Shaping Subtransmission to 2030

West Midlands – Report January 2018

WESTERN POWER DISTRIBUTION

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Contents

1 – Executive Summary

As part of a wider trend across Great Britain, WPD's West Midlands licence area has experienced unprecedented growth in the connection of Distributed Generation (DG). There is now around 1.7GW of generation connected to WPD's West Midlands network with another 2GW accepted-not-yet-connected and 1.7MW offered-not-yet-accepted. Many of the planned connections are for energy storage plant. This contrasts against an annual maximum demand of around 4.6GW and minimum demand of less than 1.5GW.

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 West Midlands Statement of Works (SoW) submissions highlighting that DG output in some parts of the West Midlands is limited by the capability of transmission network components.

WPD has committed to the rolling out of Active Network Management (ANM) across all its licence areas by 2021 in order to manage the output of generators and so reduce reinforcement requirements. Several generation-constrained networks across the licence areas have been fast-tracked to enable ANM connections on a nearer timescale.

In the West Midlands, Meaford and Feckenham have been designated as ANM zones, building out from April 2018 onwards.

The West Midlands network is also showing signs of resurgence in demand growth. Local authorities' plans propose developments that would result in strong growth in domestic, industrial and commercial demand in West Midlands. Several new and expanded demand connections have been made in recent years, and there is further interest from developers and customers. Looking into the future, there is the potential for widespread electrification of heating and transport.

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 West Midlands from 2017 to 2030. These scenarios correspond to National Grid's 2016 Future Energy Scenarios: No Progression, Slow Progression, Consumer Power and Gone Green. They cover the growth of conventional demand, several types of generation and the electrification of transport and heating. The West Midlands has not seen the same level of solar and wind plant being connected as in WPD's other licence areas, but developers have proved very capable of securing capacity for energy storage within the area. The growth of energy storage 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 West Midlands network, which consist of Grid Supply Points (GSPs), Bulk Supply Points (BSPs) and the 132kV and 66kV networks. In these studies we have moved away from traditional 'edge-case' modelling, where only the network condition which is deemed to be most onerous is analysed. Instead we have analysed network behaviour throughout the day for:

- **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, 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 loading through innovation projects including Project ENTIRE. 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 usage patterns, which may change dramatically as electric vehicles are more widely adopted.

It is recommended that National Grid assess the impact of our scenarios on their network. It is also recommended that additional studies are carried out in cooperation with Scottish Power Energy Networks (SPEN) to assess WPD and SPEN's interdependent 132kV networks supplied from Cellarhead GSP.

It is our intention to revisit these studies and the underlying scenarios on a two-yearly basis.

2 – Objective of this Report

The overall aim of this report is to:

- Assess the potential growth in Distributed Generation by:
    - fuel type
    - general location
    - year of connection
- Consider potential demand changes that come from:
    - the electrification of transport
    - the electrification of heating
    - growth in industrial, commercial and domestic demand
- Identify thermal and voltage constraints that may occur on our 132kV and 66kV networks 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 2016 as a framework to develop detailed scenarios for the growth of demand and DG in West Midlands. West Midlands 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

West Midlands Licence Area

Western Power Distribution (WPD) is the Distribution Network Operator for (DNO) the West Midlands. The area covers approximately 13,300 square kilometres and extends from Congleton in the north to the outskirts of Bristol in the south; and from Knighton and the Welsh Marches in the west, to Banbury in the east. The area includes Birmingham, the Black Country districts of Wolverhampton, Dudley, Sandwell and Walsall, plus the Potteries centred on Stoke-on-Trent. The area extends to the rural areas of Gloucestershire, Herefordshire, Worcestershire and Shropshire. The entire area serves approximately 2.4 million customers.

There is a high concentration of manufacturing and industrial activities in the West Midlands, with many automotive manufacturers in the region. The business activity is generally situated along the M5, M6, M42 and M54 corridors; as a result there are many distribution and logistics industries in the area. In the more rural areas, agriculture is an important part of the local economy.

Current Network

Western Power Distribution's West Midlands licence area receives supplies from National Grid at seventeen Grid Supply Points (GSPs):

- Iron Acton (132kV) – shared with WPD South West and National Grid
- Port Ham/ Walham (132kV)
- Feckenham (66kV)
- Bishops Wood (132kV)
- Ironbridge (132kV)
- Shrewsbury (132kV)
- Penn (132kV)
- Oldbury (132kV)
- Ocker Hill (132kV)
- Kitwell (132kV)
- Lea Marston/Hams Hall (132kV) – shared with WPD East Midlands
- Nechells (132kV)
- Bustleholm (132kV)
- Willenhall (132kV)
- Bushbury (132kV)
- Rugeley (132kV)
- Cellarhead (132kV) – shared with Scottish Power Energy Networks' SP Manweb licence area

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

Banbury BSP forms part of West Midlands licence area but is supplied from East Claydon GSP in the East Midlands. East Claydon, including Banbury BSP and the 132kV circuits supplying it, was studied as part of the East Midlands strategic studies. The report on these studies, *Shaping Subtransmission to 2030 East Midlands 2017*, is available from www.westernpower.co.uk/netstratemid

A small area of the West Midlands in the Peak District is supplied from primary substations in WPD's East Midlands licence area which are in turn supplied from Electricity North West's Buxton BSP. Buxton BSP is supplied by Stalybridge GSP, which is beyond the scope of these studies.

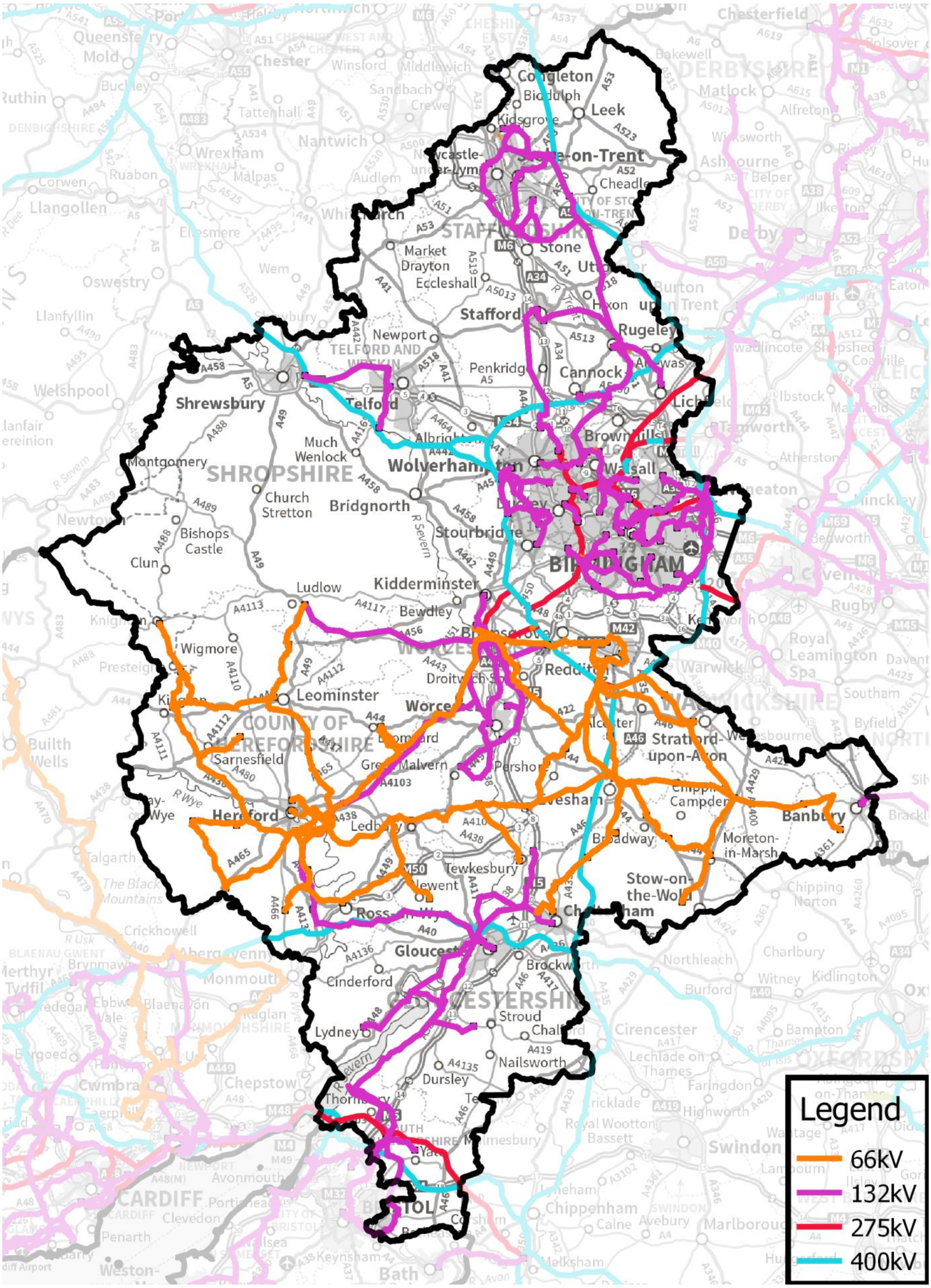

Figure 1: Network in West Midlands showing 400kV, 275kV, 132kV and 66kV networks

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 West Midlands (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	8,156,588	729,358	-	2,299,693	-	-
Other LV NHH (incl. Unmetered)	3,039,863	496,132	105,972	195,040	-	-
Other LV HH	267,126	1,025,955	1,273,582	9,365	1,263,334	199,456
HV (incl. LV Substation)	792,872	3,071,423	3,980,224	4,148	2,995,498	1,055,855
LV Generation	25,509	3,455	4,637	370	-	2,361
HV Generation	151,167	190,201	366,350	179	-	11,035
Total	**12,433,125**	**5,516,524**	**5,730,766**	**2,508,796**	**4,258,832**	**1,268,708**

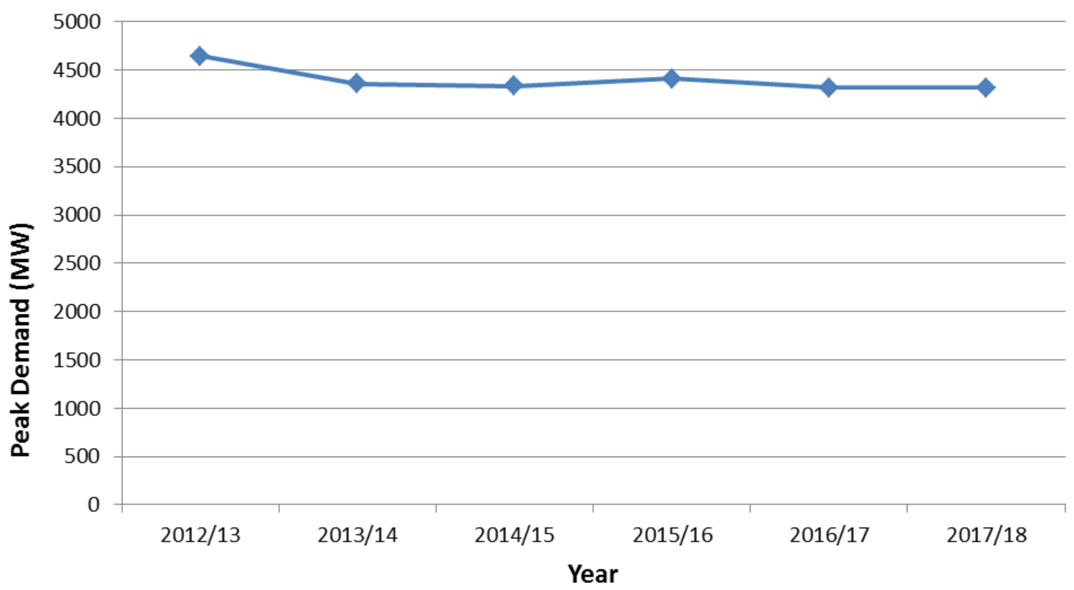

Figure 2: Historic system maximum demand in the West Midlands

The growth of new demand such as Electric Vehicles (EVs) and Heat Pumps (HPs) is expected to change demand profiles. As these technologies develop and smart meters are rolled out, opportunities for Demand Side Response (DSR) may arise, allowing demand profiles to be modified by network operators and suppliers. DSR opportunities are likely to be available for commercial and industrial customers initially, with future extension to domestic customers. WPD has a number of 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 system operator's Demand Turn Up (DTU) to reduce the need for local generation constraints as well as assisting with system balancing.
- A range of projects which aim to develop WPDs understanding of domestic customer led DSR, such as 'Community Energy Action', 'ECHO' and Sunshine Tariff.

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

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

- **Winter Peak Demand**, with minimum coincident generation,
- **Autumn Peak Demand** with minimum coincident generation,
- **Summer Peak Demand** with minimum coincident generation, and
- **Summer Peak Generation** with minimum coincident demand.

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

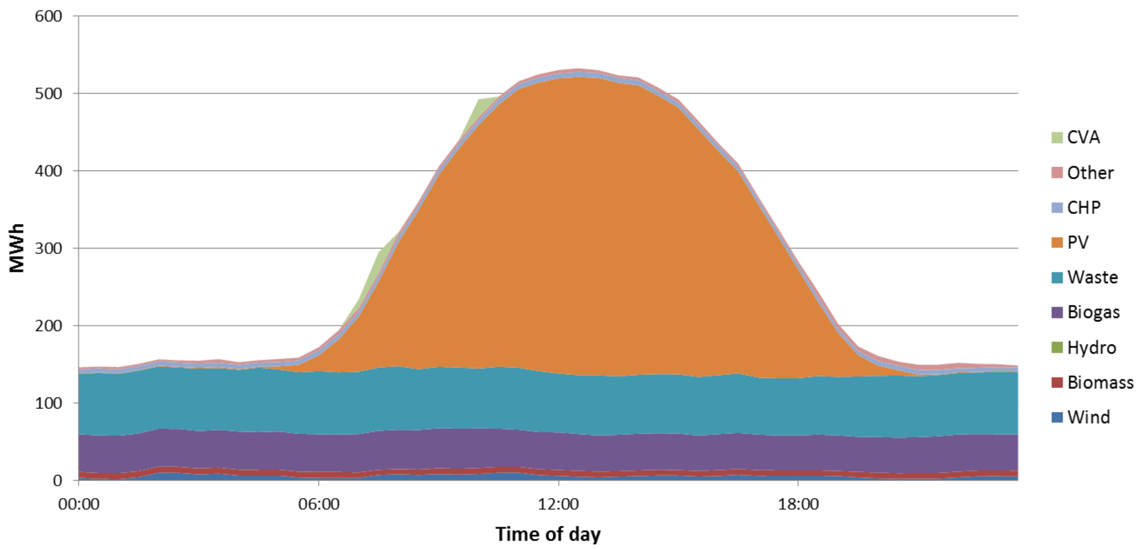

Figure 3: Breakdown of summer day generation mix by technology, MWh per half hour

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 in embedded generators, particularly combined heat and power (CHP) plant. There were also a few larger gas turbine connections.

In addition, NGET have developed various contracted services which has led to the growth in diesel and gas fuelled distribution connected plant to provide these services, generally being required to operate at or around times of peak national demand. Since around 2010, there has been a significant growth in solar PV connections, both in the volume of small roof top systems and large, MW scale, ground mounted systems. More recently there has been a growing interest in the connection of storage. This has been driven by the falling cost of storage, reduced subsidies for renewable technologies, the growing value of flexibility in timing of import/export to the network and NGET seeking frequency support services.

The current position of DG in the West Midlands is shown in Table 2. This shows the breakdown between those connected to the distribution network, those with accepted connection agreements to connect and those with outstanding connection offers.

Table 2: Connected, Accepted and Offered Distributed Generation in WPD West Midlands at the end of December 2017

Generator type	Connected [MVA]	Accepted [MVA]	Offered [MVA]	Total [MVA]
Photovoltaic	589.8	125.4	22.4	737.6
Wind	48.3	-	-	48.3
Landfill Gas, Sewage Gas, Biogas and Waste Incineration	199.7	39.0	5.1	243.8
Combined Heat and Power	17.5	328.2	2.4	348.1
Biomass and Energy Crops	33.0	15.0	-	48.0
Hydro, Tidal and Wave Power	0.6	-	-	0.6
Storage	2.9	651.7	1,188.6	1,843.2
All Other Generation	788.7	819.0	485.2	2,092.9
Total	1,680.5	1,978.4	1,703.6	5,362.5

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

Distribution Network Constraints

Some parts of the West Midlands network are already constrained due to the growth of DG. Several reinforcements that will allow existing assets to be better utilised are planned, and ANM zones have been commissioned for Meaford BSP and Feckenham GSP. Further ANM capability will be delivered out to 2021.

In addition, the reinforcement of networks including Solihull BSP, Selly Oak BSP and various 66kV projects is planned and in progress to maintain P2/6 compliance in light of ongoing demand growth.

Transmission Network Constraints

All changes to demand or generation on the distribution network have some effect on the transmission system. National Grid's Connection and Use of System Code has a requirement in it to seek National Grid's assessment of the impact and any necessary works that they need to undertake where it is deemed that there will be an impact. The initial assessment is carried out via a Statement of Works (SoW) which confirms whether NGET work or connection conditions will be required. Where works are required, a Modification Application is made to NGET. NGET then specifies the precise works or conditions needed before connection can take place.

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

Individual SoW applications have been made to NGET for Grid Supply Points in the West Midlands 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.
- Emergency disconnection facility to be provided to allow WPD to de-energise on instruction from National Grid.
- All generation connections in the Ironbridge and Shrewsbury GSP areas are required to compensate for any resulting increase in the reactive power flows from the connection of their schemes by running at an appropriate leading power factor. To date the prescribed power factor has been approximately 0.98 leading.

WPD currently has a Thermal Materiality Headroom of zero for Iron Acton GSP and Port Ham/Walham GSP; this reflects advice from NGET that there are significant challenges connecting additional thermal plant on these networks. NGET have confirmed that the connection of further Thermal and Storage plants cannot be facilitated until completion of the wider enabling reinforcement works, currently estimated as October 2026. This constraint also affects WPD’s network in South Wales.

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

The Appendix G trial aims to expedite the assessment process across the transmission and distribution boundary and enables quicker and more efficient connections to customers.

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 West Midlands distribution network, WPD commissioned Regen to produce a set of forecasts for the growth of DG and demand in the West Midlands.

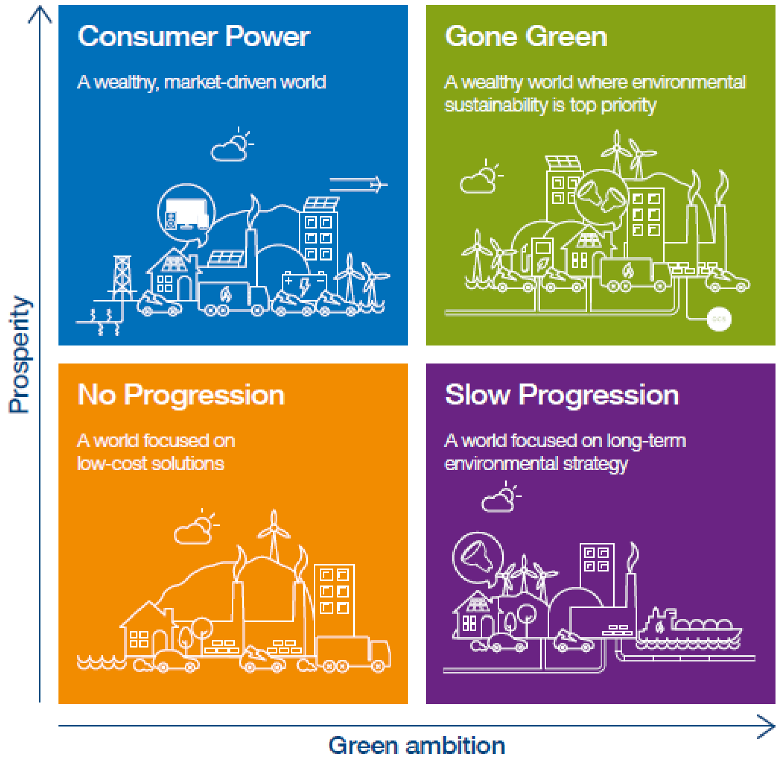

Figure 4: National Grid's Future Energy Scenarios[1]

These scenarios are named after and correspond to those developed by National Grid in the FES 2016. National Grid has revised the scenario names and descriptions for 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 2030.

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

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

Electricity Generation 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	**New Demand Technologies** • Electric vehicles • Heat pumps (domestic) **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 May 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 BEIS Renewable Energy Planning Database, current market conditions and recent policy changes, to give a forecast shared between all scenarios of what is expected to connect by 2017 or 2020 depending on technology; and

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

New Demand Technology Forecasting

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

Conventional Demand Forecasting

The West Midlands was highlighted as a licence area with high levels of proposed demand growth. 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 West Midlands 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/Gone Green and Slow Progression/No Progression into two scenarios.

Mapping the Forecasts to our Network

In order to map scenarios for demand and DG growth to the distribution network, the West Midlands licence area was divided into 161 Electricity Supply Areas (ESAs). Each ESA represents a block of demand and generation as visible from the Subtransmission network. Each is one of:

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

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. Three additional ESAs were included in the studies to represent the Tamworth area which is in WPD's East Midlands licence area but shares Lea Marston/Hams Hall GSP with WPD West Midlands.

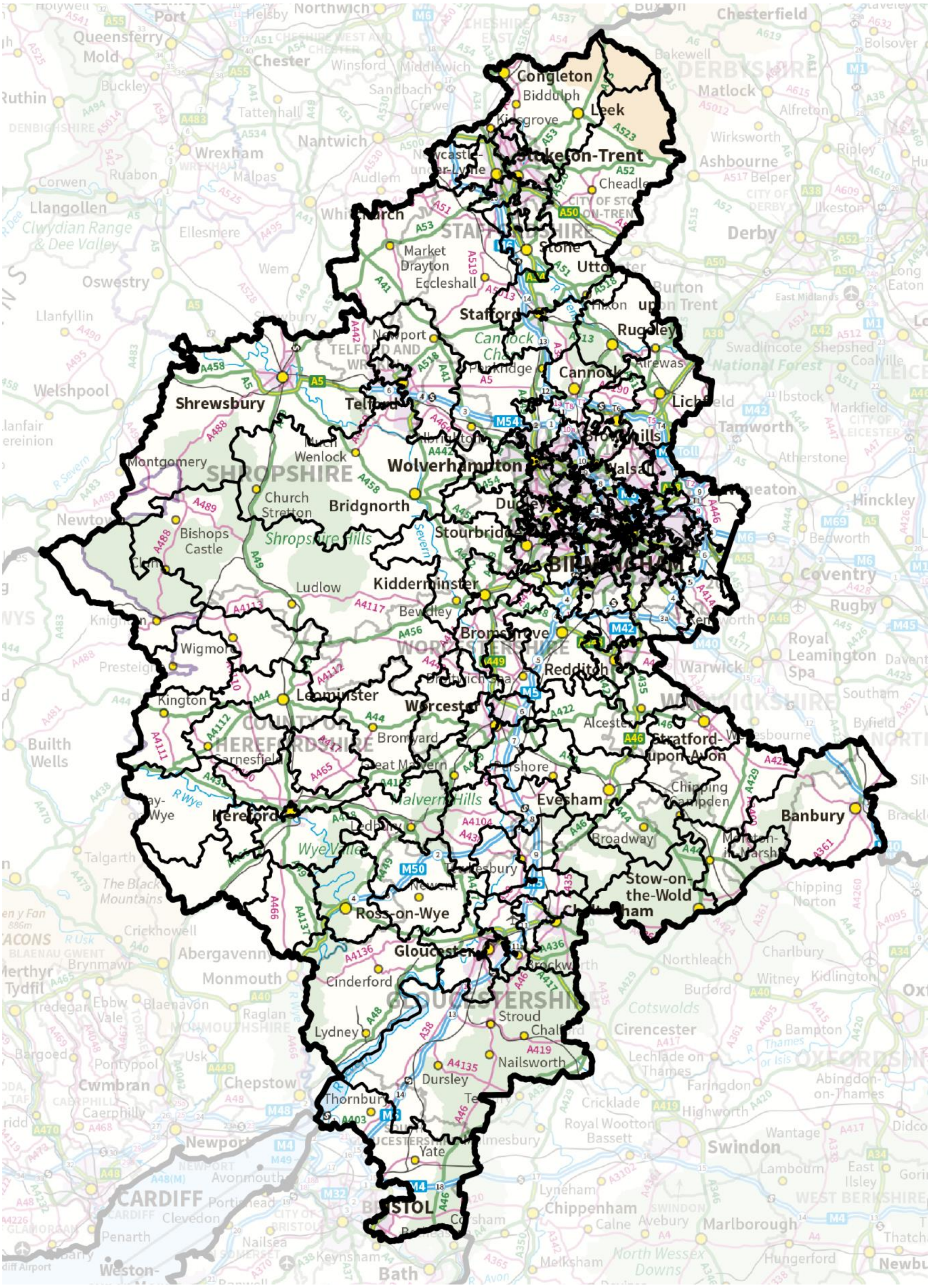

Figure 5: West Midlands geographical ESAs

Scenarios were developed for each ESA, taking into account historic and planned DG developments, local industry, population and natural resources. The results of the assessment are presented in each of the technology chapters in the Regen report and provide a projection of annual capacity deployment, by technology and scenario, for the period from 2017 to 2030. The complete Regen report, *Distributed generation and demand study -Technology growth scenarios to 2030, West Midlands licence area* is available from our website at:

www.westernpower.co.uk/netstratwmid

A summary of the DG forecasts is shown in Figure 6. From the baseline capacity of circa 1,564MW in May 2017, capacity grows to 3,215MW by 2030 under the most ambitious Gone Green scenario. Growth estimates for the other scenarios, Consumer Power, Slow Progression and No Progression are lower overall. However, even under the lowest No Progression scenario, there is an expected growth pathway to 2,243MW of DG capacity by 2030.

