Shaping Subtransmission to 2030

East Midlands –Report June 2017

WESTERN POWER DISTRIBUTION
Serving the Midlands, South West and Wales

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Contents

1 – Executive summary

As part of a wider trend across Great Britain, WPD's East Midlands licence area has experienced unprecedented growth in the connection of Distributed Generation (DG). There is now around 3.3GW of generation connected to WPD's East Midlands network with another 2GW accepted-not-yet-connected and 0.8MW offered-not-yet-accepted. This contrasts against an annual maximum demand of around 5GW and minimum demand of less than 1.9GW.

Initially we were able to minimise connection costs for generation customers by using the capacity inherent in a network designed to support demand. As this capacity was used up, DG connection applications resulted in requirements to reinforce our network. Similarly, National Grid's responses to WPD's East Midlands Statement of Works (SoW) submissions highlighted that DG output in some parts of the East Midlands is limited by the capability of transmission network components.

WPD has piloted the use of Active Network Management (ANM) in the East Midlands to manage the output of generators and so reduce reinforcement requirements. Building on the experience of these early projects, WPD is now rolling out ANM to several generation-constrained networks across its licence areas.

Meanwhile, the East Midlands network is 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 East 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 exists the potential for widespread electrification of heating and particularly transport in the East Midlands.

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

The scenarios were used as inputs to network studies, analysing the impact of future DG and demand connection. This was applied to the Subtransmission components of the WPD East Midlands network, which consist of Grid Supply Points (GSPs), Bulk Supply Points (BSPs) and the 132kV 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,
- **Summer Peak Generation** with minimum coincident demand, and
- **Spring/Autumn Typical** with average demand and generation for the arranged outage period.

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). Reactive power constraints are often met when the network is lightly loaded. WPD's transition to become a Distribution System Operator 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 two 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 Active Network Management (ANM) or other measures to curtail the output of DG to prevent network overstressing. It is important to note that ANM is not capable of mitigating all types of network constraints; furthermore it does not have an unlimited ability to mitigate constraints unless significant pre-fault curtailment of output is applied to avoid protection operation or equipment damage prior to the operation of ANM.

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 UKPN to assess WPD and UKPN's interdependent 132kV networks supplied from Walpole 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, and
    - year of connection
- Consider potential demand changes that come from:
    - the electrification of transport,
    - the electrification of heating, and
    - growth in industrial, commercial and domestic demand;
- Identify thermal and voltage constraints that may occur on our 132kV network which will limit the ability of those connections to take place;
- Undertake high level fault level studies to better understand fault level trends;
- Assess options for reinforcement; and
- Provide recommendations for 'low regret' investment, noting the Ofgem consultation on 'quicker and more efficient connections' that raised questions on the role of strategic reinforcement funded by the wider customer base.

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

We have used the four background Energy Scenarios developed by National Grid (NGET) in their Future Energy Scenarios (FES) for 2016 as a framework to develop detailed scenarios for the growth of demand and DG in East Midlands. East 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

East Midlands Network

Western Power Distribution (WPD) is the Distribution Network Operator for the East Midlands. The area covers approximately 16,000 square kilometres and extends from Coventry and Uttoxeter in the west, to the Wash on the East Coast and from the outskirts of Sheffield in the north to Milton Keynes in the south. The area is not dominated by major conurbations; however it has many medium sized cities and towns including Nottingham, Derby, Leicester, Coventry, Northampton and Milton Keynes. The geography of the area ranges from low-lying farmland in Lincolnshire to the Peak District National Park in Derbyshire. This area serves approximately 2.6 million customers.

There is a high concentration of manufacturing and industrial activities in the East Midlands, with many automotive manufacturers based in the region. The business activity is generally situated along the M1 and M40 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 East Midlands licence area receives supplies from National Grid at fifteen Grid Supply Points (GSPs):

- Berkswell (132kV)
- Bicker Fen (132kV)
- Chesterfield (132kV)
- Coventry (132kV)
- Drakelow (132kV)
- East Claydon (132kV)
- Enderby (132kV)
- Grendon (132kV)
- Ratcliffe (132kV)
- Staythorpe (132kV)
- Stoke Bardolph (132kV)
- Walpole (132kV)
- West Burton (132kV)
- Willington (132kV)
- Hams Hall/Lea Marston (132kV)

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

Most GSPs in the East Midlands are operated as mainly radial networks, although in a few instances a mesh system is utilised. Most 132kV networks have the ability to interconnect at 132kV to adjoining GSPs, however they are not operated in parallel. Any interconnection has to be controlled to ensure fault levels are kept within equipment ratings.

