GSP and Taunton GSP SGTs and 132kV interconnectors
- Bridgwater BSP and Street BSP GTs
- Taunton BSP GTs
- Landulph GSP, Abham GSP and Exeter GSP SGTs and 132kV interconnectors
- Newton Abbot BSP GTs
- Marsh Barton to Sowton tee 132kV circuit
- Tiverton BSP GTs
- Landulph BSP and St Germans BSP GTs
- Sowton BSP GTs and upstream 132kV circuits
- Exeter City BSP GTs
- Alverdiscott GSP and Indian Queens GSP SGTs and 132kV interconnectors
- East Yelland BSP GTs
- Barnstaple BSP GTs
- Camborne/Hayle 132kV ring

The additional reinforcement requirements identified in the 2025 studies should also be taken into account to minimise the risk of stranded assets.

Further modelling

Axminster GSP supplies both WPD South West and SSE’s SEPD licence area. As part of this project, we have studied the impact of the scenarios on the whole of Axminster GSP in conjunction with SSE. Results for Axminster GSP are not included in this report, but will be jointly published with SSE in an addendum later in the summer.

It is recommended that the parts of these studies affected by the operation of the transmission network are repeated in cooperation with National Grid. This may form part of a Regional Development Plan in the future.

As further outputs from WPD's Electric Nation project become available, they should be used to update the EV charging profiles used in future studies. Similarly, as outputs from WPD's FREEDOM project on heat pump behaviour become available, they should also be incorporated.

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 analysis including switchgear stressing,
2. Flexibility services and ANM including energy estimation,
3. Protection,
4. Dynamics,
5. Power quality.

12 – Definitions and References

References

External documents

P2

Engineering Recommendation P2 (*Security of Supply*), is currently in its sixth revision (P2/6). P2/6 gives requirements for security of supply towards demand customers which form a condition of WPD's licence. P2 is currently under review by a working group of the Energy Networks Association (ENA).

P27

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

Electricity Act 1989 as amended

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

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

Future Energy Scenarios (FES) 2015, 2016, 2017

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

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

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

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

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

Insight Report Electric Vehicles

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

Air Conditioning Demand Assessment Report

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

Managing the future network impact of electrification of heat Report

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

Western Power Distribution documents

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

Table of Units

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

Glossary

Acronym/ Initialism	Term	Definition
AAAC	All Aluminium Alloy Conductor	Family of overhead line conductors, each of which is composed of strands of an aluminium alloy which combines mechanical strength with electrical conductivity. Reconductoring from ACSR to a slightly larger AAAC often allows a significant improvement in circuit capacity without requiring major modifications to towers. AAAC is now commonly used for new build and refurbishment of transmission and Subtransmission lines in Great Britain. Each AAAC conductor is named after a species of tree.
ACSR	Aluminium Conductor, Steel Reinforced	Family of overhead line conductors, each of which combines steel strands for mechanical strength with aluminium strands for electrical conductivity. ACSR is the conductor traditionally used for transmission and Subtransmission lines in Great Britain. Each ACSR conductor is named after a species of mammal.
AD	Anaerobic Digestion	Generation process that utilises energy from waste products such to produce biogas for gas generator sets.
ANM	Active Network Management	The ENA Active Network Management Good Practice Guide [22] summarises ANM as: *Using flexible network customers autonomously and in real-time to increase the utilisation of network assets without breaching operational limits, thereby reducing the need for reinforcement, speeding up connections and reducing costs.*
–	Access Window	The period of spring, summer and autumn in which arranged outages are normally taken
BEIS	Department for Business, Energy & Industrial Strategy	The governmental department responsible for energy and climate change policy. Formed as a merger between the Department for Business, Innovation & Skills (BIS) and the Department for Energy & Climate Change (DECC)
BS	British Standard	The specification of recommended procedure, quality of output, terminology, and other details in a particular field, drawn up and published by the British Standards Institute (BSI).
BSP	Bulk Supply Point	A substation comprising one or more Grid Transformers and associated switchgear
CDD	Cooling Degree Days	A measurement to determine how much demand is requried to cool a building.
CHP	Combined Heat and Power	Method of utilising the excess heat energy as part of the electricity generation process to produce heat for local customers
–	Demand	The consumption of electrical energy.
DSR	Demand Side Response	Ofgem led tariffs and schemes which incentivise customers to change their electricity usage habits
DG	Distributed Generation	Generation connected to a distribution network. Sometimes known as Embedded Generation.
–	Distribution Transformer	A transformer that steps voltage down from 11kV or 6.6kV to LV