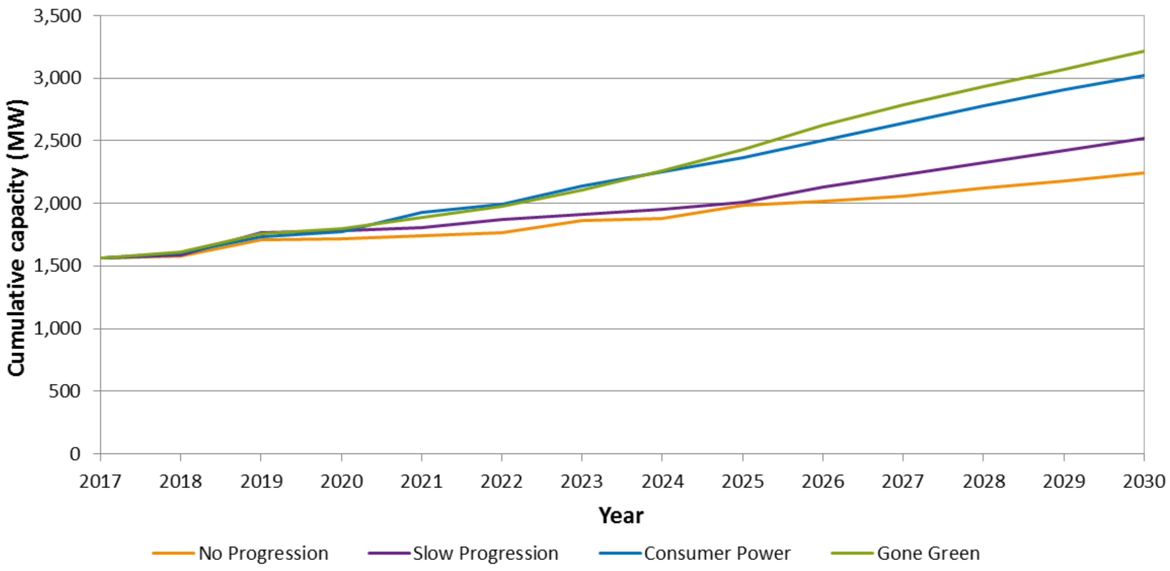

Figure 6: Total Distributed Generation capacity growth in WPD West Midlands licence area from 2017 to 2030 under each scenario

A summary of peak demand growth across the West Midlands licence area is shown in Figure 7. The demand growth is based on the growth of EVs, HPs and conventional demand growth. The total demand in 2017 was approximately 4.5GW. Demand is expected to increase to as much as 6.2GW by 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 Gone Green and Consumer Power were combined into one scenario that assumes high growth rates. Slow Progression and No Progression 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. Gone Green 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.

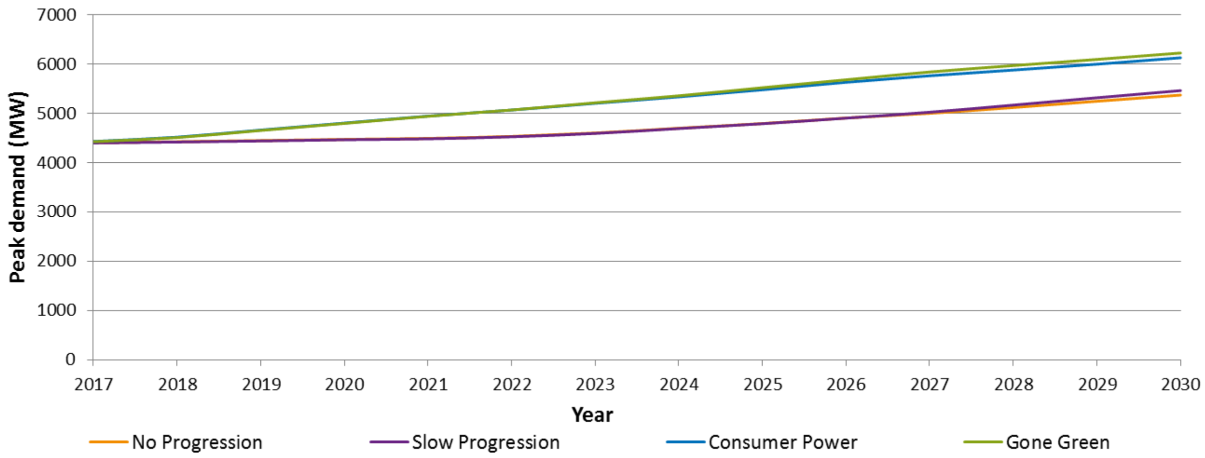

Figure 7: Total peak demand growth in WPD West Midlands licence area from 2017 to 2030 under each scenario

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 West Midlands 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. Preliminary 2030 studies identified significant model non-convergences for intact network running, making automated contingency analysis challenging. Non-convergences normally occur when the model has reached a point where the network and load attributes cause the load-flow calculation to fail. In the 2030 model this was due to such significant demand growth. To overcome this would require substantial model assumptions and major reinforcements. For this reason a focus was placed on the 2020 and 2025 scenarios, where the most likely and immediate network deficiencies could be identified.

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 West Midlands 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 West Midlands 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 West Midlands 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, four 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.
- **Midday**, representing BSP's that have a midday peak as opposed to an early evening peak. These BSP's are in urban areas and have commercial and industrial demand.

Each BSP type was assessed for each representative day to make sixteen real and reactive power demand profiles which could be applied to the network model. Figure 8 through Figure 15 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 late 2016 and 2017. For each of the BSP categories (urban, rural, mixed and midday), three BSP's from the West Midlands 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	• Kitts Green 132/11kV • Ladywood 132/11kV • Redditch South 66/11kV
Rural	• Moreton 66/11kV • Shrewsbury 132/33kV • Wooferton 66/11kV
Mixed	• Hereford South 66/11kV • Ketley 132/33kV • Lydney 132/33kV
Midday	• Black Lake 132/11kV • Cheapside 132/11kV • Chester Street 132/11kV

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 as follows:

- **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 provides a summary of when each representative day occurred for each BSP profile type.

To create demand profile curves for each BSP, a multiplying factor was applied to the normalised demand profiles. For each BSP in the West Midlands the real power demand for each BSP was found for when the GSP peak value occurred to which it is connected. That BSP demand at GSP peak was then used as the multiplying factor that was applied to the normalised MW and MVAr demand profiles for the different BSP's in the network model. These normalised profiles are shown in Figure 8 through Figure 15.

Table 5: Dates selected for underlying demand representative days

Representative Day	Dates
Winter Peak Demand	• Urban - 26/01/2017 • Rural - 05/12/2016 • Mixed - 26/01/2017 • Midday - 06/12/2016
Summer Peak Demand	• Urban - 03/05/2017 • Rural - 29/06/2017 • Mixed - 04/05/2017 • Midday - 17/05/2017
Summer Peak Generation	• Urban - 30/07/2017 • Rural - 08/07/2017 • Mixed - 03/06/2017 • Midday - 06/08/2017
Autumn Peak Demand	• Urban - 08/11/2016 • Rural - 29/11/2016 • Mixed - 30/11/2016 • Midday - 21/11/2016

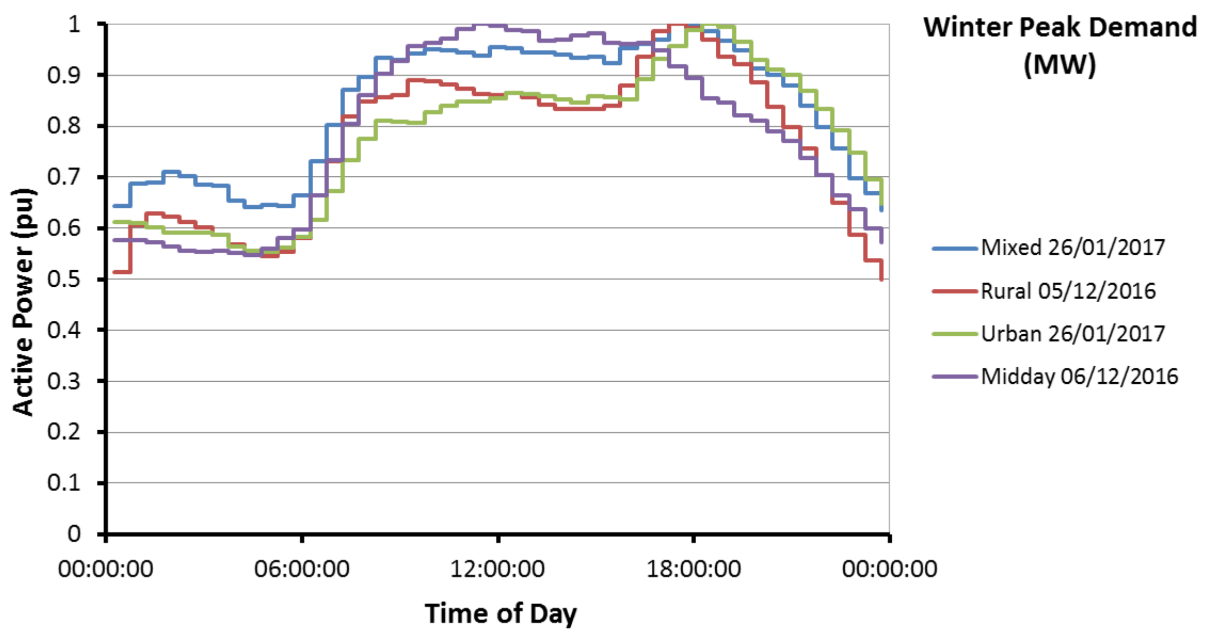

Figure 8: Real power underlying demand profiles for the Winter Peak Demand day, normalised over the peak real power annual demand

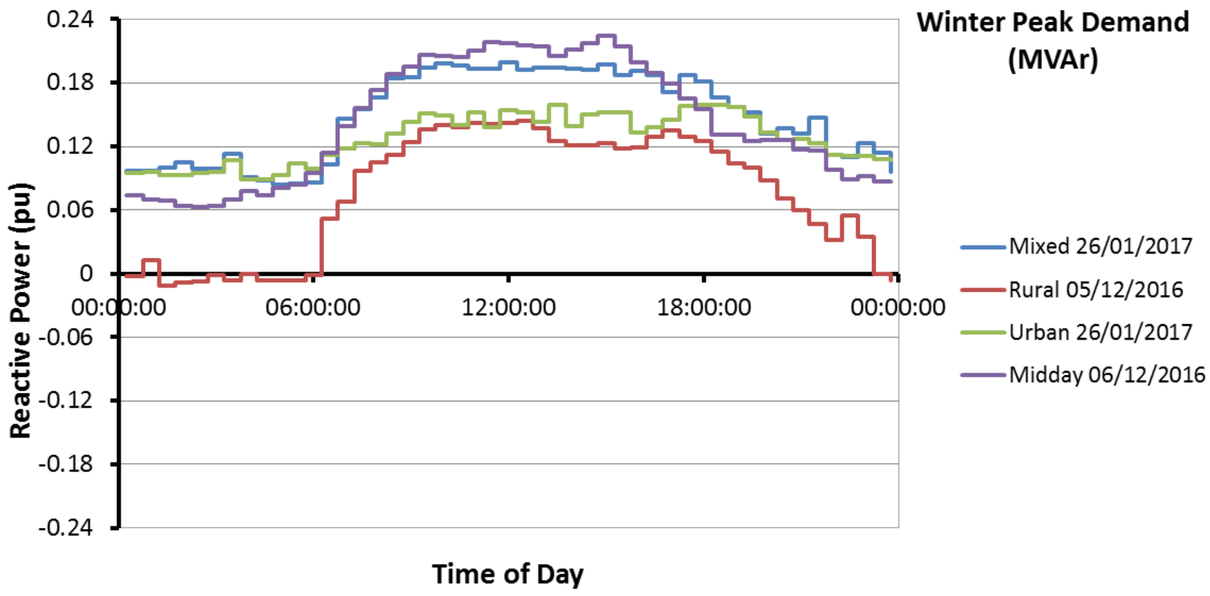

Figure 9: Reactive power underlying demand profiles for the Winter Peak Demand day, normalised over the peak real power annual demand (note: reactive power scale is not the same as the active power scale)

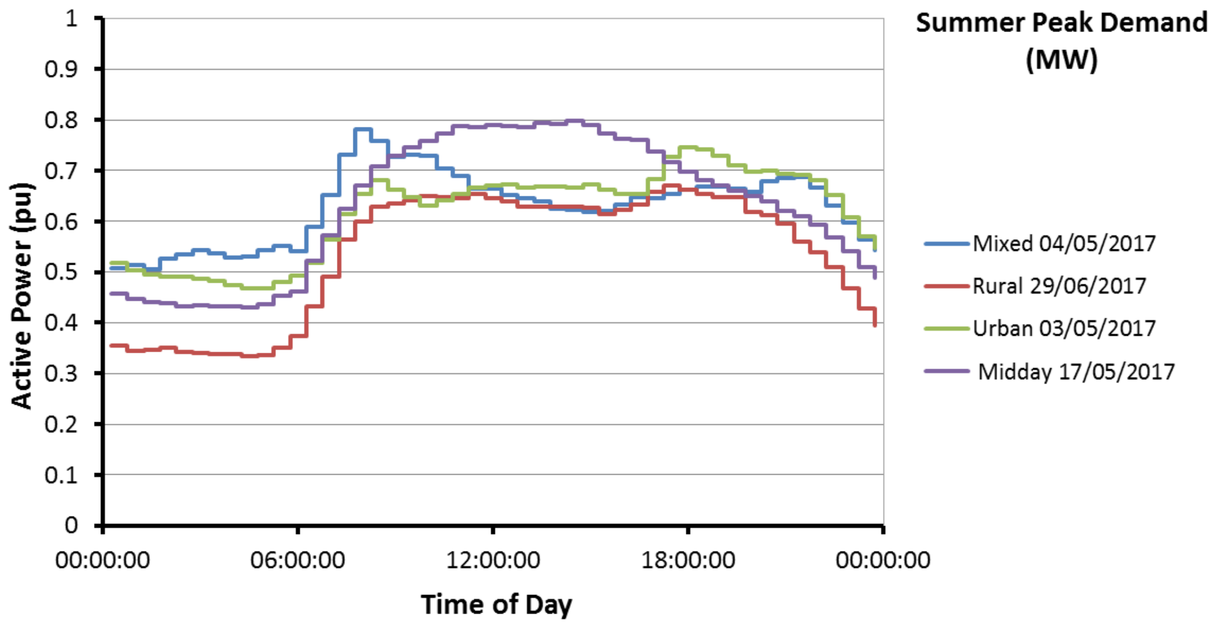

Figure 10: Real power underlying demand profiles for the Summer Peak Demand day, normalised over the peak real power annual demand

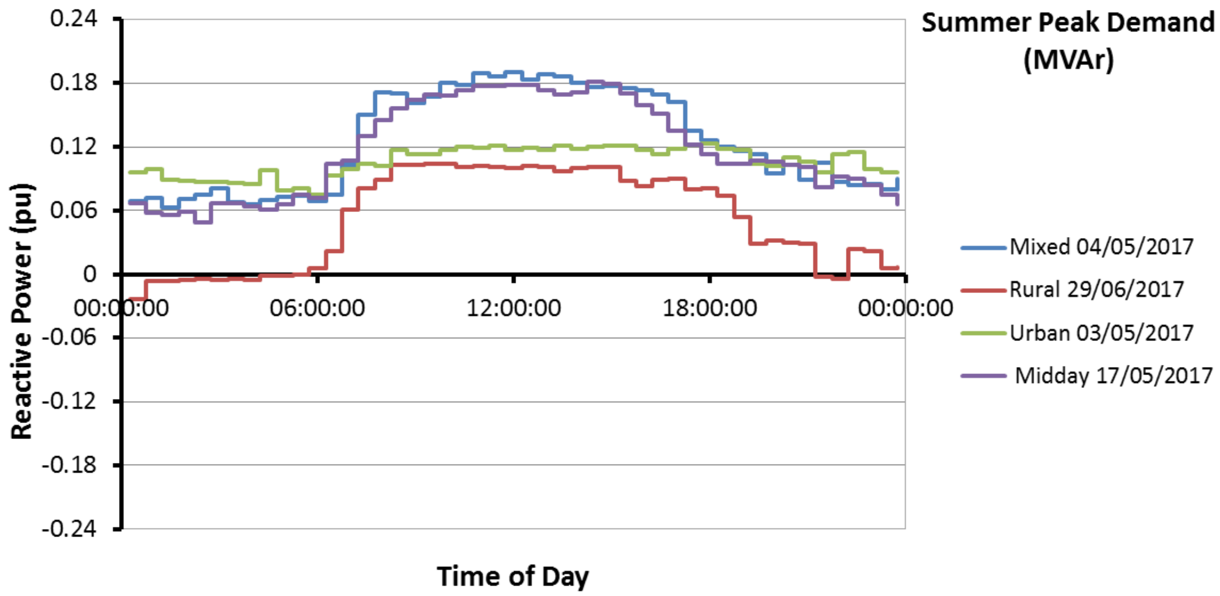

Figure 11: Reactive power underlying demand profiles for the Summer Peak Demand day, normalised over the peak real power annual demand (note: reactive power scale is not the same as the active power scale)

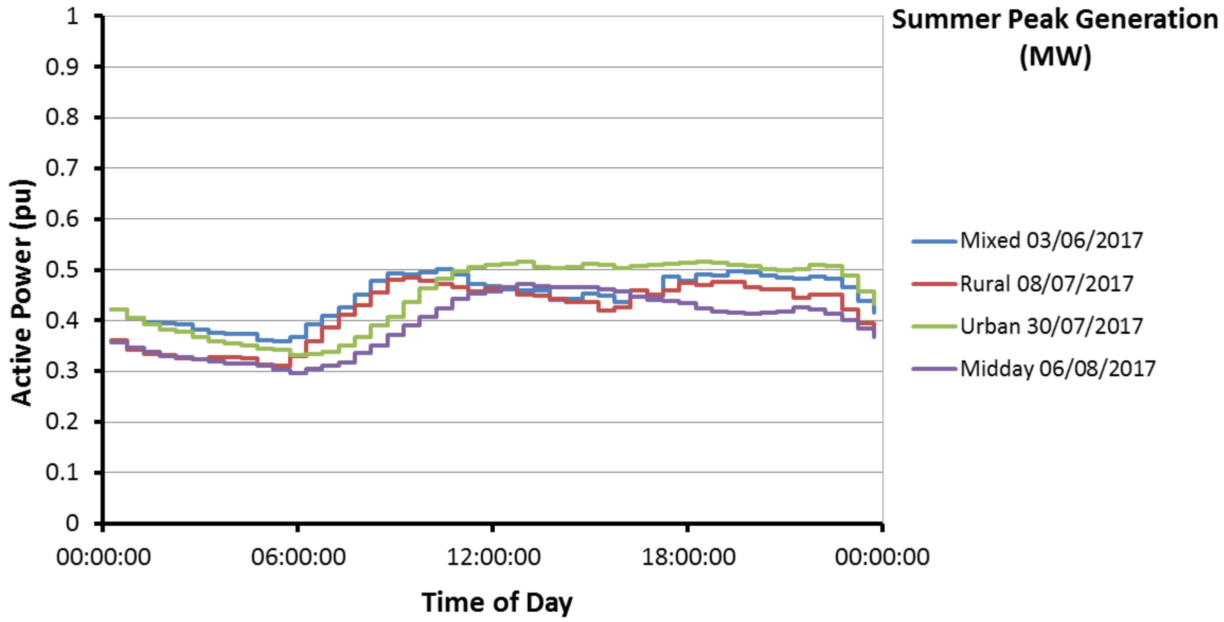

Figure 12: Real power underlying demand profiles for the Summer Peak Generation day, normalised over the peak real power annual demand

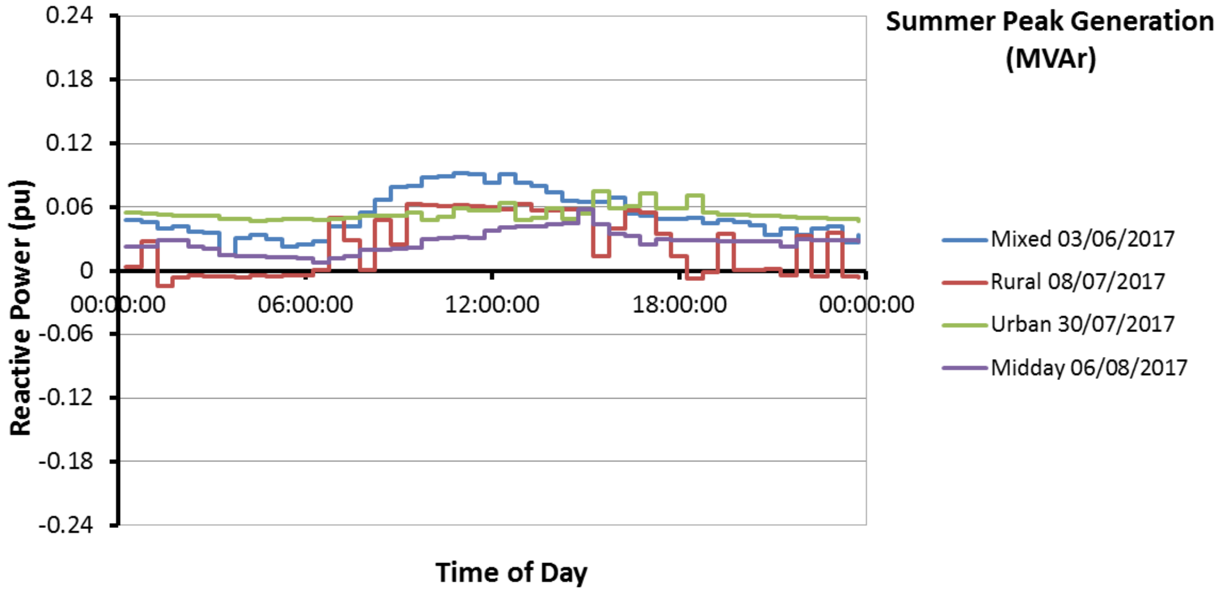

Figure 13: Reactive power underlying demand profiles for the Summer Peak Generation day, normalised over the peak real power annual demand (note: reactive power scale is not the same as the active power scale)

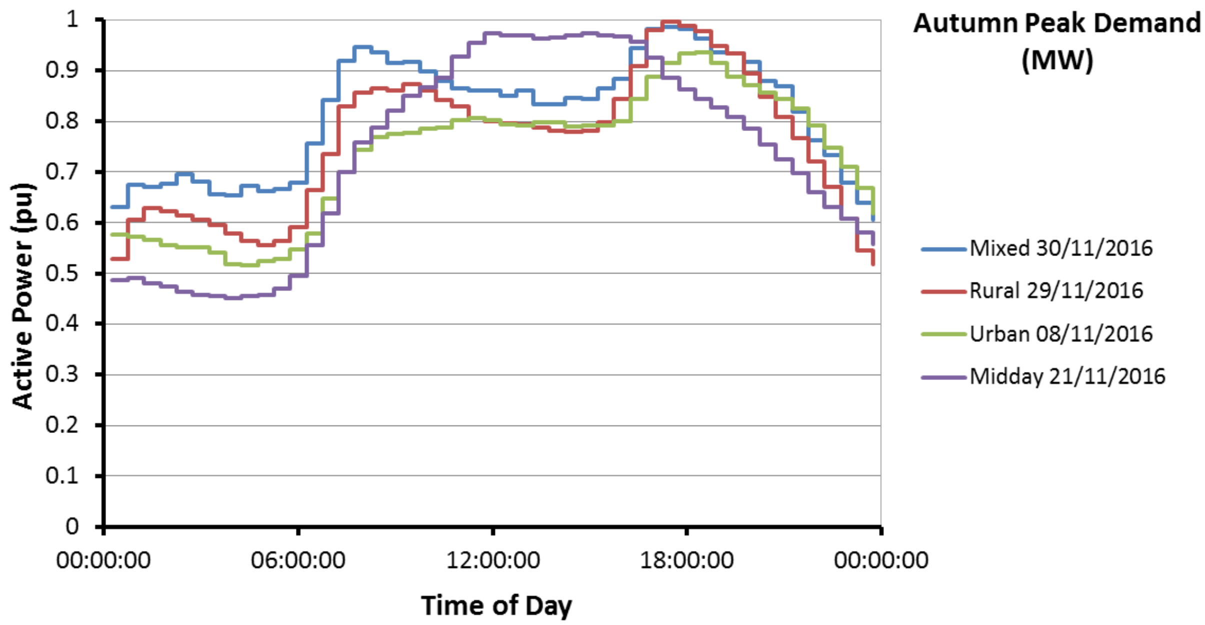

Figure 14: Real power underlying demand profiles for the Autumn Peak Demand day, normalised over the peak real power annual demand

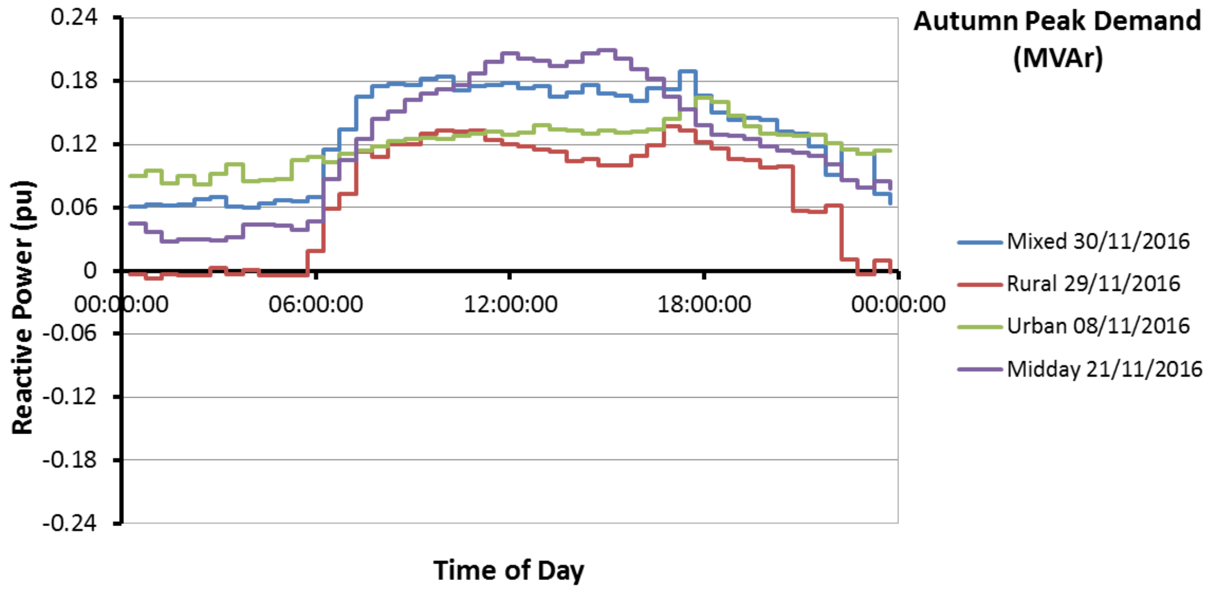

Figure 15: Reactive power underlying demand profiles for the Autumn Peak Demand day, normalised over the peak real power annual demand (note: reactive power scale is not the same as the active power scale)

Heat Pumps

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

The study considered various types of heat pump as follows:

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

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

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

Electric Vehicles

EV charging profiles were derived from the Electric Vehicles Insight Report of the Customer-Led Network Revolution project. This was based on a trial involving 143 domestic EV owners that took place in 2014. The profiles are shown in Figure 16.