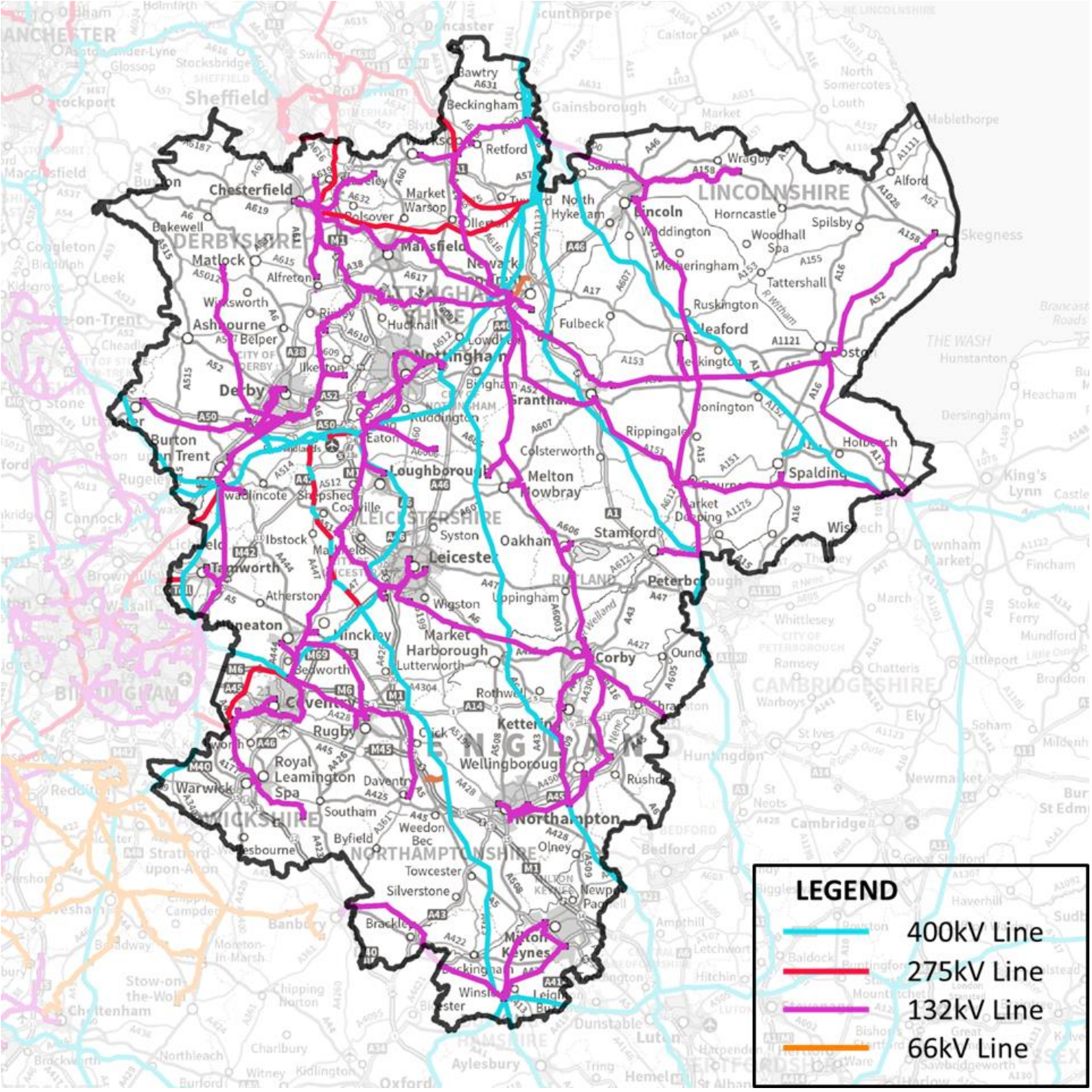

Figure 1: Network in East Midlands showing 400kV, 275kV, 132kV and 66kV networks

Demand usage of the network

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

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Table 1: Forecast units distributed in the East 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	8,188,834	1,259,464	-	2,496,481	-	-
Other LV NHH (incl. Unmetered)	3,275,169	641,567	26,750	188,217	-	-
Other LV HH	368,939	1,429,234	1,729,360	10,758	1,776,225	335,023
HV (incl. LV Substation)	793,764	2,992,388	4,119,420	3,331	2,811,943	698,025
LV Generation	38,013	3,128	3,502	277	-	3,055
HV Generation	218,450	205,384	388,129	240	-	12,473
Total	**12,883,170**	**6,531,166**	**6,267,162**	**2,699,305**	**4,588,168**	**1,048,576**