Acronym/ Initialism	Term	Definition
DNO	Distribution Network Operator	A company licenced by Ofgem to distribute electricity in the United Kingdom who has a defined Distribution Services Area.
DSO	Distribution System Operator	A role which may be established in the future whereby the DNO undertakes some of the roles of the GBSO at a regional level to balance supply and demand.
–	Distribution Substation	A substation comprising one or more Distribution Transformers and associated switchgear
ENA	Energy Networks Association	The Energy Networks Association is an industry association funded by gas or distribution or transmission licence holders.
ER	Engineering Recommendation	A document published by the Energy Networks Association.
ESA	Electricity Supply Area	Each ESA represents a block of demand and generation as visible from the Subtransmission network. Each is one of: - The geographical area supplied by a Bulk Supply Point (or group or part thereof) providing supplies at a voltage below 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)
EV	Electric Vehicle	A vehicle which uses electric motors as its method of propulsion
FCO	First Circuit Outage	P2/6 defines a First Circuit Outage as: *…a fault or an arranged Circuit outage…* Also referred to as N-1 in some contexts.
FES	Future Energy Scenarios	A set of scenarios developed by Nation Grid to represent credible future paths for the energy development of the United Kingdom.
GB	Great Britain	A geographical, social and economic grouping of countries that contains England, Scotland and Wales.
GBSO	Great Britain System Operator	National Grid is the system operator for the National Electricity Transmission System (NETS) in Great Britain. Responsible for coordinating power station output, system security and managing system frequency.
GSP	Grid Supply Point	A substation comprising one or more Super Grid Transformers and associated switchgear
GT	Grid Transformer	A transformer that steps voltage down from 132kV to 66kV, 33kV or 11kV.
-	Hotwiring	Hotwiring is a technique used by National Grid to increase the rating of a circuit. National Grid define hotwiring as: *…the ability to operate a circuit at a higher temperature than its original design by using Aerial Laser Survey methods to assess circuits' limiting factors.*
HP (also ASHP)	Heat Pump	Extracts heat from surroundings which can then be used to produce hot water or space heating. There are a number of types of heat pumps; the common air source heat pumps absorb heat from the outside air.
IEC	International Electrotechnical Commission	An organisation that prepares and publishes international standards for all electrical, electronic and related technologies.

Acronym/ Initialism	Term	Definition
NGET	National Grid	The Transmission Network Operator in England and Wales.
NIA	National Innovation Allowance	Funding scheme for innovation projects introduced as part of RIIO-ED1. For the RIIO-ED1 period, WPD requested the minimum 0.5% of total regulated income.
Ofgem	Office for Gas and Electricity Markets	Ofgem is responsible for regulating the gas and electricity markets in the United Kingdom to ensure customers' needs are protected and promotes market competition.
–	Primary Distribution	The sections of an electrical distribution network which provide the interface between transmission and primary or Secondary Distribution. In WPD's network the 33kV circuits and Primary Substations are considered to be Primary Distribution.
–	Primary Substation	A substation comprising one or more primary transformers and associated switchgear
–	Primary Transformer	A transformer that steps voltage down from 66 or 33kV to 11kV or 6.6kV
PV	Photovoltaic	Type of distributed generation which uses solar irradiance to generate electricity.
RAS	Remedial Action Scheme	Add-on module supplied by Siemens for PSS/E power system analysis software that enabled simulation of Corrective Action, control room actions in reaction to specific network conditions
RDP	Regional Development Plan	A joint study between National Grid and WPD on possible 132kV reinforcement options in the South West.
SCO	Second Circuit Outage	P2/6 defines a Second Circuit Outage as: *…a fault following an arranged Circuit outage...* Also referred to as N-1-1 or N-2 in some contexts.
SGT	Super Grid Transformer	A transformer that steps voltage down from 400kV or 275kV to 132kV, 66kV or 33kV
–	Secondary Distribution	The final section of an electrical distribution network which provides the interface between Subtransmission or Primary Distribution and most final customers. In WPD's network the 11kV, 6.6kV and LV circuits and the distribution substations are considered to be Secondary Distribution.
SoW	Statement of Works	The process under which DNOs request that National Grid assesses the potential impact of the connection of DG upon the National Electricity Transmission System.
SQC	Sequential Control	Method of managing the network without the need for manual intervention from a Control Engineer.
–	VAR Compensator	A device which may be used on electricity networks to provide reactive power at particular point to adjust system voltage or perform power factor correction.
TOUT	Time Of Use tariff	National Grid's FES 2016 defines a Time Of Use Tariff as: *A charging system that is established in order to incentivise residential consumers to alter their consumption behaviour, usually away from high power demand times.*
TO	Transmission Owner	A company licenced by Ofgem to transmit electricity in the United Kingdom.