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 2015. The FES report assumed that a TOUT will be applied for the Gone Green and Slow Progression scenarios from 2020, while uninhibited charging was assumed for the Consumer Power and No Progression scenarios up to 2030. The TOUT results in a two-hour delay in peak demand, but no reduction in total energy consumption.

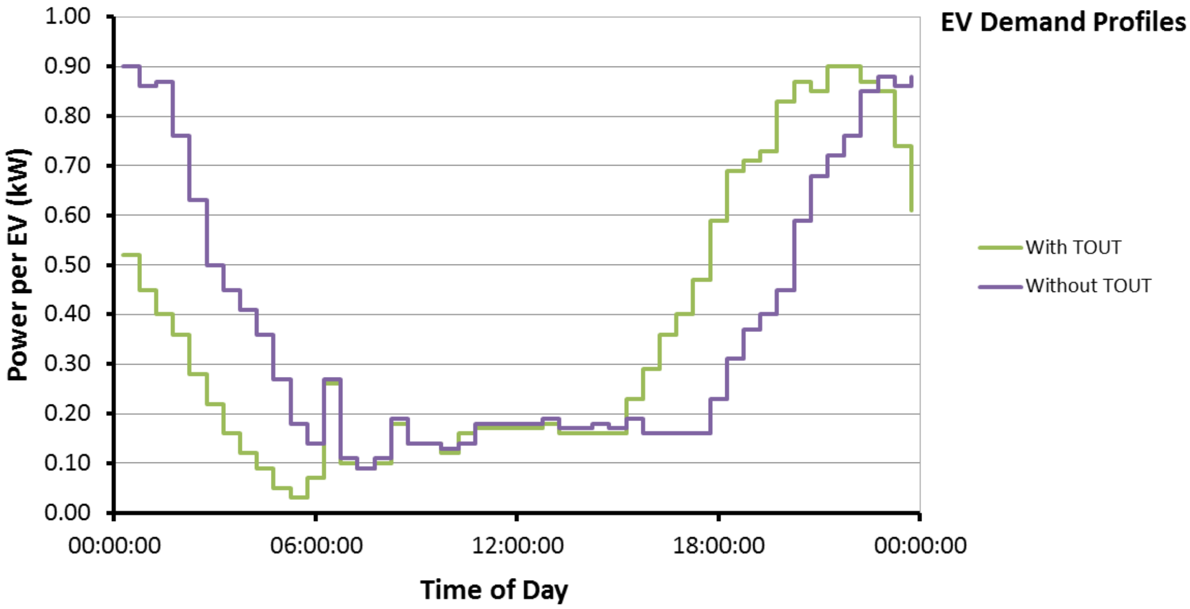

Figure 16: EV Winter Profile (per EV)

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

Conventional Demand Growth

The West Midlands strategic studies included forecasts for conventional demand growth, including domestic, industrial and commercial development in each ESA.

The domestic demand growth is measured as the number of houses expected to be built in the region out to 2030. A different approach was used to the East Midlands studies which used a domestic profile based on the Elexon Class 1 profile, with a seasonality factor derived from customer metering data. In this study, the domestic profiles were derived solely from half hourly aggregated and anonymised customer data obtained as part of the 'LV Networks Template' innovation project run by Western Power Distribution. These profiles included seasonal variation which corresponded to each of the representative days used. The domestic profiles used are shown in Figure 17.

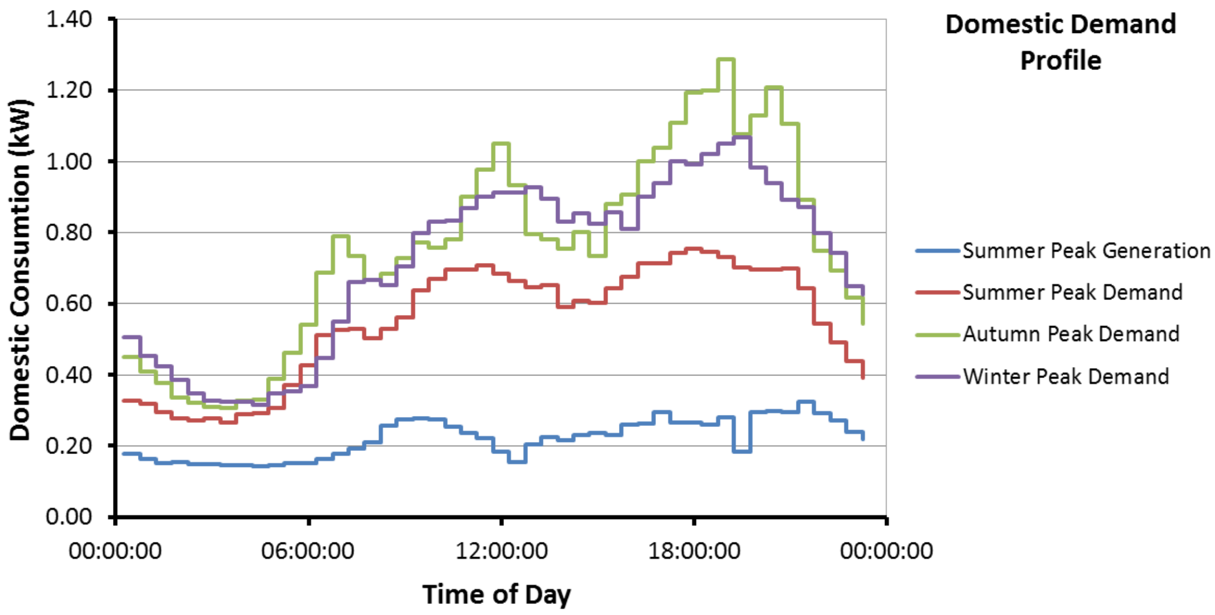

Figure 17: Domestic profile (per house)

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 2030. 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. As an extension to the method used for demand profiles in the East Midlands study, further work was undertaken to collate aggregated and anonymised half hourly customer metering data 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 and 66kV Demand Customers

The West Midlands networks supplies a number of large demand customers with 132kV connections or dedicated grid transformers (GTs) at WPD BSPs and Primary substations, including railway traction supplies. Such customers often do not have a regular daily or seasonal demand profile. Demand at these sites can vary in response to factors including commodity prices and train timetables. As a result, the assumed profile for these 132kV and 66kV 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 to the West Midlands and South Wales networks. 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 West Midlands licence area was collected and aggregated by each half hour for late 2016 and 2017. Only PV sites with an installed capacity greater than or equal to 1 MW were considered. The PV generator data sample comprised 70 sites, with an installed capacity of 405MW. The geographical spread of solar PV sites in the data sample is shown Figure 18.

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 19 through Figure 20 show the PV generation profiles that were imposed on the network models.

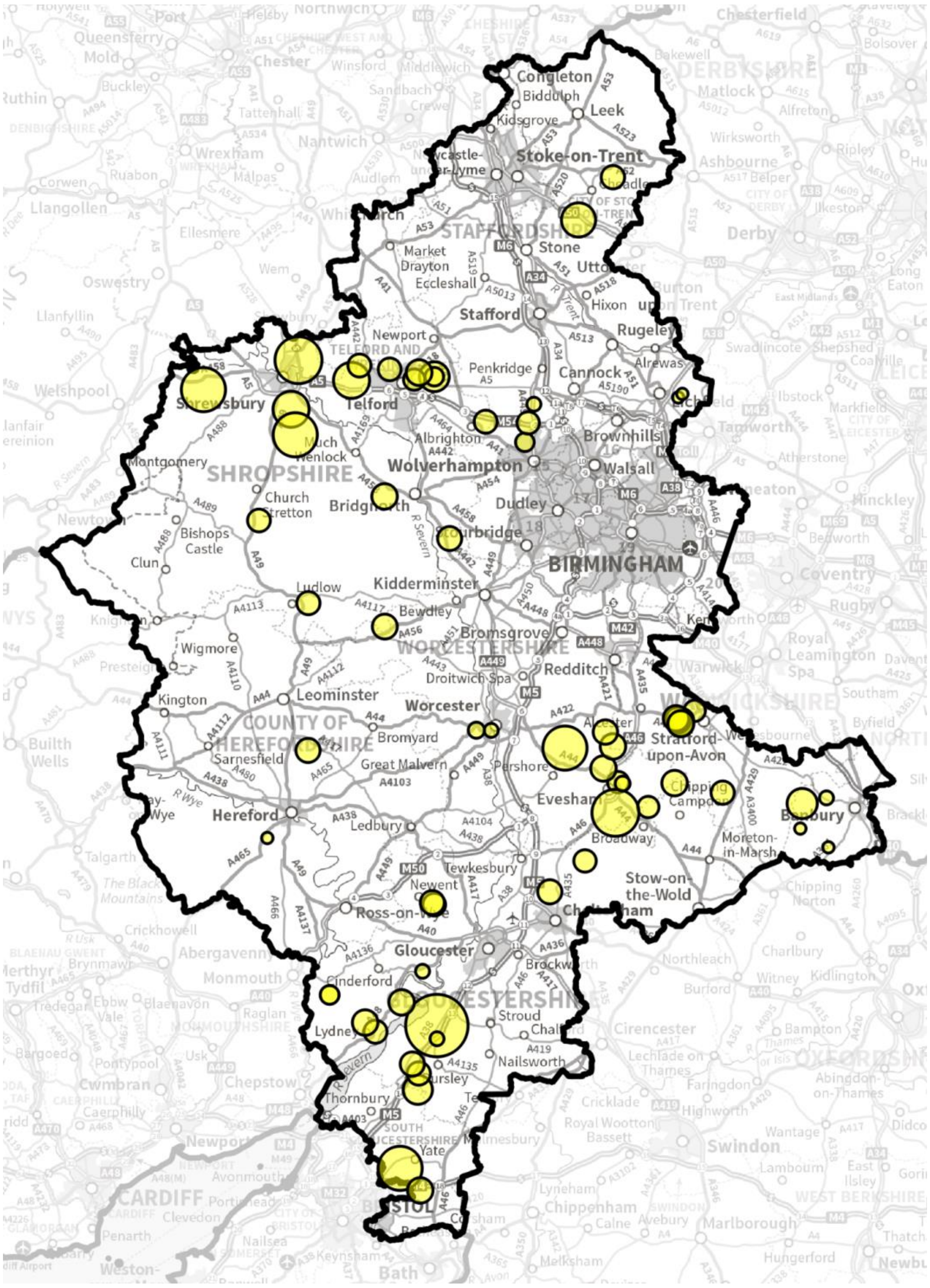

Figure 18: Map of Solar PV sites contributing to generation profiles; symbol area proportional to installed capacity [MW]

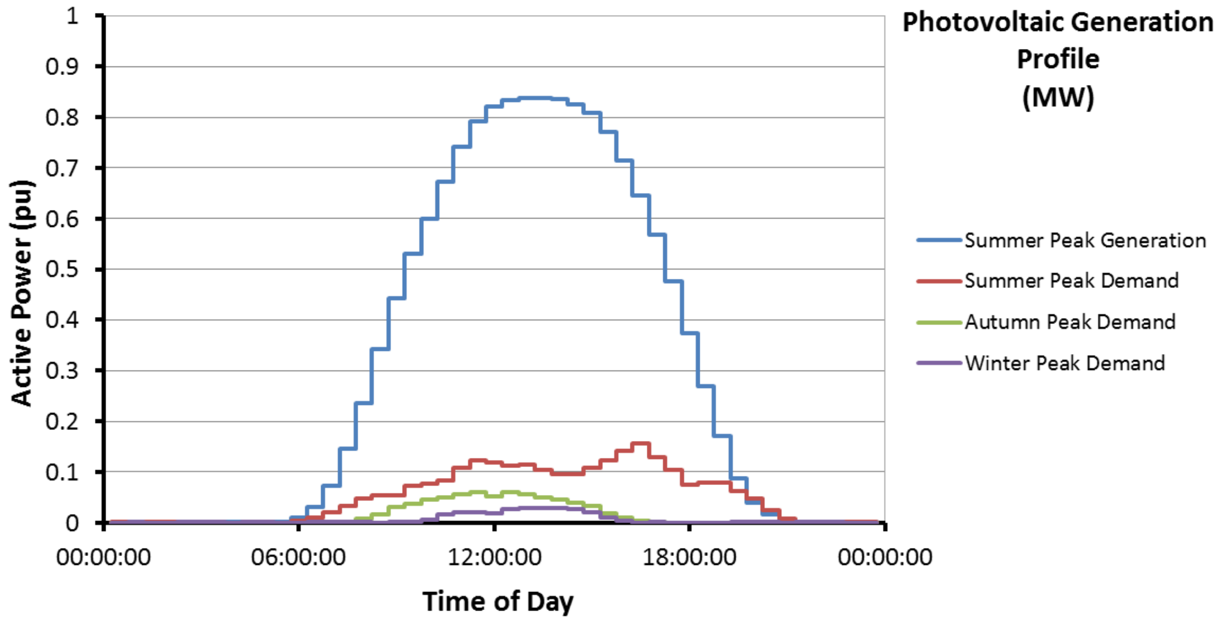

Figure 19: Normalised PV generation profile for each representative day

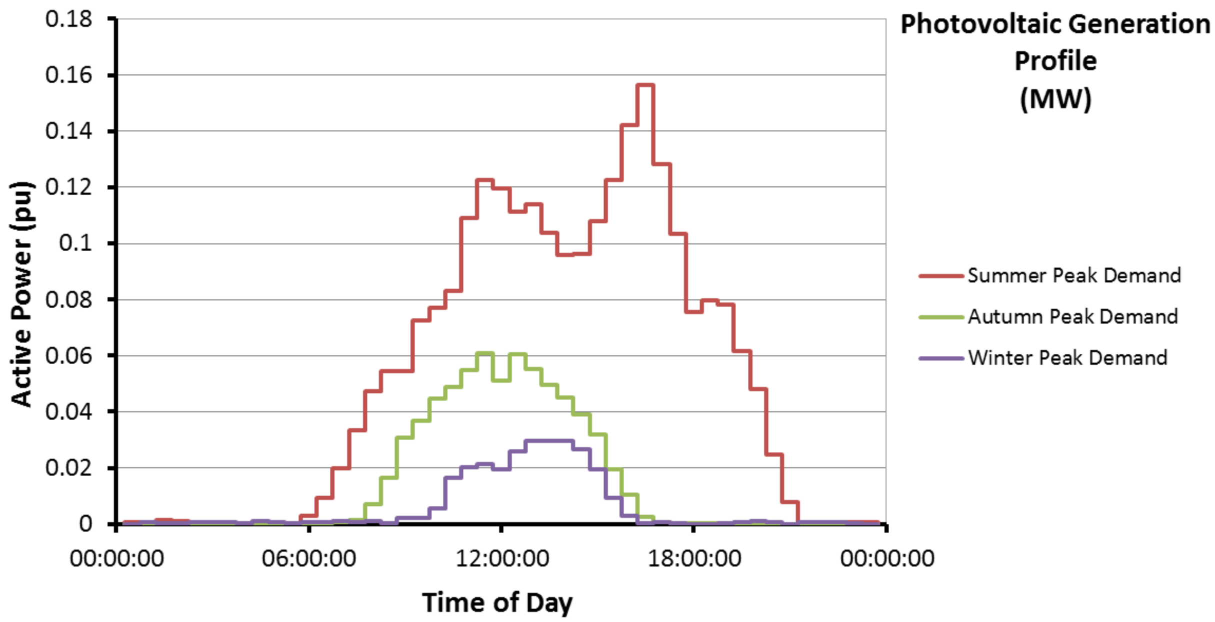

Figure 20: Detailed view of normalised PV generation profiles used for the Summer Peak, Autumn Peak and Winter Peak demand representative days

Onshore Wind

A similar process used for the PV generation profiles was used to create the Onshore Wind profiles. However, due to the small amount of Onshore Wind generator sites in the West Midlands licence area, it was decided that data from the WPD South Wales licence are would be used instead. The West Midlands only has 3 Onshore Wind sites that are larger than 1MW with a total installed capacity of 38MW. South Wales had 24 Onshore Wind sites that are greater than 1MW and have a total installed capacity of 363MW. Using the South Wales data gave more realistic generation profiles to impose on the network models. The geographical spread of the Onshore Wind sites in the West Midlands and South Wales licence areas are shown by Figure 21 and Figure 22, respectively.

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 23 through Figure 24 show the PV generation profiles that were imposed on the network models.

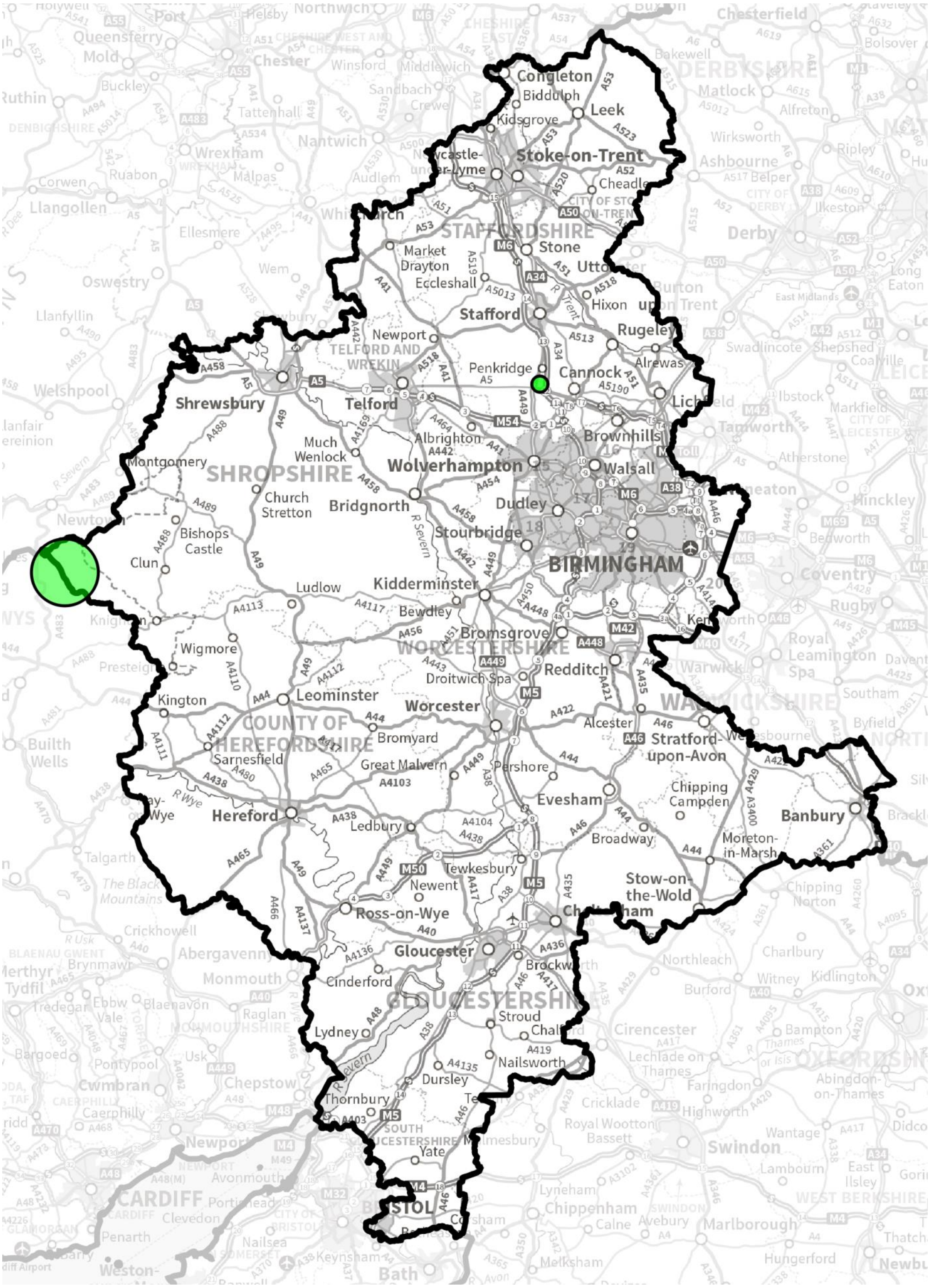

Figure 21: West Midlands - Map of Onshore Wind sites contributing to generation profiles; symbol area proportional to installed capacity [MW]

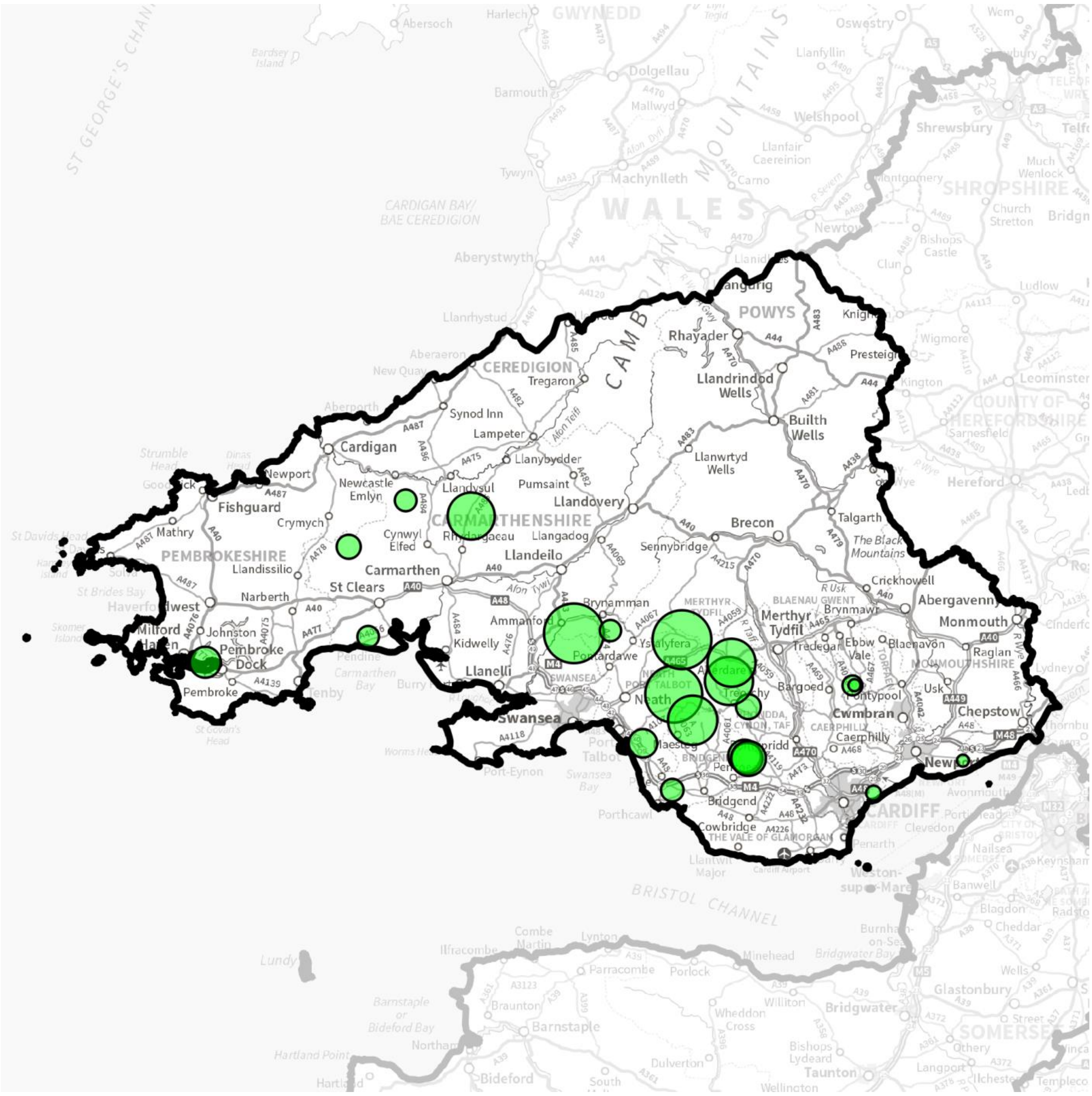

Figure 22: South Wales - Map of Onshore Wind sites contributing to generation profiles; symbol area proportional to installed capacity [MW]

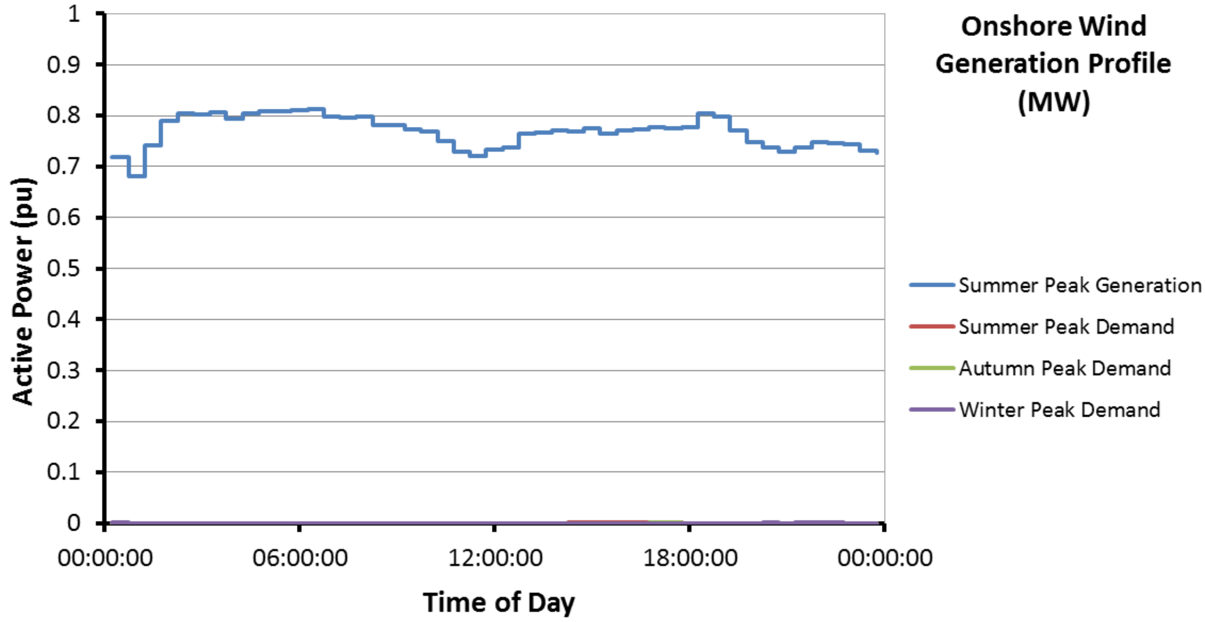

Figure 23: Normalised Onshore Wind generation profile used for each representative day. Note that due to the scale, the profiles for the demand days are near-zero

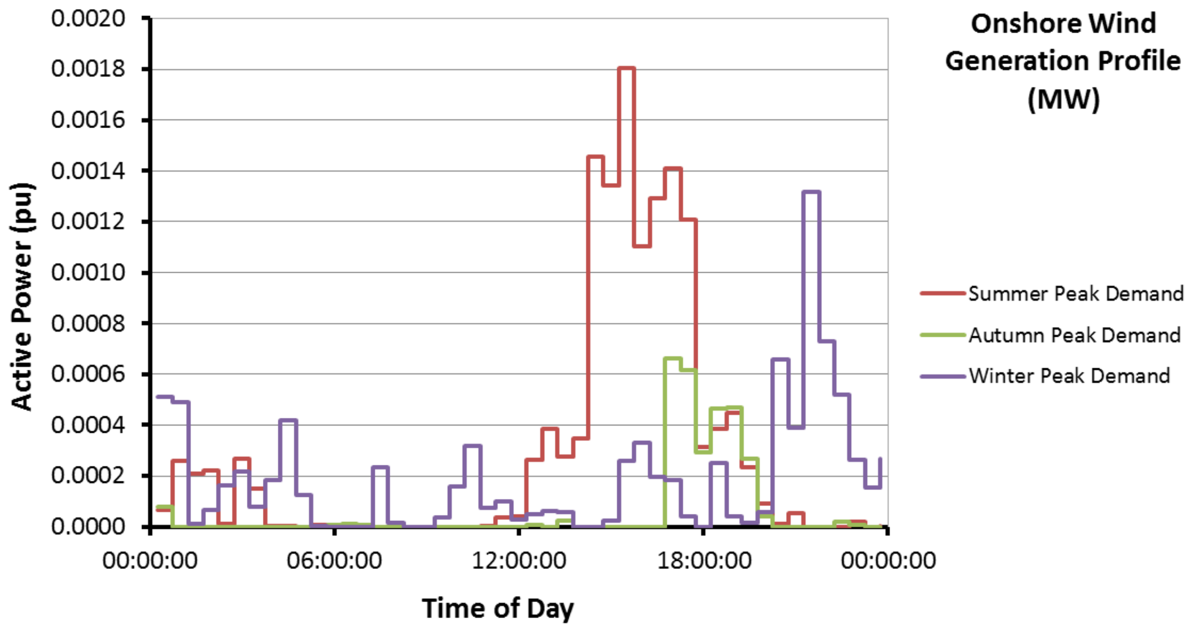

Figure 24: : Detailed view of normalised Onshore Wind generation profiles used for the Summer Peak, autumn Peak and Winter Peak demand representative days

Other Generation

The remaining DG types modelled were:

- Anaerobic Digestion
- 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 System Operator 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

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	GG Gone Green
NP No Progression	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 8 – Definitions and References.

Summary

Table 6: Summary of network deficiencies identified by year, scenario and GSP

GSP	2020				2025			
Bishops Wood			CP	GG	NP	SP	CP	GG
Bushbury							CP	GG
Bustleholm							CP	GG
Cellarhead					NP	SP	CP	GG
Feckenham	NP	SP	CP	GG	NP	SP	CP	GG
Iron Acton								
Ironbridge and Shrewsbury			CP	GG			CP	GG
Kitwell							CP	GG
Lea Marston/Hams Hall			CP	GG	NP	SP	CP	GG
Nechells	NP	SP	CP	GG	NP	SP	CP	GG
Ocker Hill							CP	GG
Oldbury								
Penn						SP	CP	GG
Port Ham/Walham			CP	GG	NP	SP	CP	GG
Rugeley			CP	GG	NP	SP	CP	GG
Willenhall				GG		SP	CP	GG

2017

In 2017 all four scenarios represent the demand and DG connected to the network as of 2017. The 2017 studies were used to benchmark the future years. While the 2017 studies did not identify network deficiencies, they did highlight the importance of accurately modelling the network automation and operational measures that are used to maintain compliance. A large number of Python scripts were written to mimic the normal operation of networks in the West Midlands, particularly switched-firm networks and parallel three-circuit groups. Descriptions of those modes of operation are given below.

Switched-firm networks

Unlike most 132kV and 66kV networks in WPD’s other licence areas, many of the 132kV and 66kV circuits in the West Midlands are operated with demand at first-fault risk. P2/6 compliance is reliant on automatic demand restoration from alternative circuits. This method of operation is often known as ‘switched-firm’. It is used for several reasons, particularly:

- To control power flows, particularly to avoid the interconnection of multiple substations;
- To reduce fault levels and so prevent switchgear overstressing; and
- To allow increased utilisation of transformer capacity at sites with three or more transformers. While this can increase the effective capacity of a substation, it does increase the risk of premature transformer ageing.

Switched-firm operation generally reduces the risk of overloads and voltage excursions, but at the cost of an increased risk of customers experiencing short interruptions.

Some networks in the West Midlands, particularly at 66kV, rely upon extensive transfers between substations for the duration of arranged outages to maintain supplies to customers and prevent overloading for subsequent faults. While this is not inherently a problem, it highlights the importance of thorough network analysis to ensure that network capacities are not exceeded where they cannot be determined by simple examination.

Parallel operation of three-circuit groups below 300MW demand

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 (SCO). This does not, however, mean that the possibility of a second circuit outage can be ignored.

Consider the network shown in Figure 25. Each of the circuits A, B and C has a rating of 90MVA. The three circuits share load evenly. There is 140MW of demand supplied from the 33kV bar at the BSP.

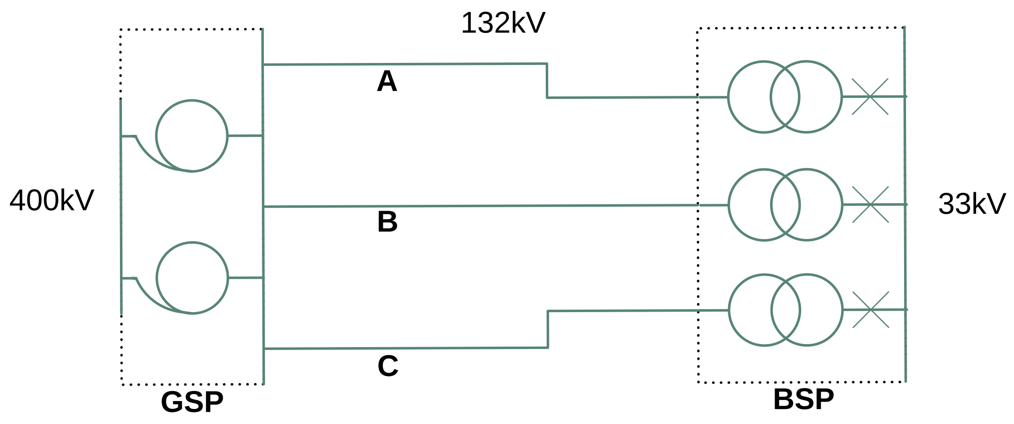

Figure 25: Three-circuit group example

120MW of demand puts the group into class D of P2/6. This requires that:

1. For a first circuit fault (i.e. during normal running):
    a. Group demand minus up to 20MW (automatically disconnected), i.e. 120MW, is met immediately; and
    b. Group demand is met within three hours.
2. For a second circuit fault (i.e. during an arranged outage):
    a. Group demand minus 100MW, i.e. 40MW, is met within three hours; and
    b. Group demand is met within the time taken to restore the arranged outage.

The first circuit fault of one of the three circuits leaves the 140MW demand fed by the remaining two circuits, total rating 180MVA. This does not present any problems with P2/6 compliance or network capability.

The second circuit fault of one of the three circuits during the arranged outage of another of the circuits leaves the 140MW demand fed by the one remaining circuit, rating 90MVA. While the remaining circuit is sufficient to supply the demand required by P2/6 (40MW), it is overloaded by the demand that would actually be connected to it in this situation (140MW).

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

1. Reinforcing all three circuits so that any one circuit can support the group demand of 140MW;
2. Splitting the 33kV bar into two sections for the duration of the arranged outage, with each section connected to one of the circuits and 70MW of the demand. In the event of a second circuit fault, 70MW of demand would be disconnected, but the remaining circuit would not be overloaded;
3. Installing intertripping or overload schemes to detect and trip any circuit that is overloaded.

2020

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.

Relatively few reinforcement requirements have been identified – those that have been occur mostly in Gone Green and Consumer Power.

Bishops Wood GSP

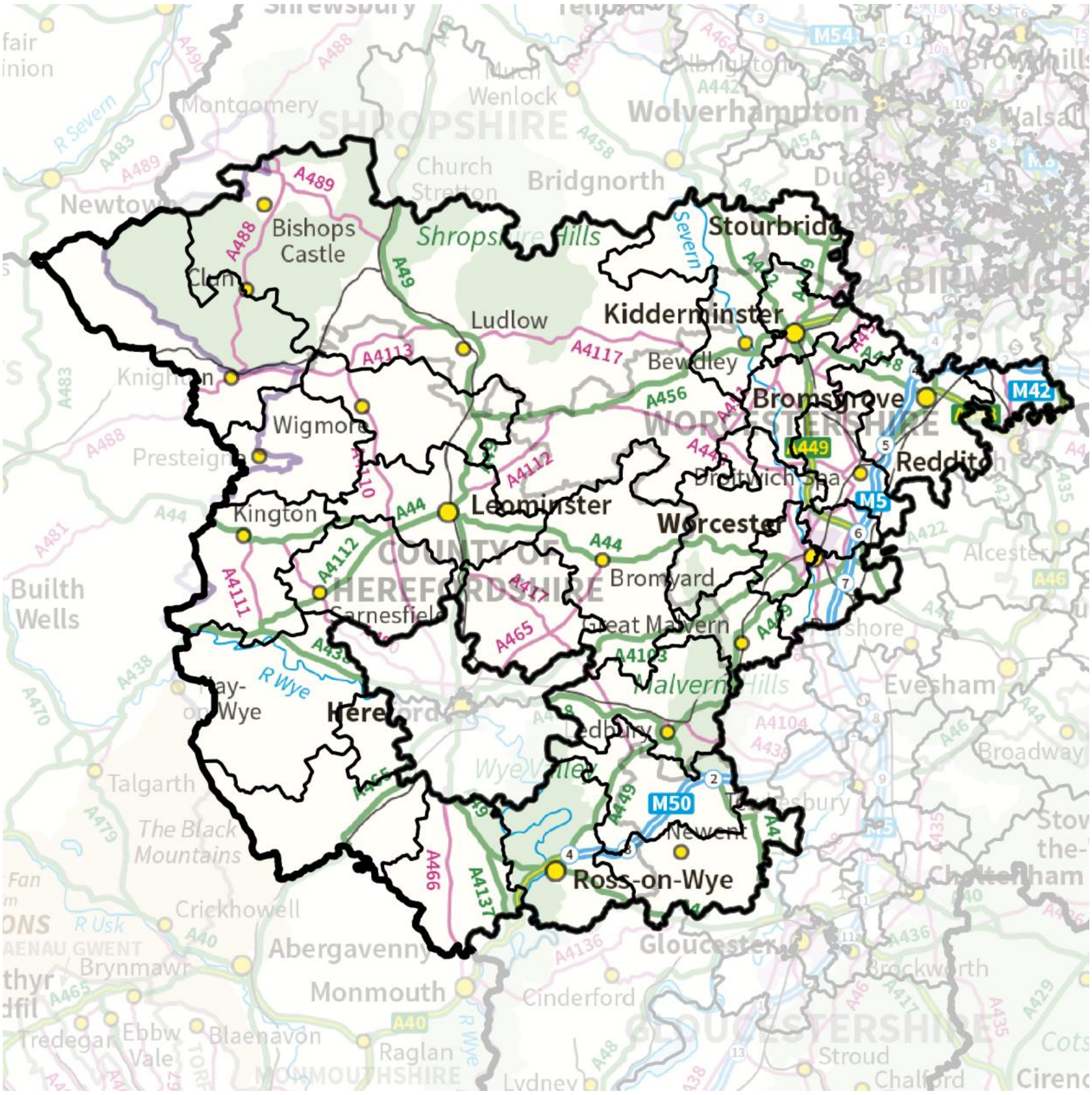

Figure 26: Area supplied by Bishops Wood GSP

Upton Warren BSP

GG CP

Upton Warren BSP is currently supplied by two 132kV circuits from Bishops Wood GSP. One circuit feeds the 60MVA 132/11/11kV GT4, while the other feeds the 90MVA 132/66kV GT3 transformer. GT3 in turn feeds:

- Primary transformer T4 at Stourport,
- Primary transformer T3 at Redditch North,
- A 66kV generator, and
- Primary transformers T1 and T2 at Upton Warren (both of which are normally off load).

For an arranged outage of GT4, its load is transferred onto T1 and T2, each of which is a 12/24MVA CER unit. Following demand growth to 2020, the group demand of Upton Warren 11kV reaches 40MW (Consumer Power) or 44.7MW (Gone Green). This overloads T1, T2 and the 66kV cable between GT3 and the 66kV busbars at Upton Warren.

It is recommended that the 66/11kV transformers at Upton Warren are reinforced by replacement with 20/40MVA units, and the 66kV cable overlaid appropriately. Alternatively, a second 132/11/11kV GT could be established and banked with GT3.

Bushbury GSP

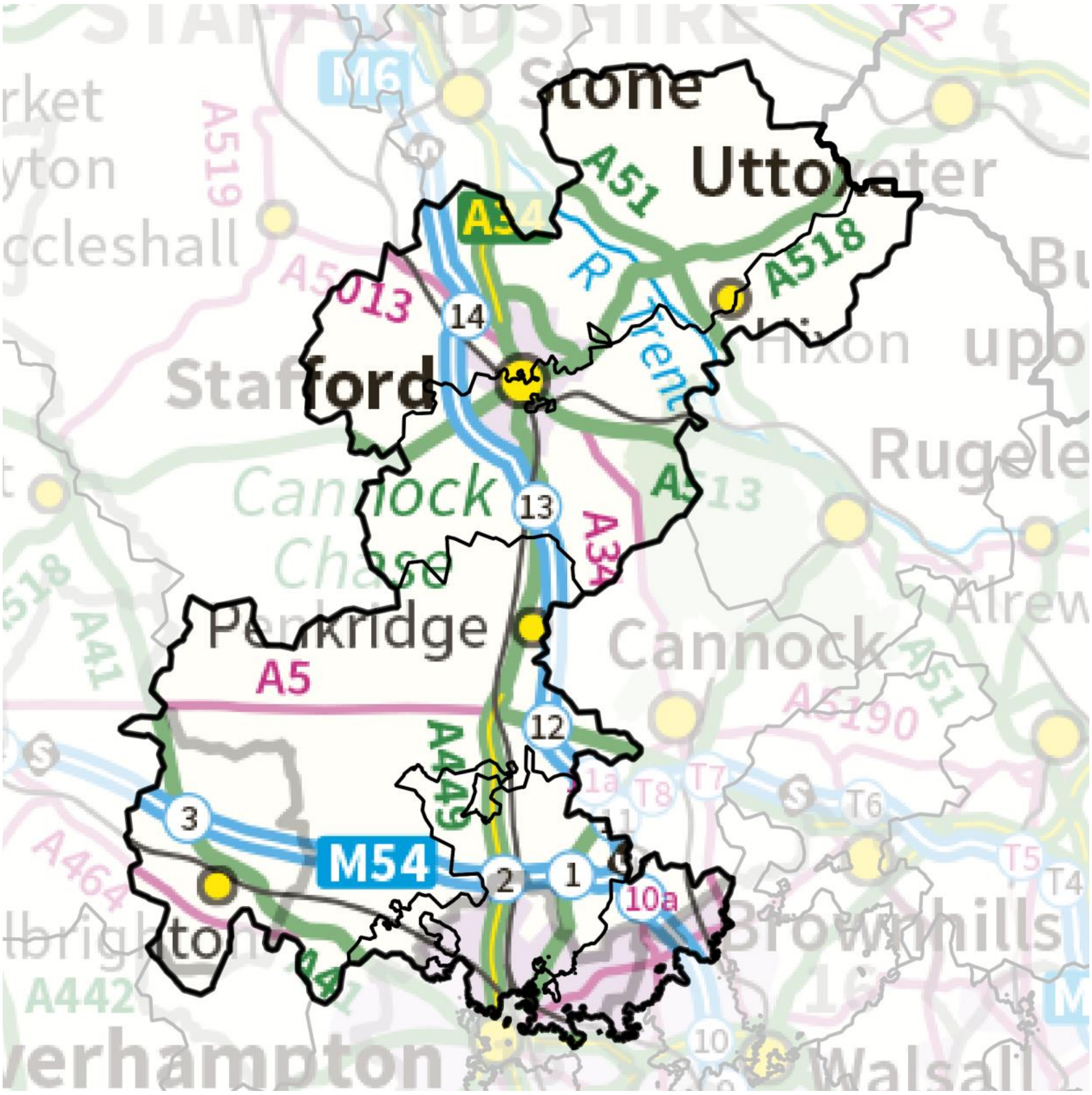

Figure 27: Area supplied by Bushbury GSP

No new reinforcement requirements were identified in the 2020 scenarios for Bushbury GSP.

Bustleholm GSP

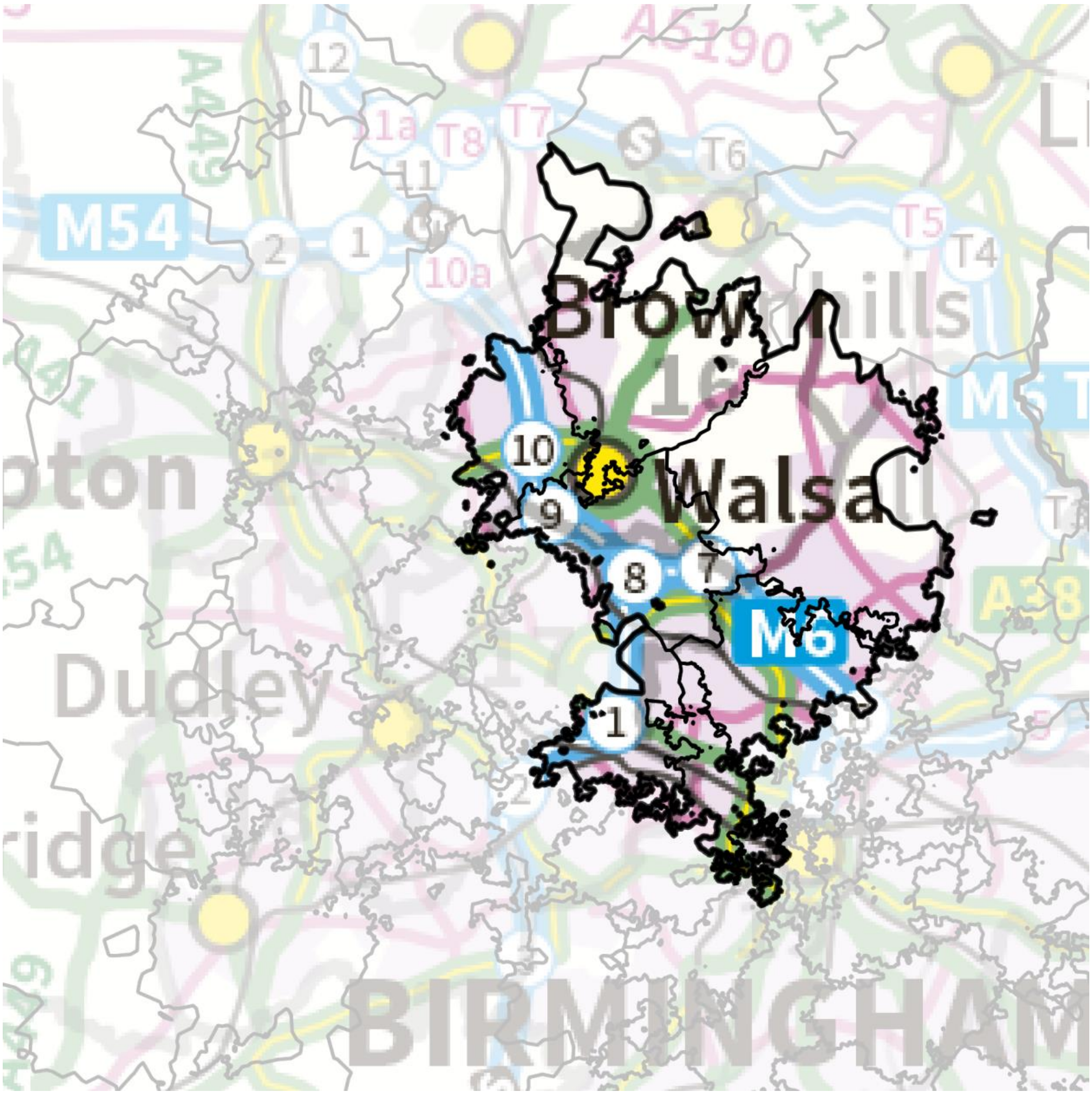

Figure 28: Area supplied by Bustleholm GSP

No new reinforcement requirements were identified in the 2020 scenarios for Bustleholm GSP.