Acronym/ Initialism	Term	Definition
UK	United Kingdom	A geographical, social and economic grouping of countries that contains England, Scotland, Wales and Northern Ireland.
WPD	Western Power Distribution	A Distribution Network Operator (DNO) company that is licenced by Ofgem to distributed electricity in the East Midlands, West Midlands, South West, and South Wales regions of United Kingdom.
XLPE	Cross Linked Poly-Ethylene	Commonly used name for type of underground cable, which uses cross linked poly-ethylene insulation. They can be different sizes and are used extensively on the distribution network.
–	Subtransmission	The sections of an electrical distribution network which provide the interface between transmission and primary or Secondary Distribution. In WPD's South West network the GSPs, 132kV circuits, and BSPs are considered to be Subtransmission.

Transformer Ratings

Transformer Cooling Methods

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

Rating Categories

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

Applied ratings

Grid Transformers

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

Notes:

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

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

Appendix

Network Modelling and Analysis

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

Analysis Program

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

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

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

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

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

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

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

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

The processes followed by the analysis program are summarised in Figure 41.

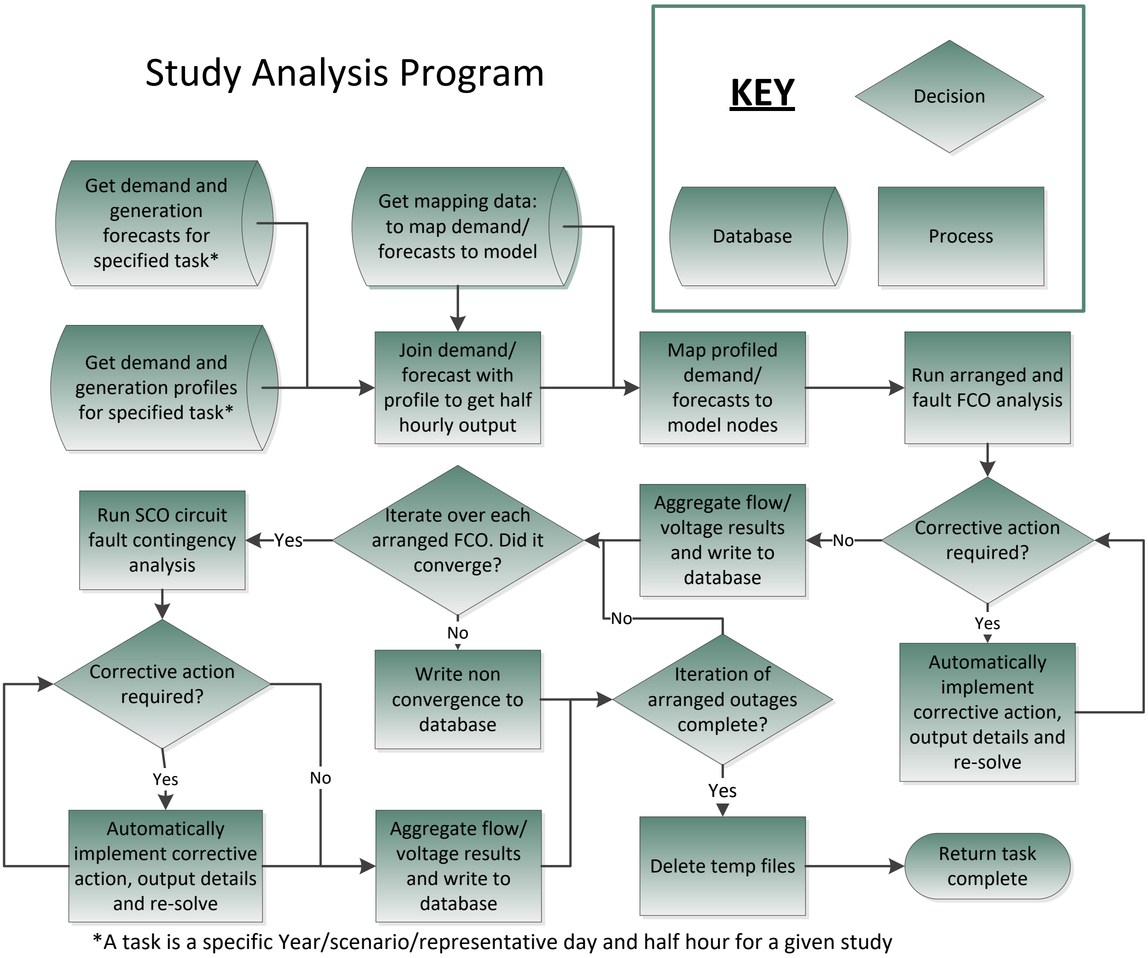

Figure 41: Summary of network analysis process

Modelling Network Automation and Manual Switching Schemes

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

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

Contingency Analysis

The demand and generation capacity of a network is not normally limited by its characteristics under normal running conditions, but by its characteristics under abnormal running conditions. Abnormal running arrangements occur due to faults, maintenance, network construction and other reasons.

WPD's network is required to comply with Engineering Recommendation (ER) P2/6 for demand security, and must safely cope with credible fault conditions beyond the scope of ER P2/6. There is currently no standard for providing security of supply to DG. Contingency analysis is the analysis of the network under abnormal conditions to confirm that the network complies with these requirements.

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

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

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

Modelling Limitations