Cellarhead GSP

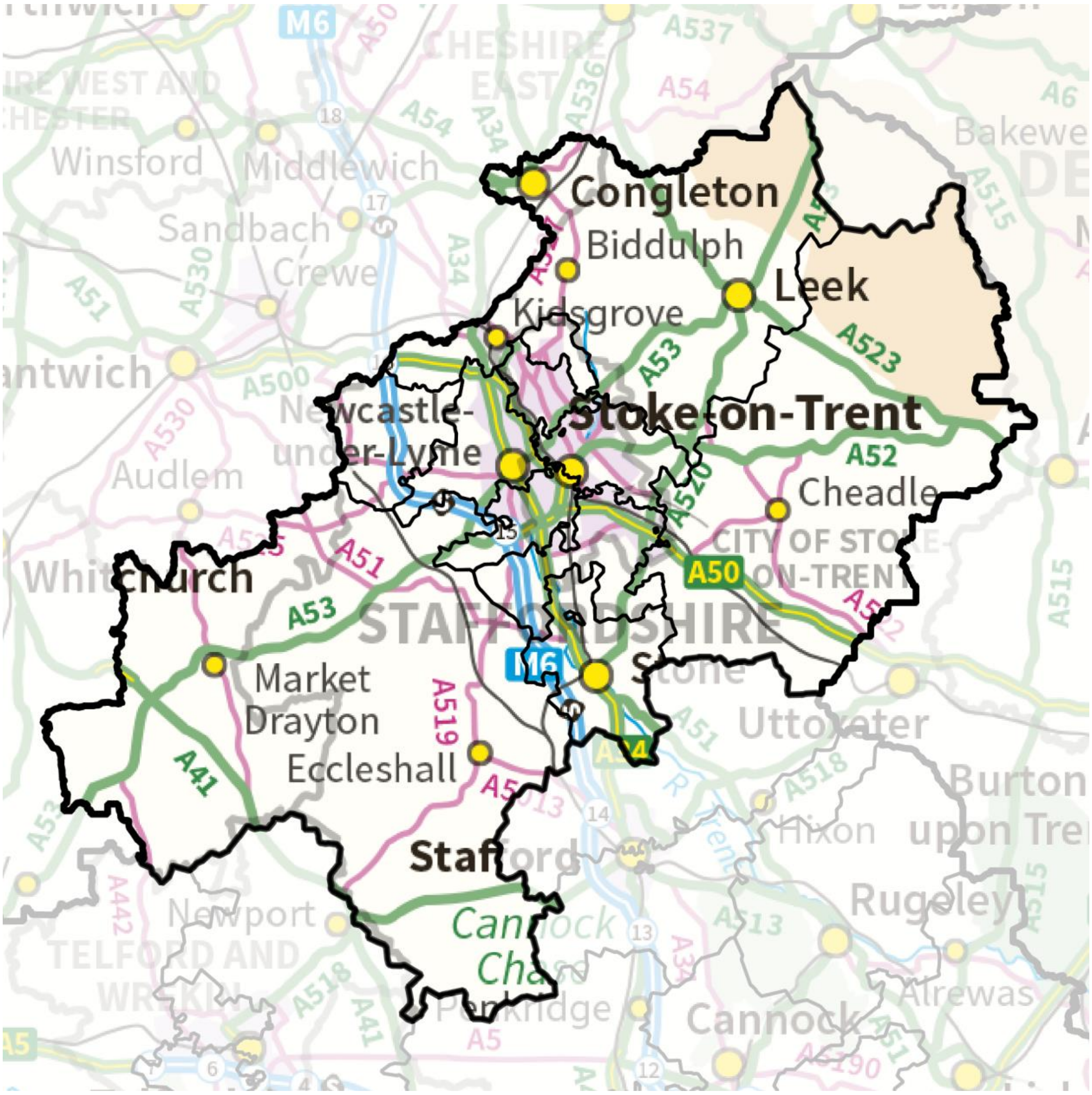

Figure 29: Area supplied by Cellarhead GSP. Supplies area also provided to several BSPs in SPEN's SP Manweb licence area.

Cellarhead GSP is shared between WPD West Midlands and SPEN's SP Manweb network. WPD's Stoke area network is supplied by six 132kV circuits from Cellarhead, and SPEN's Crewe area network is supplied by one 132kV circuit from Cellarhead. Two further 132kV circuits interconnect WPD and SPEN's networks. The interconnection between the two networks operates normally closed. This interdependence means that detailed studies of WPD's network require extensive data on the composition, loading and behaviour of SPEN's network.

It is recommended that the impact of these scenarios on the interdependent Stoke and Crewe area 132kV networks is studied in more detail in conjunction with SPEN to inform their future development.

Feckenham GSP

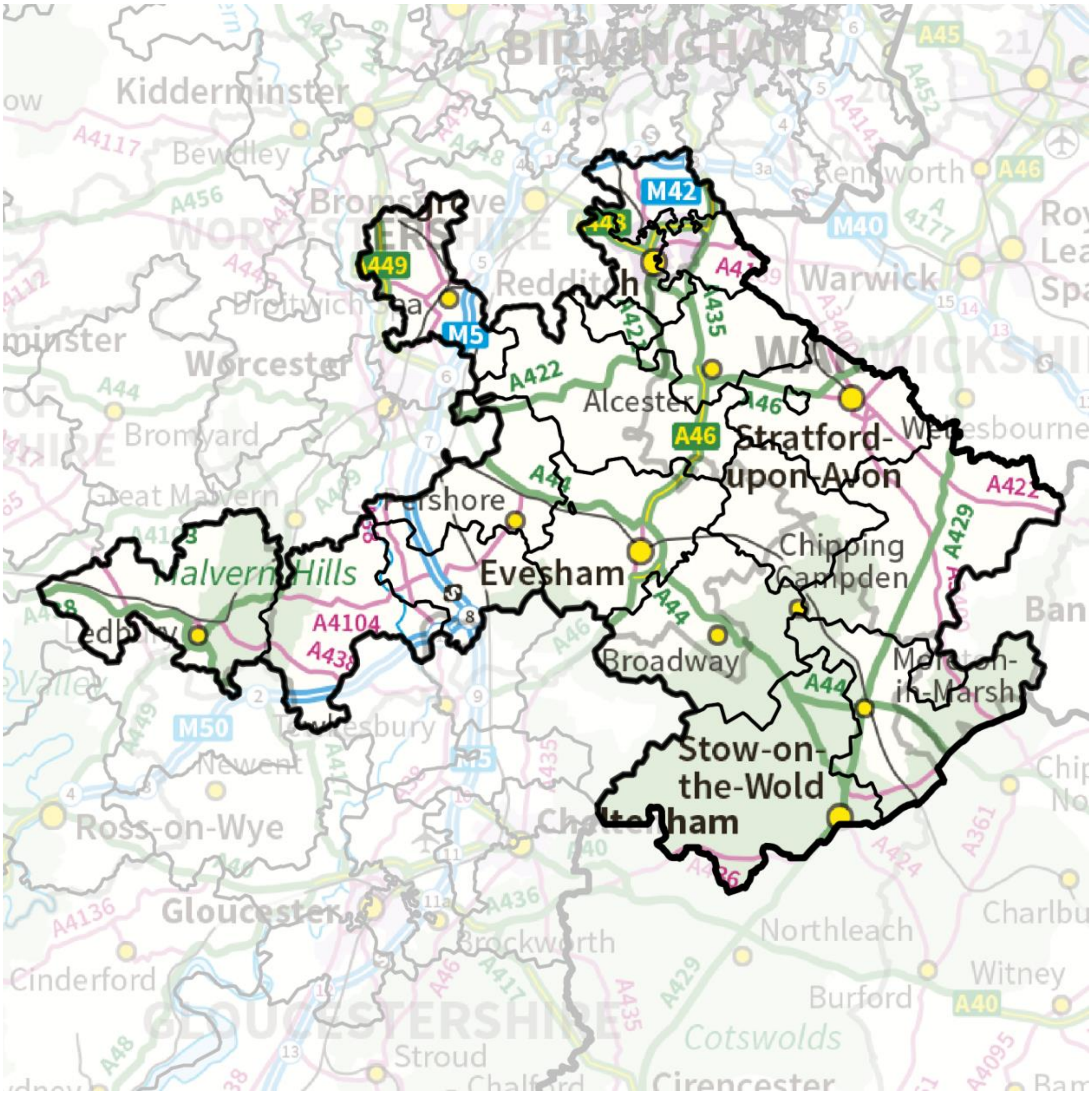

Figure 30: Area supplied by Feckenham GSP

Feckenham 66kV busbar faults

GG CP SP NP

The network to the south and east of Feckenham GSP is normally fed by four 66kV circuits from Feckenham. It normally supplies the following primary substations:

- Great Alne,
- Drayton Farm North,
- Stratford,
- Bevington,
- Long Marston,
- Shipston,
- Moreton (part of),
- Epwell, and
- Bloxham.

A busbar fault between circuit breakers 2S0 and 3S0 on the 66kV bar at Feckenham leaves the group supplied by two out of the four circuits. Following demand growth to 2020, this fault overloads the 66kV circuit from Feckenham 9L5 to Bevington. It would be necessary for a control engineer to promptly reconfigure the network to minimise the risk resulting from the overload.

It is recommended that, if reasonably practicable, this overload should be resolved in the design of any future reinforcement or asset replacement scheme for this area of network.

Evesham

GG CP

Four 66kV circuits from Feckenham GSP feed a pair of 30MVA 66/11kV ONAN transformers at Evesham. In 2020 demand growth in the area takes the group demand to approximately 35MW. An arranged or fault outage which leaves the group supplied by a single transformer results in a marginal overload of this transformer.

It is recommended that the primary transformers at Evesham are reinforced by replacement with 20/40MVA CER units or the installation of a third primary transformer. Further demand growth to 2025 under Gone Green and Consumer Power would exhaust the capacity of a pair of 20/40 CER transformers – a third primary transformer may be a better long-term solution.

Iron Acton GSP

Figure 31: Area supplied by Iron Acton GSP. Supplies are also provided to several BSPs in WPD's South West licence area.

Iron Acton GSP supplies Chipping Sodbury and Ryeford BSPs in the West Midlands, and part of WPD's South West network. The supplies to the South West were not considered in this project.

No new reinforcement requirements were identified in the 2020 scenarios for Chipping Sodbury and Ryeford BSPs or the 132kV circuits supplying them. Iron Acton GSP will be studied in further detail as part of the South West counterpart to this project in the first half of 2018.

Ironbridge GSP and Shrewsbury GSP

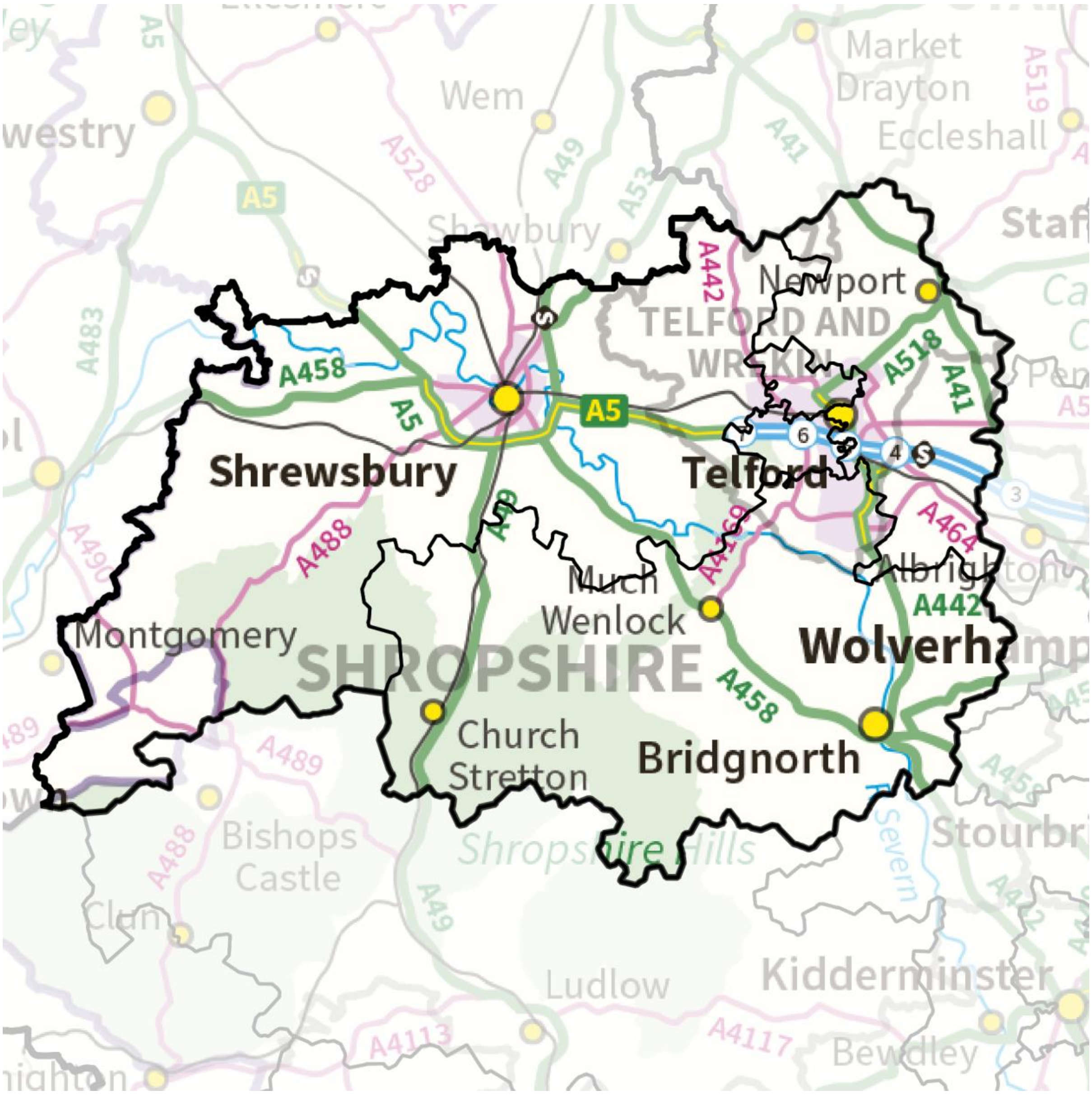

Figure 32: Area supplied by Ironbridge and Shrewsbury GSPs

132kV network

GG CP

The Ironbridge-Shrewsbury 132kV network is supplied by three SGTs at Ironbridge GSP and one SGT at Shrewsbury GSP. Two 132kV circuits interconnect the GSPs via Ketley and Hortonwood BSPs. There is also a 132/33kV BSP local to each GSP.

Ironbridge GSP has three SGTs. The 132kV board is operated split into three sections to keep fault levels within plant ratings:

1. SGT1 supplies main bar section 1
2. SGT2 supplies main bar section 2
3. SGT4 supplies reserve bar sections 1 and 2

The three bar sections are remote-coupled at 132kV at Shrewsbury GSP and loose-coupled by the Ironbridge 33kV busbars and Ketley 33kV busbars.

An arranged outage of Shrewsbury SGT3 (or associated 132kV circuit breakers or isolators) leaves Shrewsbury 132/33kV BSP supplied by the two 132kV circuits from Ironbridge GSP. The subsequent fault loss of one of these circuits or one of the SGTs at Ironbridge can give rise to overloads on the 132kV circuits or 132/33kV GTs at Ironbridge and Ketley. It would be possible to avoid some overloads by operating the Ironbridge 132kV bar solidly coupled, but this is prevented by the aforementioned fault level constraint.

Alternative mitigation relies upon the pre-fault transfer of demand from Shrewsbury 33kV network to Ironbridge 33kV network. Following demand growth to 2020 under Gone Green and Consumer Power, this transfer capacity is exhausted.

It is recommended that a combination of the following reinforcement projects is considered in order to secure the projected growth and improve 132kV network operability:

1. **A second SGT and expanded 132kV board at Shrewsbury GSP;**
2. **Fault level reinforcement to allow the parallel operation of SGTs at Ironbridge GSP;**
3. **Expanding the 132kV switchgear at Ketley BSP to a full four-corner mesh to mitigate flows through loose-coupled GTs; and**
4. **Reconductoring and cable overlays of the 132kV circuits between Ironbridge GSP and Ketley BSP.**

The Shrewsbury SGT3 constraints identified in Gone Green and Consumer Power in 2025 should be considered when determining appropriate reinforcement.

Kitwell GSP

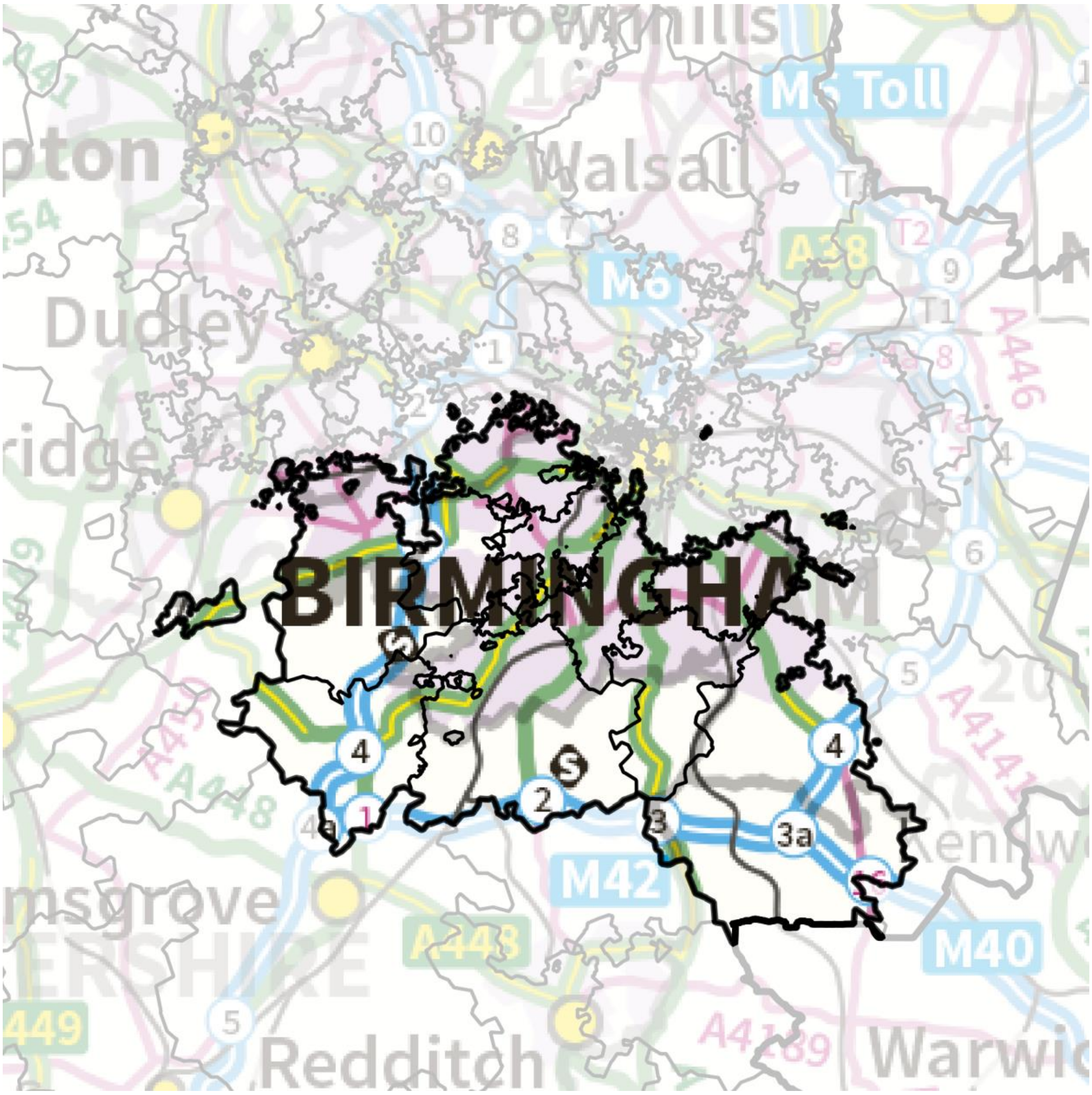

Figure 33: Area supplied by Kitwell GSP

No new reinforcement requirements were identified in the 2020 scenarios for Kitwell GSP.

Lea Marston/Hams Hall GSP

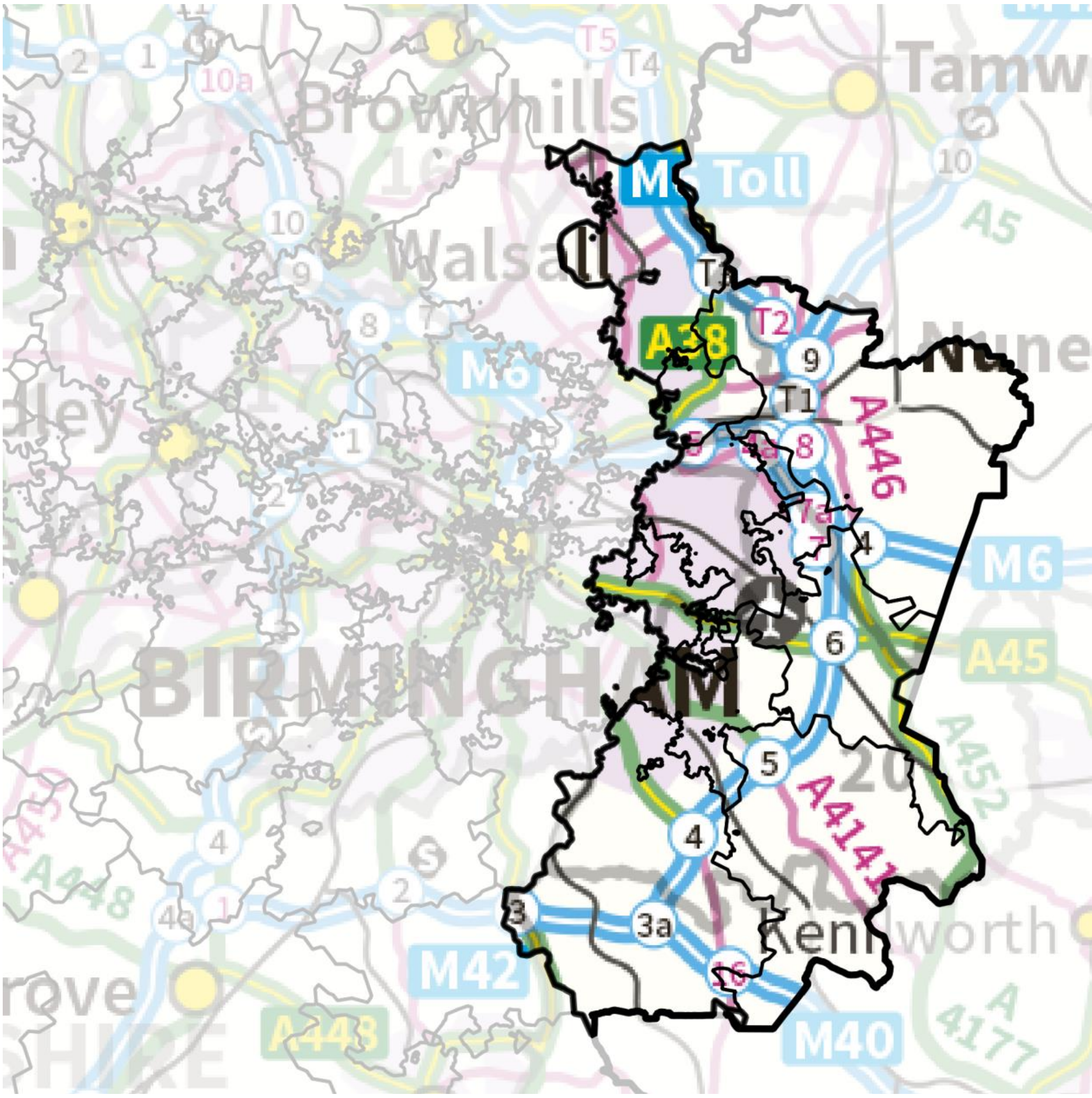

Figure 34: Area supplied by Lea Marston/Hams Hall GSP. Supplies are also provided to several BSPs in WPD's East Midlands licence area.

Copt Heath/Elmdon 132kV network

GG CP

Three interconnected 132kV circuits from Lea Marston GSP supply Copt Heath, Elmdon and Solihull BSPs, and GT1 at Shirley BSP. GT2 and GT3 at Shirley BSP are normally supplied from Kitwell GSP, with normally open interconnection available at both 132kV and 11kV.

By 2020, the maintenance period demand of the group grows to around 144MW under the Gone Green scenario. An arranged outage of one of the circuits from Lea Marston, followed by a fault outage of a second leaves the remaining circuit supplying the whole group. Demand growth to 2020 under the Gone Green scenario overloads the remaining circuit, despite having transferred the load normally supplied by Shirley GT1 (~16MW demand) onto Shirley GT2 and GT3 for the duration of the arranged outage.

The two 132kV circuits from Lea Marston to Copt Heath are due to be reconductored with 300mm² AAAC (Upas) due to asset condition before 2020; this will resolve the projected overloads on those circuits.

It is recommended that reinforcement of the 132kV circuit from Lea Marston to Elmdon is considered to secure the projected demand growth. Reprofiling the existing conductor to 65°C or more would alleviate the projected overload; if that proves impractical it would be necessary to reconductor. Further demand growth in the scenarios to 2025 may make reconductoring a better long term solution.

Nechells GSP

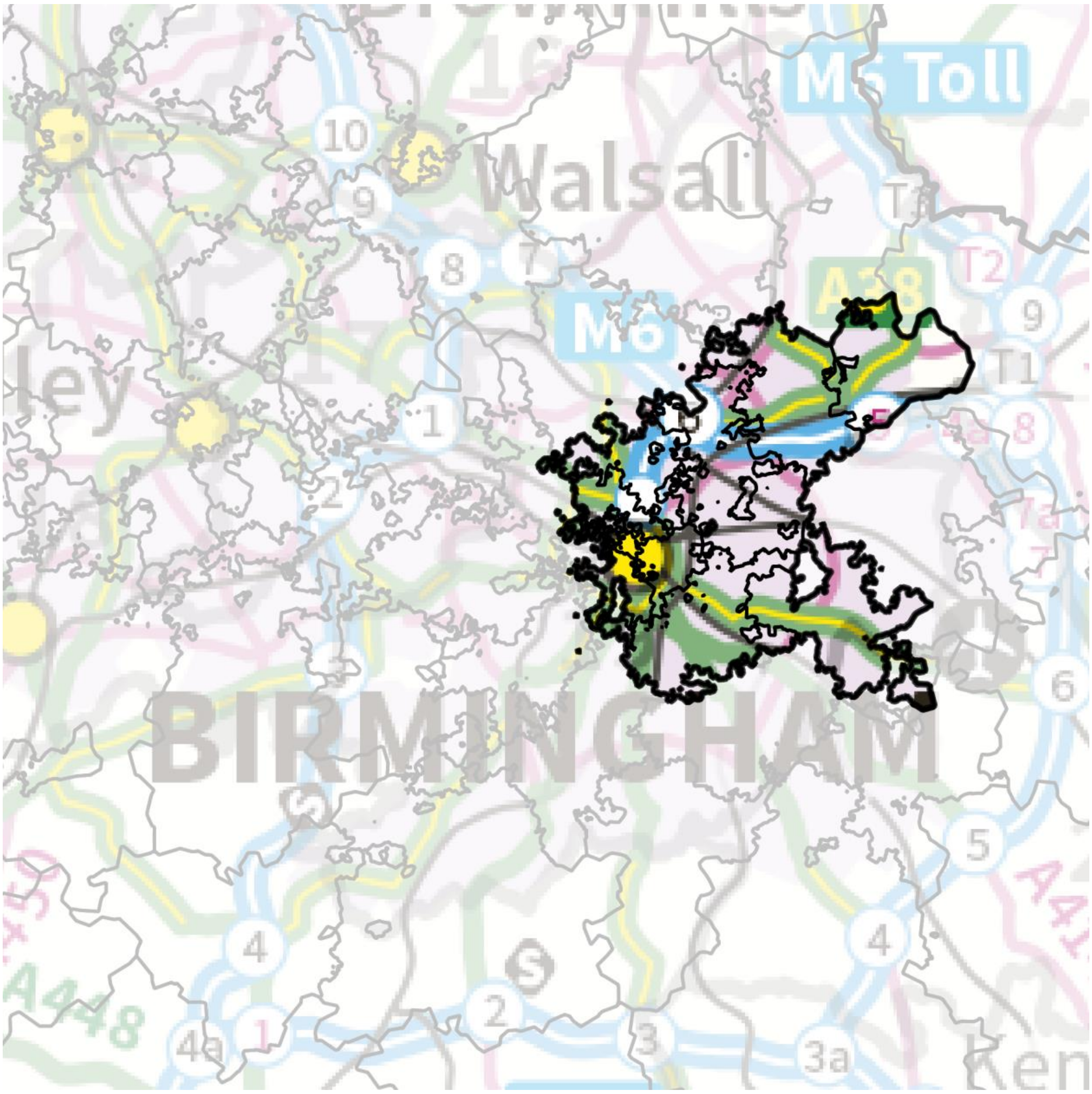

Figure 35: Area supplied by Nechells GSP

SGT capacity

GG CP SP NP

The arranged outage of 132kV mesh corner 2 at Kitts Green BSP requires the transfer of Kitts Green GT3 (maintenance period demand ~16MW) and Boughton Road GT1 (maintenance period demand ~16MW) from Lea Marston/Hams Hall GSP onto Nechells GSP. Following demand growth to 2020 under Gone Green and Consumer Power, the subsequent fault of Nechells SGT1 or SGT3 overloads the remaining SGT of that pair to around 104% of rating. Under Slow Progression and No Progression, the overload is only to around 101% of rating. An example of the overload can be seen in Figure 36.

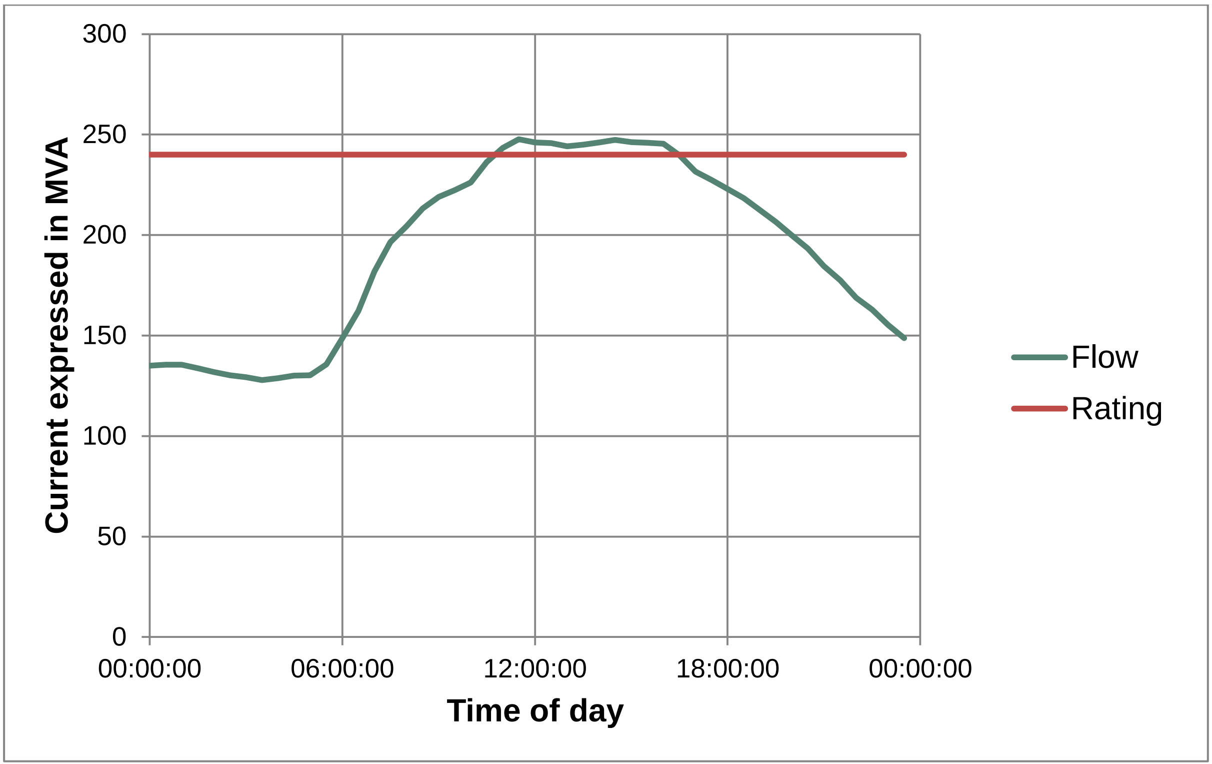

Figure 36: Graph of Nechells SGT1 loading (Consumer Power 2020, Autumn Peak Demand day, during outage of Nechells SGT3)

The projected overload could be alleviated by any of the following means:

1. **Running all four SGTs in parallel at Nechells GSP, if allowed by ongoing fault level reinforcement;**
2. **Agreeing short-term post-fault ratings for Nechells SGT1 and SGT3 with National Grid to allow post-fault switching;**
3. **Pre-fault demand transfers out of the Nechells SGT1 and SGT3 group for the duration of the arranged outage; or**
4. **Reconfiguring connections to the Kitts Green 132kV board so that the Lea Marston and Chelmsley Wood circuits are connected to mesh corners 1 and 3, and the Boughton Road circuit is connected to mesh corner 2.**

Ocker Hill GSP

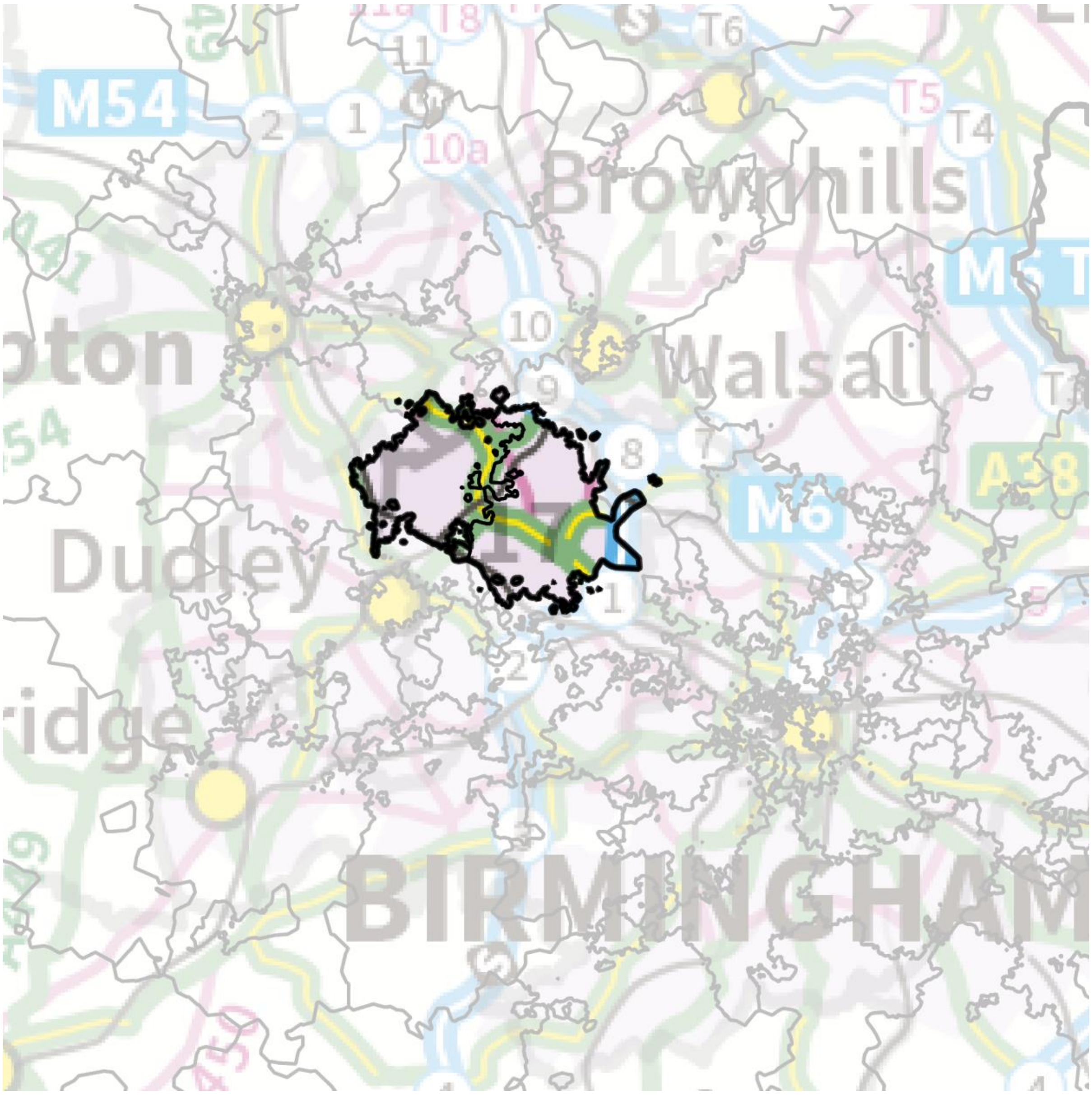

Figure 37: Area supplied by Ocker Hill GSP

No new reinforcement requirements were identified in the 2020 scenarios for Ocker Hill GSP.

Oldbury GSP

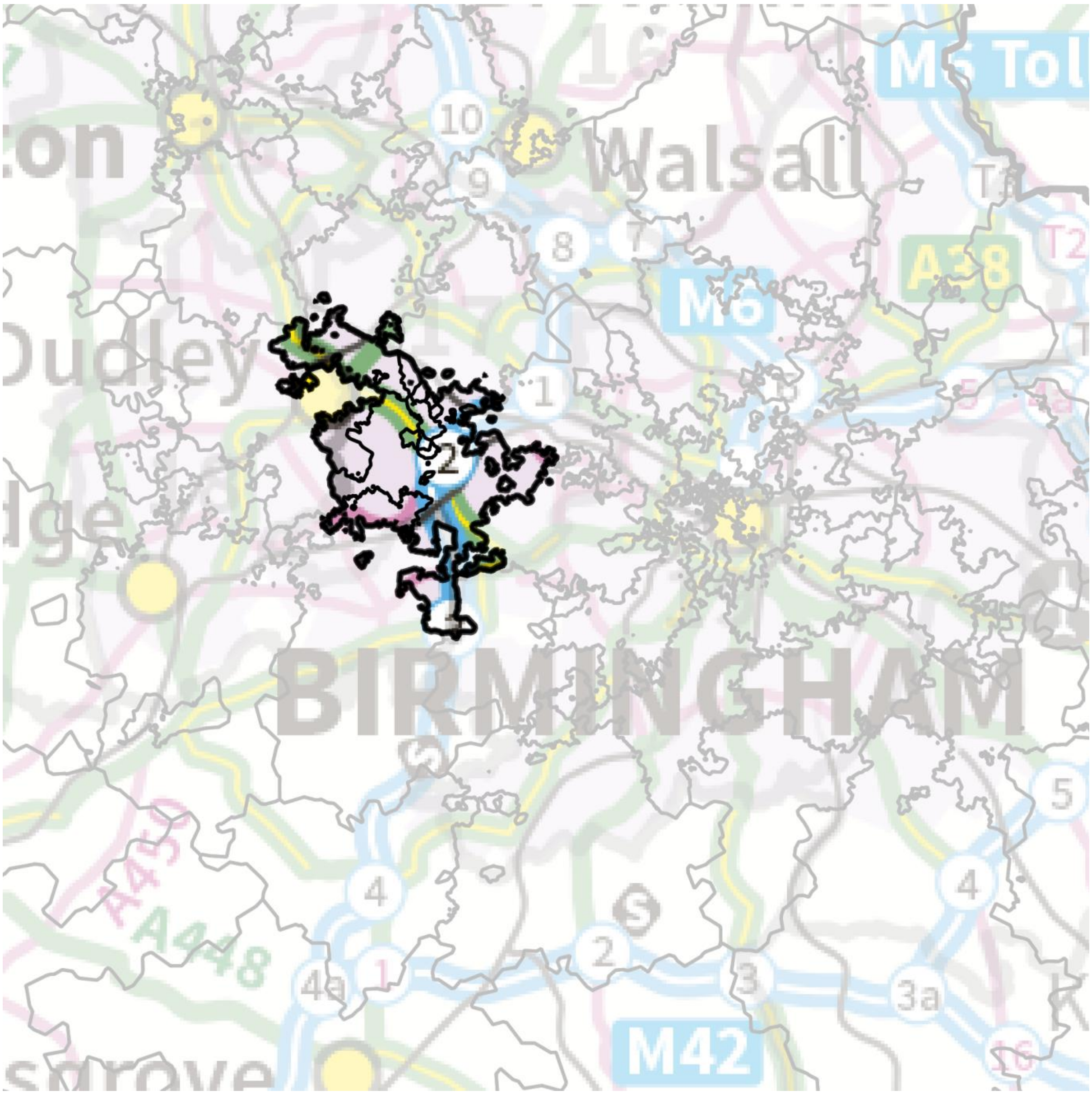

Figure 38: Area supplied by Oldbury GSP

No new reinforcement requirements were identified in the 2020 scenarios for Oldbury GSP.

Penn GSP

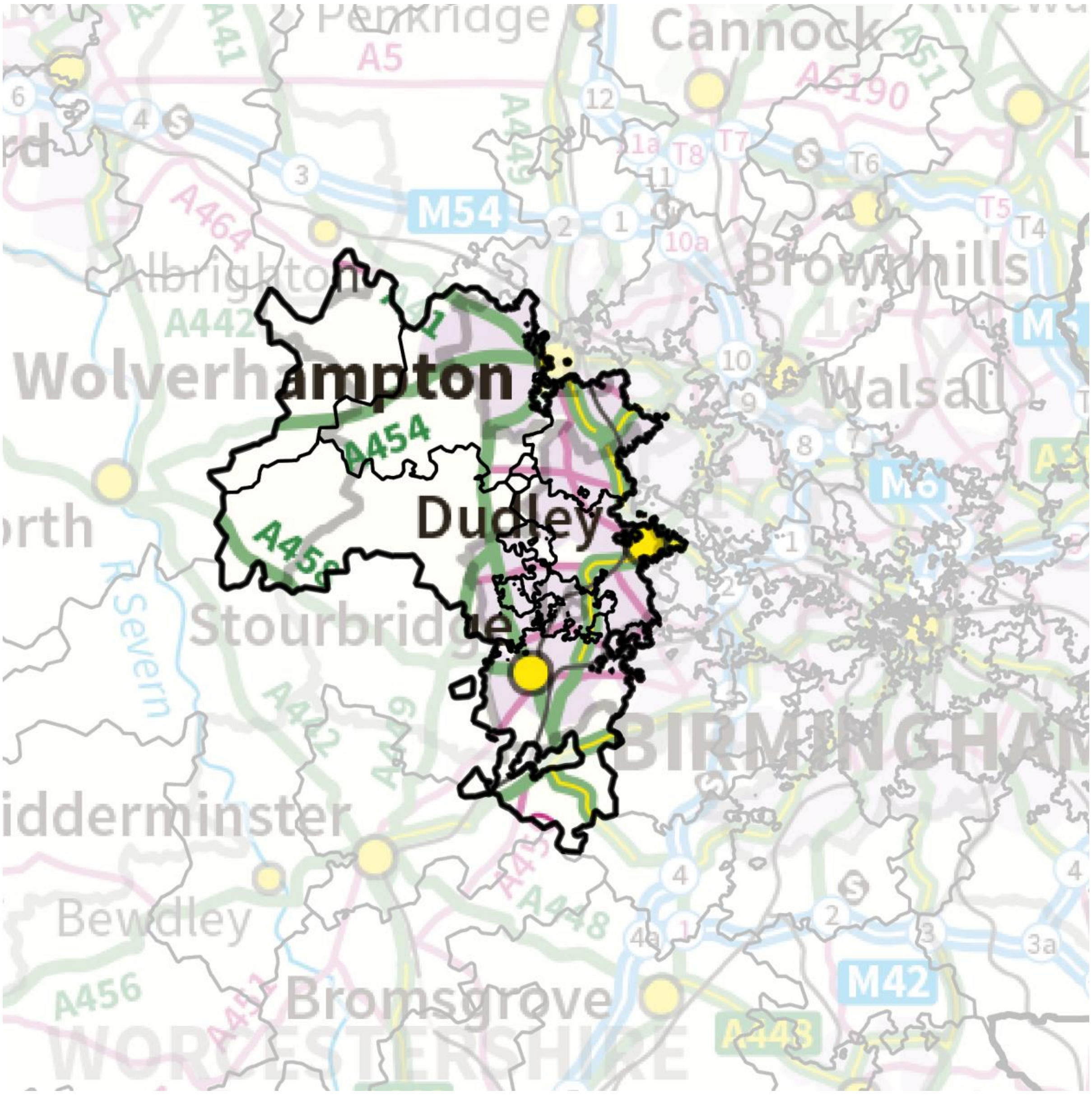

Figure 39: Area supplied by Penn GSP

No new reinforcement requirements were identified in the 2020 scenarios for Penn GSP.

Port Ham/Walham GSP

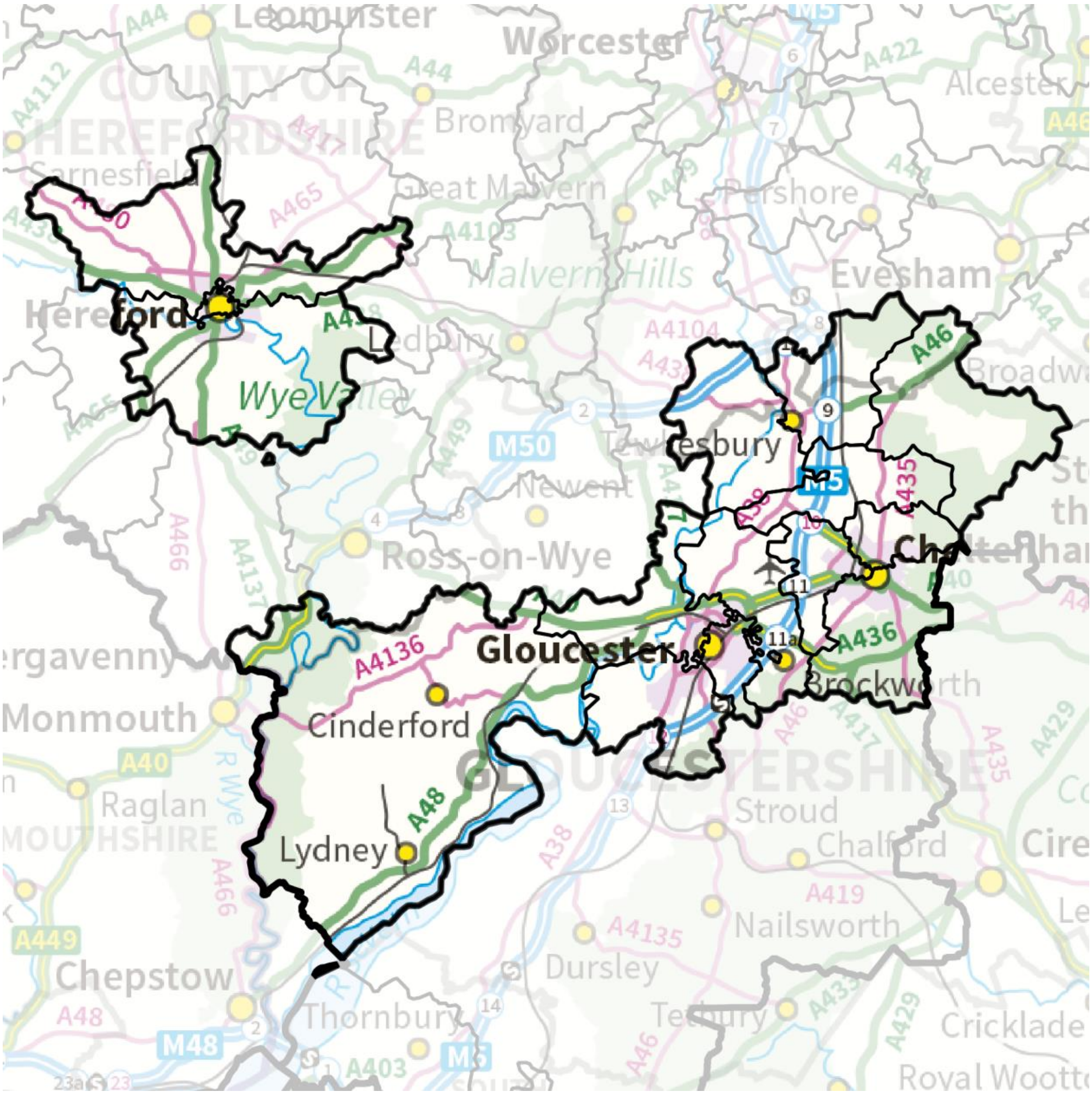

Figure 40: Area supplied by Port Ham/Walham GSP

Hereford South Primary

GG CP

Two 66kV circuits from Hereford BSP feed a pair of 20/40MVA CER 66/11kV transformers at Hereford South Primary. In 2020 demand growth in the area takes the group demand to approximately 37MW. An arranged or fault outage which leaves the group supplied by a single transformer results in a marginal overload of this transformer.