1. A minor limitation of the program was that a very small minority of contingencies were unable to converge for the most onerous scenarios. Where this occurred the condition was evaluated separately to ensure that it did not indicate an issue with the network model or the network itself.
2. Fault outages were modelled by assuming that each area of network enclosed by circuit breakers represents a protective zone. Sectionalising and subsequent auto-reclose operations were not modelled. Circuit breaker failure outages were not modelled.
3. Arranged outages were modelled by assuming that each area of network enclosed by isolators represents a zone of isolation. The outage required to maintain each isolator was also modelled.
4. Flows on the WPD network can be influenced by the transmission network. Better results are obtained by having accurate data about the transmission network, and the other demands and generators connected to it. The network model used for these studies includes a detailed representation of the transmission network in the South West, with a reduced equivalent of the wider transmission network. This allowed transmission outages within the South West to be assessed, but not transmission outages on the wider network that may affect flows within the South West. Although transmission outages close to the boundary of the reduced network were studied, the accuracy of results for those outages was limited.
5. In the absence of more detailed models of credible worst-case customer behaviour, battery storage was modelled as:
   a. Importing at full capacity when assessing demand security, and
   b. Exporting at full capacity when assessing generation security.
6. At present, there is limited data available on the charging behaviour of large populations of fast-charging, high-capacity EVs with a broad range of users. WPD's is currently hosting the Electric Nation project in partnership with EA. The aim of this project is to determine the impact EVs will have on the network and the effectiveness of demand side management. There is not currently sufficient data to derive new profiles from this project, but the available data will be periodically reviewed. For this reason, EV charging profiles were derived from the Electric Vehicles Insight Report of the Customer-Led Network Revolution project. This was based on a trial involving 143 domestic EV owners that took place in 2014. It is possible that

increases in power and energy consumption per EV will plateau at some point (despite improvements in charging speed and battery capacity) as EV capabilities come to match the demands of EV users, but it is not known when this will happen or at what level. The EV profiles used in the studies peaked at just 0.9kW per EV after diversity. Whilst there is not currently enough data from the Electric Nation trial to create new profiles, there was sufficient data to back up the Customer-Led Network Revolution profiles used. More information on WPD’s Electric Nation project is available at www.electricnation.org.uk

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

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