The projected overloads could be alleviated by transferring demand at 11kV onto Hereford Central, which currently has surplus capacity. Consideration should be given to the suitability of this approach if further demand growth is concentrated in the Hereford South area.

Rugeley GSP

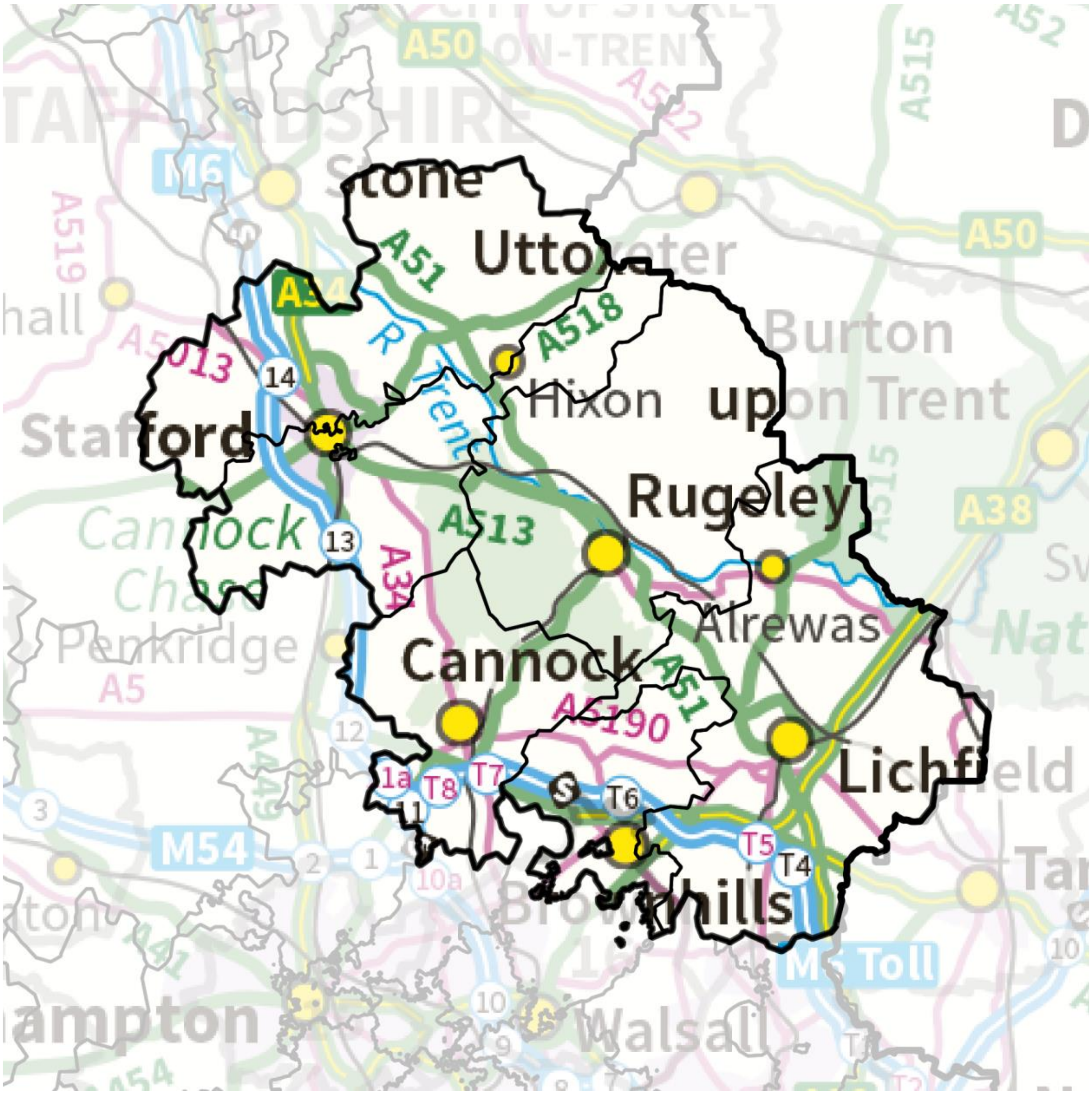

Figure 41: Area supplied by Rugeley GSP

SGT capacity

GG CP

Rugeley GSP has two 240MVA SGTs, supplied by two 400kV circuits. Following demand growth to 2020 under Gone Green, the fault outage of either SGT overloads the other to around 112% of rating. Under Consumer Power, the overload is to around 110% of rating. An example of the overload can be seen in Figure 42.

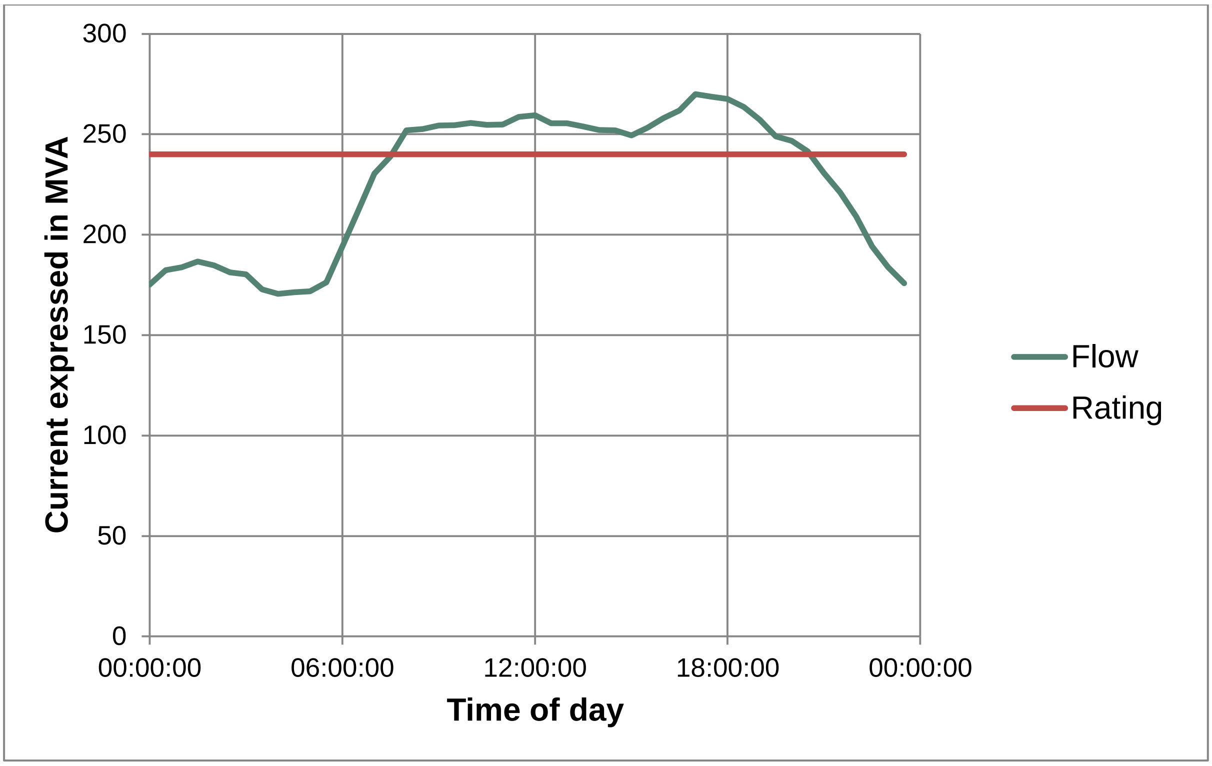

Figure 42: Graph of Rugeley SGT2 loading (Gone Green 2020, Winter Peak Demand day, during outage of Rugeley SGT1)

A third SGT at Rugeley would alleviate the projected overloads, but would not contribute to second-circuit capacity because there are only two 400kV circuits into Rugeley. Further demand growth to 2025 under Gone Green and Consumer Power takes group demand above 300MW into class E of P2/6, effectively requiring supply by three or more circuits.

As described below, a third SGT at Willenhall GSP and demand transfers from Rugeley to Willenhall might be a more efficient solution to SGT capacity constraints at both Rugeley and Willenhall.

Willenhall GSP

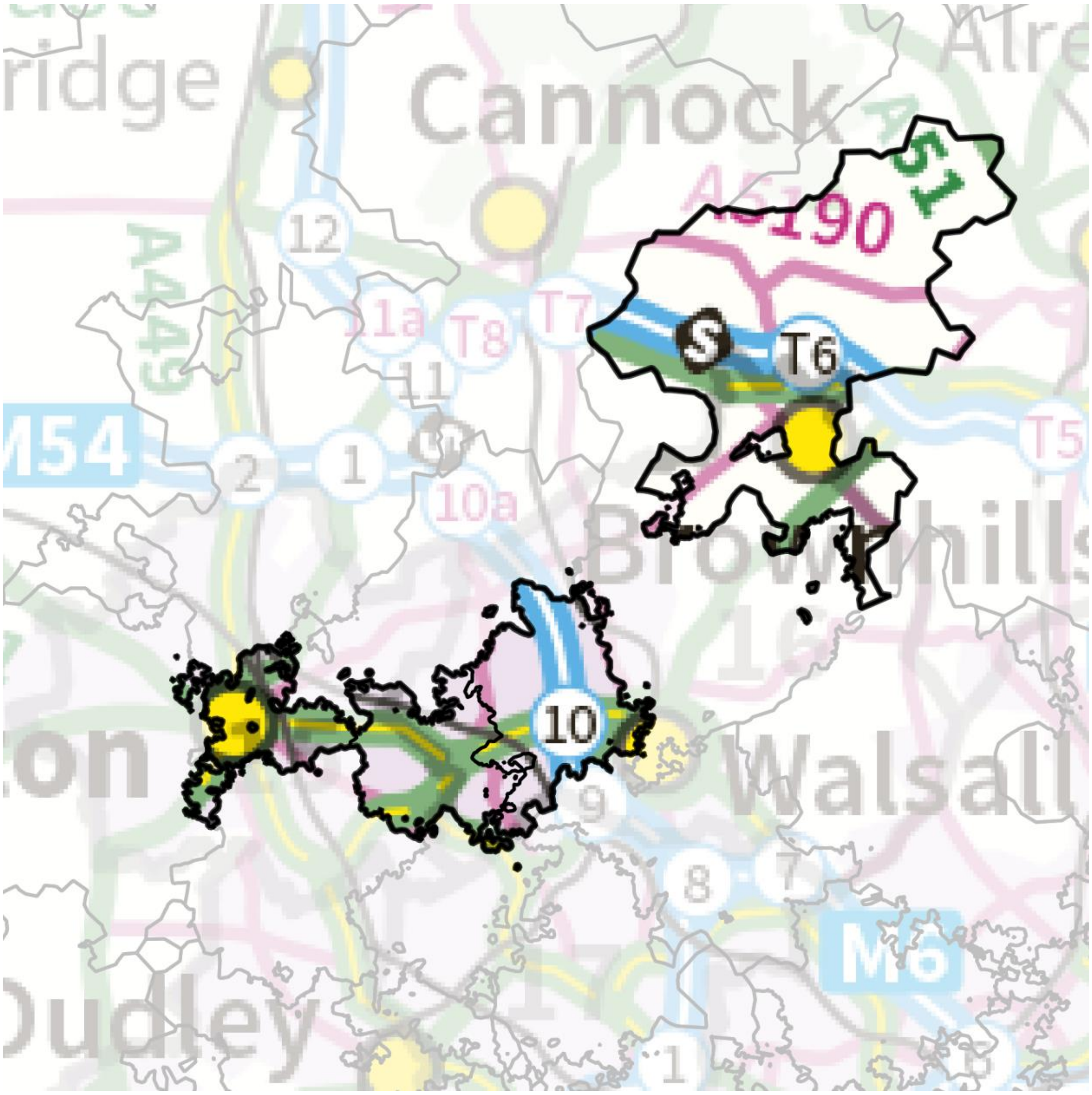

Figure 43: Area supplied by Willenhall GSP

SGT capacity

GG

Willenhall GSP has two 240MVA SGTs, supplied by three 275kV circuits. Willenhall supports various transfers from Rugeley and Bustleholm GSPs under outage conditions. For an arranged outage of the 132kV cable from Bustleholm GSP to Rushall BSP, Rushall and part of Bentley BSP are transferred onto Willenhall. Following demand growth to 2020 under Gone Green, the fault outage of either Willenhall SGT during this arranged outage overloads the other Willenhall SGT to around 103% of rating.

It is likely that the projected overload could be managed by agreeing short-term post-fault ratings for Willenhall SGT1 and SGT2 with National Grid to allow post-fault switching. An alternative scheme would be to establish a third SGT at Willenhall. This would enable the transfer of Burntwood and Cannock BSPs from Rugeley to Willenhall, alleviating SGT capacity constraints at both Willenhall and Rugeley. The third transmission circuit into Willenhall gives greater scope for future expansion than is available at Rugeley.

2025

Bishops Wood GSP

SGT capacity

GG CP SP NP

Bishops Wood GSP is supplied by four 240MVA SGTs. Following demand growth in the group to 2025 in all scenarios takes the group demand in excess of 480MW for an autumn and summer peak demand day. For an arranged outage of a SGT followed by a second circuit fault of another SGT, the remaining 2 SGTs in service are overloaded.

For low growth scenarios, transferring some of the 66kV primary substations out of group and onto Feckenham GSP, either permanently or for as part of arranged outage switching, would be required to alleviate the projected overloads. This however is not a long term solution as further demand growth in other areas of the network will limit the capability of making such transfers.

Detailed study into the Bishops Wood and Port Ham GSP groups should be considered in order to achieve a cost effective and elegant solution. Given the large geographic area, it may be more appropriate to establish a new GSP to transfer load away from Bishops Wood and Port Ham GSPs. A suitable location could be next to Hereford BSP, to move the demand of Hereford BSP onto a new GSP. A tower line of 400kV construction runs from Hereford BSP to a a point near to National Grid's 400kV route between Walham and Rassau/Pembroke. It currently forms part of the 132kV circuits from Port Ham to Hereford. It may be possible to repurpose this line to provide 400kV infeed at Hereford.

Malvern BSP

GG CP SP NP

Malvern BSP has two 15/30MVA 132/11kV GTs, with three points of 132kV infeed from Bishops Wood GSP:

- A teed connection from the Bishops Wood-Hereford/Worcester ring to a 132kV bus section at Malvern BSP
- Bishops Wood 505 to Malvern GT2 (with Timberdine BSP looped in)
- Bishops Wood 705 to Malvern GT1 (with Warndon BSP looped in)

Following demand growth to 2025 all scenarios, the group demand increases to 36MW. As a result, the arranged or fault outage of either transformer overloads the remaining transformer.

A third 132/11kV transformer at Malvern BSP would alleviate the projected overloads.

Warndon BSP

GG CP

Warndon BSP is fed via two 30/60MVA 132/11/11kV transformers, looped into a 132kV circuit from Bishops Wood 705. Following demand growth to 2025, the group demand increases to 88MW (Consumer Power) and 93MW (Gone Green). As a result, the arranged or fault outage of either transformer overloads the remaining transformer.

A third 132/11kV transformer at Warndon BSP would alleviate the projected overloads.

Bushbury GSP

Bushbury GSP Busbar Fault

Bushbury B BSP has two 132/33kV 45/90MVA transformers and one 132/33kV 15/30MVA transformer. The 33kV bars are run solidly coupled with the 15/30MVA transformer run on hot-standby. Each transformer is fed via a 132kV circuit from Bushbury GSP. Each circuit is teed to feed one of the three 132/11KV 15/30MVA transformers at Bushbury C BSP.

The fault of Bushbury GSP reserve 2 busbar loses the infeed to one to one of the 45/90MVA transformers at Bushbury C and a 15/30MVA transformer at Bushbury C. This overloads one of the circuits from Bushbury GSP as it is supplying all the demand at Bushbury B and two thirds of the demand at Bushbury C. A third of the demand at Bushbury C is being supplied via the 33kV at Bushbury B.

It is recommended that, if reasonably practicable, this overload should be resolved in the design of any future reinforcement or asset replacement scheme for this area of network.

Bustleholm GSP

Rushall BSP

Rushall BSP has four 132/11kV 15/30MVA GTs. For the arranged or fault outage of any one GT, its load is transferred to another GT. Following demand growth to 2025 under Consumer Power and Gone Green, each GT is overloaded for outages where it has the load of another GT transferred to it. An example of the overload can be seen in Figure 44.

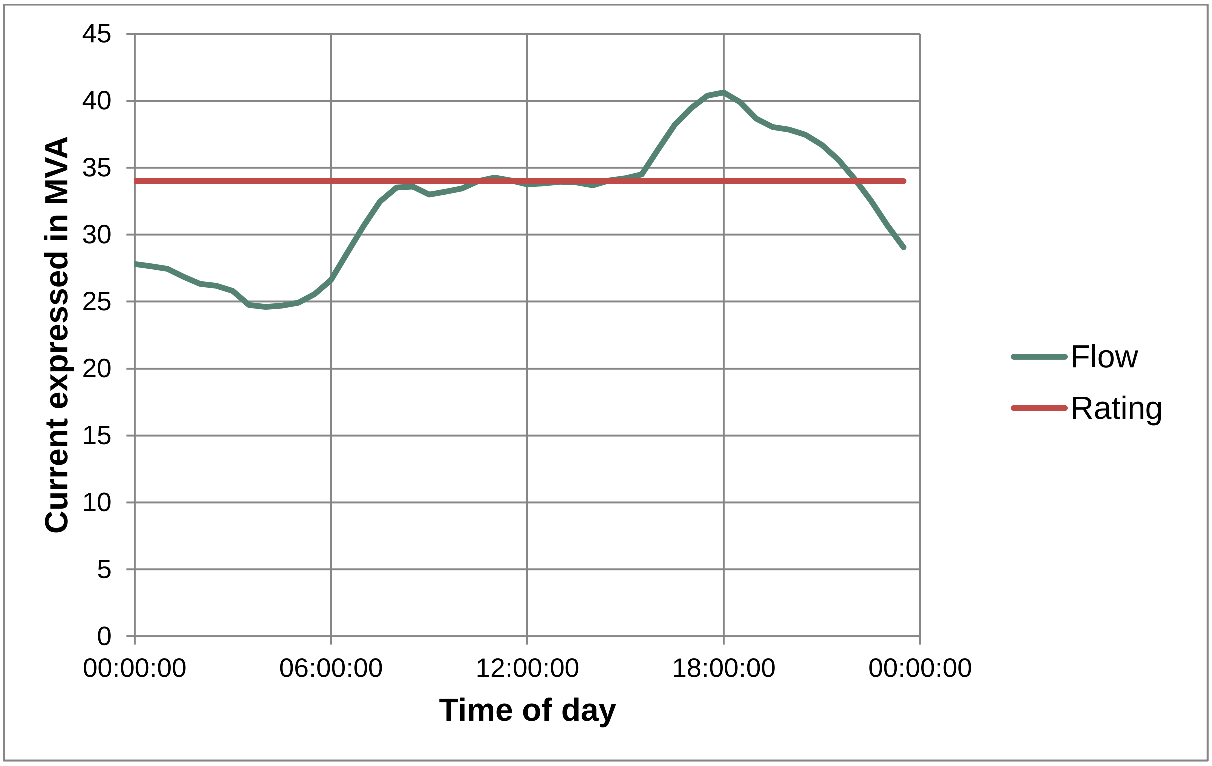

Figure 44: Graph of Rushall GT4 loading (Gone Green 2025, Autumn Peak Demand day, during outage of Rushall GT3)

New 11kV infeed in the area (e.g. at Walsall BSP) or more complex 11kV load transfers could be used to resolve the overloads. Alternative measures such as demand-side response (DSR)

or generator turn-up services might allow reinforcement to be deferred if that proves more cost effective.

Cellarhead GSP

Meaford C BSP

GG CP

Meaford C has two 45/90MVA 132/33kV GTs which are supplied via a double circuit from the nearby Barlaston switching station. Following demand growth to 2025, the group demand increases to 109MW (Gone Green) and 107MW (Consumer Power). An arranged or fault outage which leaves the group supplied by a single transformer overloads the remaining transformer in autumn and is showing at near capacity under the summer and winter peak demand representative days.

A third 132/33kV transformer at Meaford C with a third circuit from Barlaston would alleviate the projected overloads.

Newcastle and Meaford C Lost Load

GG CP

Barlaston 132kV switching station is the meshing point for 3 double circuits fed from Cellarhead GSP and a single circuit from SPEN's SP Manweb network. It also supplies Meaford C BSP via a double circuit and a single circuit supplies part of Longton BSP.

The 132kV double circuits from Cellarhead have a number of teed and looped-in BSPs. Under normal running Barlaston is run solidly coupled, meaning the Cellarhead and SPEN network are operated highly interconnected.

The arranged outage of Barlaston mesh corner 1 one requires the outage of one of the circuits supplying Meaford C BSP and the only direct 132kV circuit from Cellarhead. The subsequent fault of Barlaston mesh corner 6 loses the remaining circuit supplying Meaford C BSP and the Main 2 side of Newcastle BSP. The lost load is 161MW, of which there is a requirement that 54MW is restored within 3 hours. The lost load at Newcastle can be restored via the 11kV auto changeover scheme and the 33kV interconnection with Whitfield BSP.

It is recommended that any demand-driven reinforcement of Meaford C considers the 33kV transfer capacity with Longton to ensure P2/6 compliance for this outage condition. Additional 132kV switchgear at Newcastle towards Meaford/Barlaston may also assist with compliance.

Stagefields/Boothen 132kV Network

GG CP SP NP

Stagefields and Boothen BSPs are supplied by a double circuit between Cellarhead GSP and Barlaston switching station. The arranged outage of one of the circuits between Cellarhead GSP and Stagefields, followed by the Cellarhead 605 circuit to Barlaston causes overloads on the Barlaston to Stagefields circuit under all scenarios.

Due to the highly interconnected nature of the Cellarhead 132kV network with SPEN's SP Manweb network, determination of the best reinforcement strategy will require detailed study work with in collaboration with SPEN.

Feckenham GSP

The 66kV area supplied by Feckenham GSP is large and is an area susceptible to low voltages, although these low voltages do not result in voltage issues on the 11kV network for customers. In the high growth scenarios in 2025, the significant demand growth in the group leads to non-convergences for first and second circuit contingencies.

Given the characteristically low voltages of a network designed like Feckenham, detailed study should be considered in order to ascertain what solutions are available to provide extra sources of 132kV or 275/400kV infeed into the area. Options for this could include:

1. **Establishing 132/66kV transformers at Banbury BSP and 66kV circuits from Banbury BSP to Bloxham; or**
2. **Establish a new GSP further south than Feckenham to improve voltage performance in the more remote areas of the 66kV network.**

SGT capacity

GG CP SP NP

Feckenham GSP consists of a 66kV ring busbar supplied by four SGTs, 3 180MVA units (one of which is run on no-load) and a 120MVA unit. The 66kV area supplied by Feckenham GSP is large and is an area susceptible to low voltages. In 2025, the group demand increases to 332MW (No Progression), 342MW (Slow Progression), 400MW (Consumer Power) and 418MW (Gone Green). For a first circuit outage (FCO) followed by a second circuit fault, the group demand exceeds the SGT capacity of the group.

For low growth scenarios, transferring some of the 66kV primary substations out of group and onto Bishops Wood GSP, either permanently or for as part of arranged outage switching, would be required to alleviate the projected overloads. This however is not a long term solution as further demand growth in other areas of the network will limit the capability of making such transfers. A fifth SGT at Feckenham GSP would alleviate the projected overloads. Conversely, establishing another GSP further south of Feckenham may be more appropriate given the aforementioned voltage issues.

Pershore

GG CP

Two 66kV circuits from Feckenham GSP feed a pair of 12/19/24MVA 66/11kV transformers at Pershore Primary. In 2025 demand growth in the area takes the group demand to approximately 25MW. An arranged or fault outage which leaves the group supplied by a single transformer results in a marginal overload of this transformer.

The projected overloads could be alleviated by transferring demand at 11kV onto Strensham, which currently has surplus capacity. Consideration should be given to the suitability of this approach if further demand growth is concentrated in the Pershore area.

Evesham

GG CP

Despite transformer reinforcement in 2020, further demand growth in 2025 under Consumer Power and Gone Green takes the group demand in excess of 44MW. For an arranged or fault outage of one of the transformers or transformer feeders, the remaining transformer is overloaded.

Demand growth in the Evesham area should be considered when assessing potential reinforcement options in 2020. A third primary transformer at Evesham would alleviate the projected overloads in both 2020 and 2025.

Iron Acton GSP

No new reinforcement requirements were identified in the 2025 scenarios for Chipping Sodbury and Ryeford BSPs or the 132kV circuits supplying them.

Ironbridge GSP and Shrewsbury GSP

Shrewsbury SGT3

GG CP

Demand growth to 2025 under Consumer Power and Gone Green takes the group demand of the group containing Ketley BSP, Hortonwood BSP and Shrewsbury BSP above 300MW. This puts the group 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.

For an arranged outage of either 132kV circuit from Ironbridge to Ketley followed by a fault outage of the other circuit, the group is left supplied by Shrewsbury SGT3. The projected maintenance period demand of the group exceeds the rating of that SGT, as shown in Figure 45.

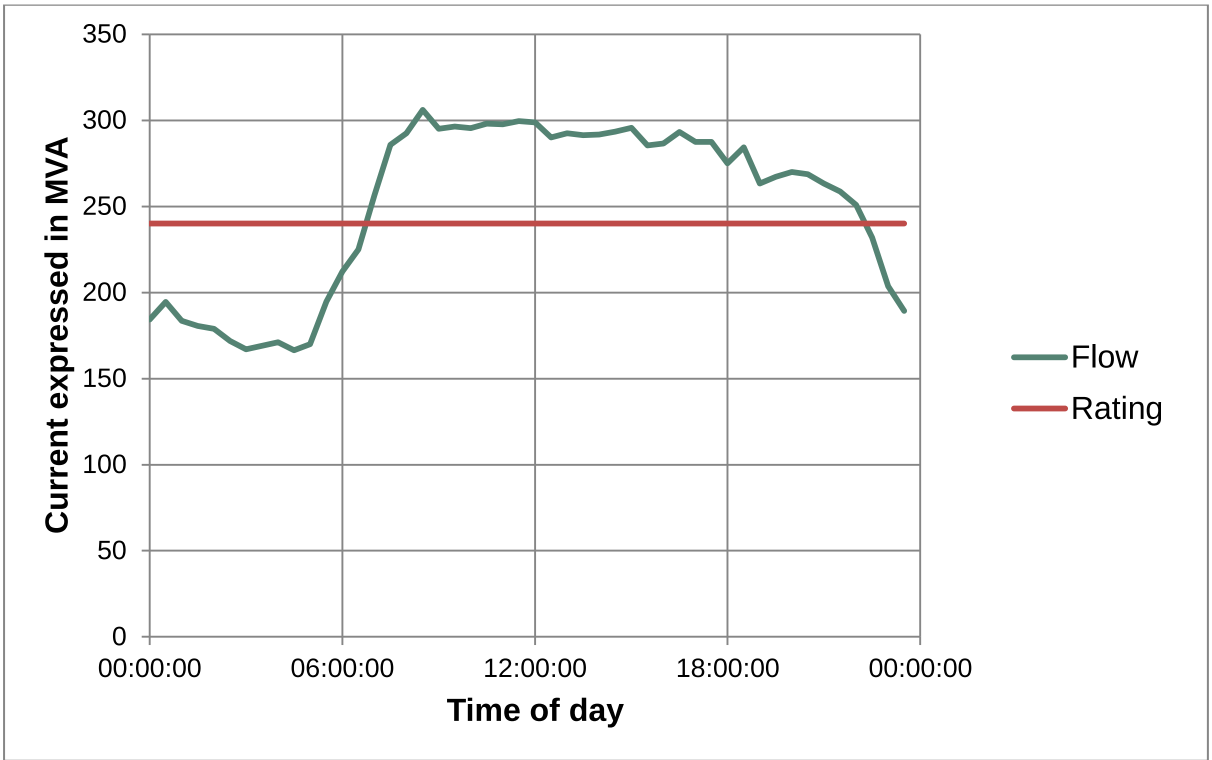

Figure 45: Graph of Shrewsbury SGT3 loading (Gone Green 2020, Summer Peak Demand day, during outage of both 132kV circuits from Ironbridge)

Additional 132kV infeed to the group would be required to alleviate the projected overload. Options include:

1. **A second SGT and expanded 132kV board at Shrewsbury GSP; or**
2. **A third 132kV circuit into the group from Ironbridge GSP.**

Kitwell GSP

132kV network east of Kitwell

GG CP

The BSPs to the east of Kitwell GSP are supplied by seven 132kV circuits from Kitwell which are meshed at several of the BSPs. A subset of that group of BSPs (Highers Heath, Hall Green and Shirley) is supplied via three 132kV circuits, whose first sections are:

- Kitwell 1205 to Longbridge
- Kitwell 405 to Selly Oak

- Bournville to Hall Green

Following demand growth to 2025 under Gone Green and Consumer Power, the arranged outage of one of those circuits followed by the fault outage of a second results in overloads on the remaining circuit supplying the group.

Reinforcing the overloaded circuits by overlaying cable sections and reconductoring or reprofiling overhead sections would alleviate the projected overloads. Additional 132kV switchgear at Longbridge, Selly Oak and/or Bournville might be used to avoid some of the circuit reinforcement by sharing load with other circuits in the Kitwell 132kV network.

It may be possible to defer reinforcement by transferring demand onto Lea Marston/Hams Hall GSP at Shirley BSP for the duration of arranged outage.

Lea Marston/Hams Hall GSP

SGT capacity

GG CP

The 132kV board at Lea Marston is supplied by four SGTs at the adjacent Hams Hall GSP. Following demand growth to 2025 under Gone Green and Consumer Power, the arranged outage of one SGT followed by the fault outage of another overloads the two remaining SGTs.

A fifth SGT at Hams Hall supplying the Lea Marston 132kV board would alleviate the projected overloads.

Copt Heath/Elmdon 132kV network

GG CP SP NP

Further demand growth under Gone Green and Consumer Power to 2025 reintroduces overloads on the 132kV circuit from Lea Marston to Elmdon, despite reprofiling in 2020.

Reconductoring the affected circuit would alleviate the projected overloads.

Demand growth to 2025 under Slow Progression and No Progression causes similar overloads to Gone Green and Consumer Power in 2020.

The same measures proposed in 2020 would apply.

Hams Hall South BSP

GG CP

Hams Hall South BSP has two 60MVA 132/11/11kV GTs supplied from Lea Marston. Following demand growth to 2025 under Gone Green and Consumer Power, the arranged or fault outage of either GT overloads the other.

A third GT, potentially connected to the passing 132kV circuit from Lea Marston to Kitts Green BSP, would alleviate the projected overloads.

Solihull BSP

GG CP

Solihull BSP has two 60MVA 132/11/11kV GTs, each supplied by a 132kV cable from Copt Heath BSP. Following demand growth to 2025 under Gone Green and Consumer Power, the arranged or fault outage of either transformer feeder overloads the remaining transformer and cable.

A third 132kV circuit to Solihull BSP supplying a third GT would alleviate the projected overloads.

Nechells GSP

SGT capacity

GG CP SP NP

Further demand growth to 2025 increases the scale of the overloads predicted in 2020 to between 105% and 111% of rating, depending on scenario. This may affect which reinforcement or mitigation is chosen.

Ocker Hill GSP

Black Lake BSP

GG CP

Black Lake BSP has 4 GTs and is supplied by two 132kV circuits from Ocker Hill GSP, with each circuit supplying a 60MVA 132/11/11kV GT and a 132/11kV 15/30MVA GT.

Further demand growth under Gone Green and Consumer Power to 2025 overloads the 15/30MVA transformers for the arranged outage or fault of the circuit feeding the other 15/30MVA transformer. Both 60MVA GTs are overloaded under Gone Green for the arranged outage or fault resulting in the outage of the other 60MVA transformer.

The projected overloads could be alleviated by transferring demand at 11kV onto either Ocker Hill BSP or Oldbury BSP, as these BSPs are located at GSPs and any additional capacity requirements can be met more easily.

Oldbury GSP

No new reinforcement requirements were identified in the 2025 scenarios for Oldbury GSP.

Penn GSP

Hinksford BSP

GG CP SP

Hinksford is supplied by two direct circuits from Penn GSP and has transformations from 132kV to 33kV and 11kV. There are two 132/11kV 15/30MVA transformers, a 132/33kV 22.5/45MVA transformer and a 33/11kV transformer.

Following demand growth to 2025, the group demand increases to 92MW (Gone Green), 86MW (Consumer Power) and 76MW (No Progression). A fault of either 132/11kV transformer means the remaining 132/11kV transformer is insufficient to automatically pick-up the lost load.

It is recommended that a detailed assessment is undertaken to ensure that there is sufficient transfer capability at 33kV and 11kV to meet P2/6 compliance.

Port Ham/Walham GSP

SGT capacity

GG CP SP NP

Port Ham 132kV board is supplied by four 240MVA SGTs from the adjacent Walham GSP. Following demand growth in the group to 2025 in all scenarios takes the group demand in excess of 480MW for an autumn representative day. For an arranged outage of a SGT followed by a second circuit fault of another SGT, the remaining 2 SGTs in service are overloaded.

For low growth scenarios, transferring Lydney BSP out of group and onto Iron Acton, either permanently or for as part of arranged outage switching, would be required to alleviate the

projected overloads. This however is not a long term solution as further demand growth in other areas of the network will limit the capability of making such transfers.

When resolving this issue, consideration should be given to the establishment of a new GSP at Hereford as described above in Bishops Wood 2025.

Hereford BSP

GG CP SP

Two 132kV circuits from Port Ham GSP feed two 45/90MVA 132/66kV grid transformers at Hereford BSP, which in turn feed the area covering the urban area in Herefordshire (Hereford Central, South and North). Demand growth in the areas supplying Hereford city surpasses 100MW in 2025 in Slow Progression, Consumer Power and Gone Green scenarios. For an arranged outage of one of the grid transformers, the other transformer is overloaded based on the cyclic rating.

Installing a 6th Grid Transformer at Hereford BSP (to leave the Hereford North, Hereford South and Hereford Central group supplied via 3 GTs) would alleviate the projected overloads. However given the projected overloads at Port Ham GSP, consideration should be given to the wider network when assessing the potential reinforcement options, such as establishing a new GSP at Hereford as described above in Bishops Wood 2025.

Lydney BSP

GG CP SP

Two 132kV circuits from Port Ham GSP feed two 45/90MVA 132/33kV grid transformers at Lydney BSP. One of the circuits is supplied directly from Port Ham GSP; the other is connected via a 132kV switching station at Cambridge Arms. Demand growth in the areas surpasses 100MW in 2025 in Slow Progression, Consumer Power and Gone Green scenarios. For an arranged outage or circuit fault of one of the grid transformers or transformer feeders, the other transformer is overloaded based on the cyclic rating. Under a Gone Green and Consumer Power scenario, the 132kV transformer feeder from Port Ham is also overloaded for this outage combination.

Establishing two 132/11kV grid transformers at Lydney BSP teed off the incoming 132kV circuits would alleviate the issue. Under Gone Green and Consumer Power, it would also be necessary to reinforce the 132kV circuits to Lydney by reprofiling for 75°C operation or reconductoring.

Rugeley GSP

SGT capacity

GG CP SP NP

Further demand growth under Gone Green and Consumer Power to 2025 takes the group demand of Rugeley GSP above 300MW into class E of P2/6, effectively requiring supply by three or more circuits.

Supporting a group demand above 300MW at Rugeley would require a third transmission circuit into Rugeley. In light of this, a third SGT at Willenhall with demand transfers from Rugeley to Willenhall may prove more efficient.

Demand growth to 2025 under Slow Progression and No Progression causes similar overloads to Gone Green and Consumer Power in 2020.

The same measures proposed in 2020 would apply.

Rugeley Town BSP

GG CP

Rugeley Town BSP has two 30MVA 132/11kV GTs. Following demand growth to 2025 under Gone Green and Consumer Power, the arranged or fault outage of either transformer overloads the other.

A third 30MVA 132/11kV GT at Rugeley Town together with 132kV switchgear or a new 132kV cable from Rugeley GSP would alleviate the projected overload. Alternatively, a new BSP could be established to the north of Rugeley, connected to either of the 132kV tower lines running north from Rugeley GSP.

Willenhall GSP

SGT capacity

GG CP SP

Demand growth to 2025 under Gone Green, Consumer Power and Slow Progression exacerbates the issues seen under Gone Green in 2020.

As described above, a third SGT at Willenhall GSP would alleviate the projected overloads at Willenhall GSP and allow transfers from Rugeley GSP to alleviate all or part of the projected overloads at Rugeley.

7 – Next Steps

Low regret reinforcement schemes

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 all reinforcement requirements identified in the 2020 studies are assessed in further detail to determine if a reinforcement scheme is required based on actual demand, generation and storage uptake. The affected network areas are:

- Upton Warren BSP 11kV infeed;
- Feckenham GSP 66kV busbar;
- Evesham primary substation;
- Ironbridge-Shrewsbury 132kV network;
- Copt Heath/Elmdon 132kV network;
- Nechells GSP SGT capacity;
- Hereford South primary substation;
- Rugeley GSP SGT capacity; and
- Willenhall GSP SGT capacity.

Given the further requirements identified in the 2025 studies, it is recommended that options are developed for:

- Transformer capacity at Port Ham/Walham GSP, Bishops Wood GSP and Hereford BSP; potentially a new GSP at Hereford;
- Additional GTs at Malvern BSP and Warndon BSP;
- Busbar fault mitigation at Bushbury GSP;
- Meaford C BSP;
- The wider development of the Cellarhead 132kV network;
- SGT capacity at Feckenham GSP; potentially a new GSP to the south of Feckenham;
- Primary transformer capacity at Pershore and Evesham;
- Further 132kV infeed to the northern part of the Ironbridge-Shrewsbury network;
- 132kV circuit reinforcement to the east of Kitwell GSP;
- SGT capacity at Lea Marston/Hams Hall GSP;
- 132kV circuit reinforcement between Lea Marston and Elmdon;
- A third GT at Hams Hall South BSP;
- A third GT and 132kV circuit for Solihull BSP;
- GT capacity at Black Lake BSP;
- Transformer capacity at Hinksford BSP;
- GT capacity at Lydney BSP;
- SGT capacity at Rugeley and Willenhall GSPs; and
- GT capacity at Rugeley Town BSP.

Further modelling

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

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

2. The impact of these scenarios on National Grid's own network. Where it is decided that it is more appropriate to curtail generator output than to reinforce National Grid's network, the level and impact of this curtailment should be assessed.

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

It is also recommended that additional studies are carried out in cooperation with SPEN to assess WPD and SPEN's interdependent 132kV networks supplied from Cellarhead GSP.

As 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. ANM including energy curtailment estimation,
3. Protection,
4. Dynamics,
5. Power quality.

8 – Definitions and References

References

External documents

P2

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

P27

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

Electricity Act 1989 as amended

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

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

Future Energy Scenarios (FES) 2015, 2016

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

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

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

Distributed generation and demand study -Technology growth scenarios to 2030, West Midlands licence area 2017

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

Insight Report Electric Vehicles

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

Western Power Distribution documents

1. ST:SD8A/2 (*Relating to Revision of Overhead Line Ratings*), used in conjunction with ER P27 to determine the ratings applicable to overhead lines;
2. ST:SD8C/1 (*Relating to 132kV, 66kV and 33kV Medium Power Transformer Ratings*), 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. West Midlands Subtransmission network geographic map and single line diagrams; available from our website at: www.westernpower.co.uk/netstratwmid

Table of Units

Term	Definition
kV	Kilovolt, a unit of Voltage ($x10^3$)
LV	This refers to voltages up to, but not including, 1kV
HV	Voltages over 1kV up to, but not including, 22kV
EHV	Voltages over 20kV up to, but not including, 132kV
kW	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; sometimes referred to informally as *maintenance period*
BEIS	Department for Business, Energy & Industrial Strategy	The governmental department responsible for energy and climate change policy. Formed as a merger between the Department for Business, Innovation & Skills (BIS) and the Department for Energy & Climate Change (DECC)
BSP	Bulk Supply Point	A substation comprising one or more Grid Transformers and associated switchgear
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
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 132kV; - A customer directly supplied at 132kV or by a dedicated BSP
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.

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. Sometimes referred to simply as *System Operator*.
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.
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.
–	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.

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

Transformer Ratings

Transformer Cooling Methods

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

Rating Categories

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

Applied ratings

Grid Transformers

Nameplate rating [MVA]	Final Forced cooling method	CMR_{ONAN}	CMR_{FINAL}	$Cyclic_{WINTER\ FINAL}$	$CER_{SUMMER\ FINAL}$
10/20	OFAF	10	20	26	23
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

Conventional 66/11kV Primary Transformers

Nameplate rating [MVA]	Final Forced cooling method	CMR_{ONAN}	CMR_{FINAL}	$Cyclic_{WINTER\ FINAL}$	$CER_{SUMMER\ FINAL}$
5	ONAN	5	5	6.5	6
6	ONAN	6	6	7.8	7
10/10	ONAN	10	10	13	12
10/14	OFAF	10	14	16.25	15
12	ONAN	12	12	15.6	14
15	ONAN	15	15	19.5	18
15/21	OFAF	15	21	27.3	23.5
16	ONAN	16	16	20.8	19
16/20	OFAN	16	20	25.6	22.4
20	ONAN	20	20	26	24
20/28	OFAF	20	28	36	30
30	ONAN	30	30	39	36

CER-type 66/11kV Primary Transformers

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

132/25kV Traction Supply Transformers

Nameplate rating [MVA]	Final Forced cooling method	CMR_{ONAN}	CMR_{FINAL}
7.5/12.5	OFAF	7.5	12.5
15	ONAN	15	15
18/26.5	OFAF	18	26.5

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:*

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

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

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

Appendix

Network Modelling and Analysis

WPD West Midlands Subtransmission network and Primary Distribution network are normally analysed using TNEI's IPSA power system software. The IPSA load flow tool is designed to analyse a snapshot of the network and has the functionality to perform fault level and basic contingency analysis.

Data Migration Program

For this project it was decided that PSS/E was a more suitable analysis engine, as it has more advanced contingency analysis with corrective action modelling and a more advanced scripting interface. This required the migration of data from the master IPSA models and circuit database into the PSS/E database format. This was achieved by taking a snapshot of the master IPSA models and using an in-house conversion program to convert the network model. The model was automatically validated throughout the conversion process and manual validation was also carried out to ensure the PSS/E model accurately represented the network.

Analysis Program

The main benefit of converting to PSS/E was it allowed utilisation of the bespoke power system analysis program written for the South Wales strategic studies. The program is written in Python 2.7. It uses PSS/E 33 as its core analysis engine to perform the actual load-flow calculations, and uses some of PSS/E's built-in contingency analysis tools for efficiency.

To better represent network operations throughout a representative day, the custom program was written so each half hour or the representative day could be overlaid with the demand and generation onto the master model. For each half hour a full intact, 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 144 unique tasks for the 3 representative days studied, which were stored on the centralised database and run on all available pool computers. Each active computer checks if any tasks are available from the server and runs a full intact, first outage and second outage study for any available task and writes the processed results to the database. To further improve runtime efficiency, the python multiprocessing module was utilised which allowed up to 6 parallel processes to run on each computer: significantly increasing CPU utilisation.

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

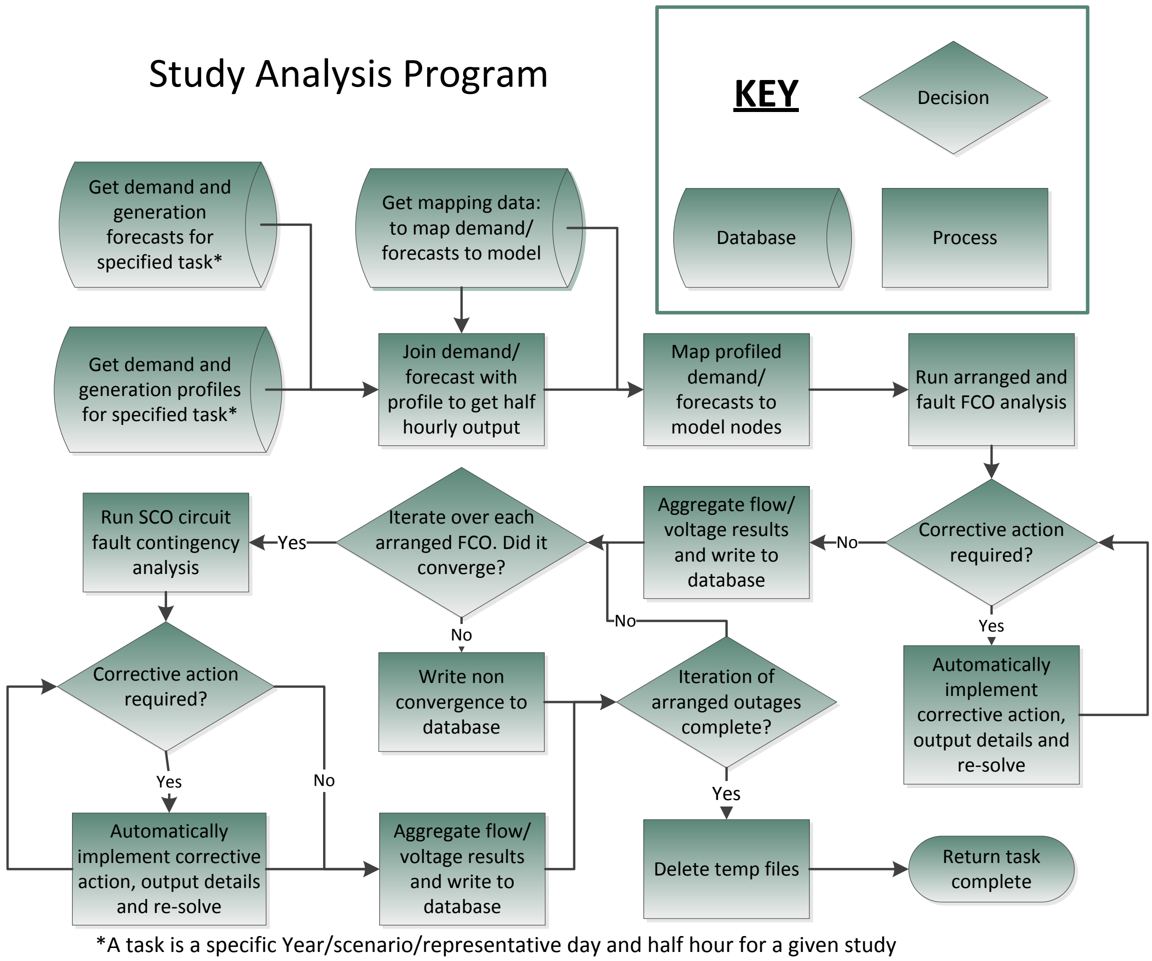

Figure 46: Summary of network analysis process

Modelling Network Automation and Manual Switching Schemes

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

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

Contingency Analysis

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

Circuit breakers were included in the network model in order to determine the protective zones bounded by circuit breakers which are deenergised under fault conditions. Isolators were included in the network model to determine the isolatable zones bounded by isolators which are deenergised 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 contingency of each zone that includes at least one 132kV or 66kV node was assessed. This included all Super Grid Transformers (SGTs) and GTs. Transmission contingencies were not modelled exhaustively, as the static model of the transmission network would limit the accuracy of results.

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. The current equivalent in the West Midlands model is an equivalent generator connected to the 400kV or 275KV side of the SGT transformers for each GSP. Ironbridge and Shrewsbury GSPs are run in parallel on the 132kV. For this network, a single swing bus is located at the 400kV at Ironbridge and a 400kV equivalent circuit connects to Shrewsbury 400KV to represent the transmission

network. No detailed assessment was undertaken to determine the impact transmission network events would have on this GSP group.

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. No data was available on the charging behaviour of large populations of fast-charging, high-capacity EVs with a broad range of users. EV charging profiles were derived from the Electric Vehicles Insight Report of the Customer-Led Network Revolution project. This was based on a trial involving 143 domestic EV owners that took place in 2014. It is possible that increases in power and energy consumption per EV will plateau at some point (despite improvements in charging speed and battery capacity) as EV capabilities come to match the demands of EV users, but it is not known when this will happen or at what level. The EV profiles used in the studies peaked at just 0.9kW per EV after diversity. WPD's Electric Nation innovation project aims to resolve many of these data issues; more information 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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