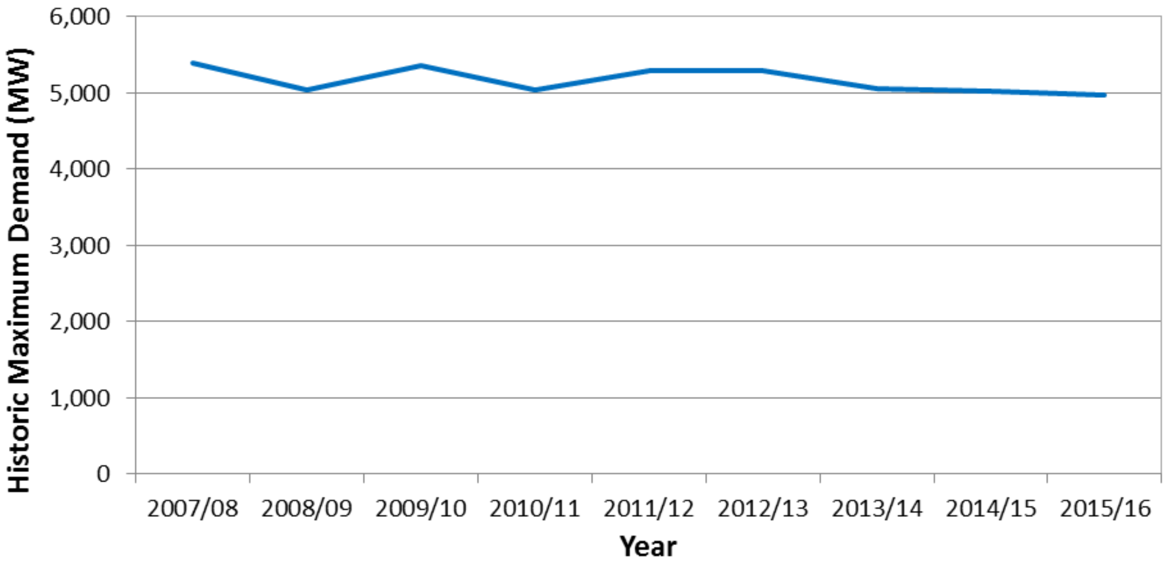

Figure 2: Historic system maximum demand in the East Midlands

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

- **Winter Peak Demand**, with minimum coincident generation,
- **Summer Peak Generation** with minimum coincident demand, and
- **Spring/Autumn Typical** with average demand and generation for the arranged outage period.

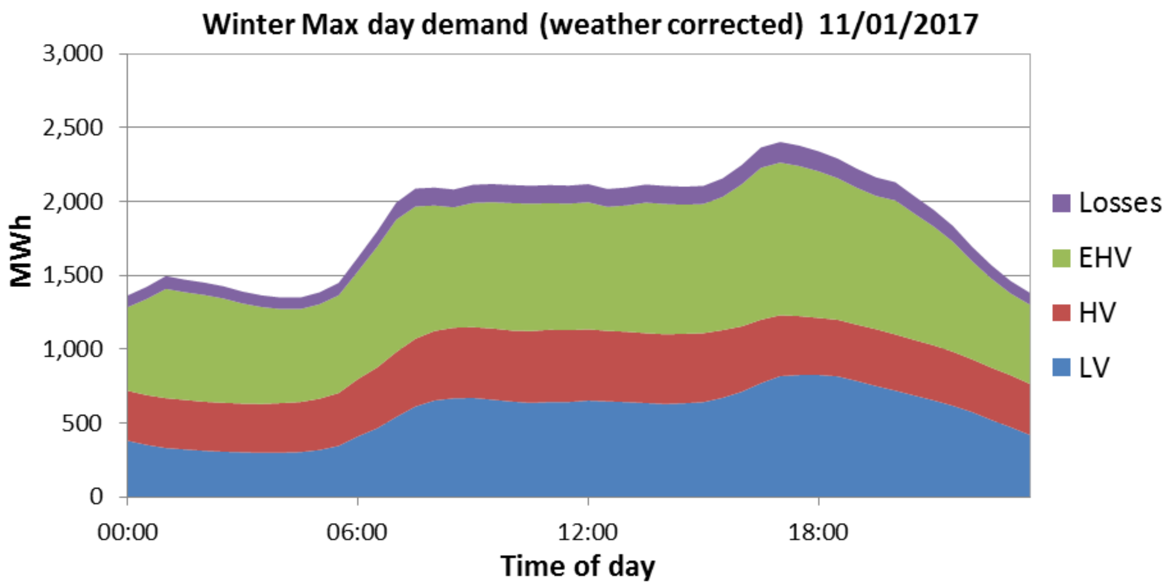

Figure 3: Typical winter day energy usage profile, MWh per half hour

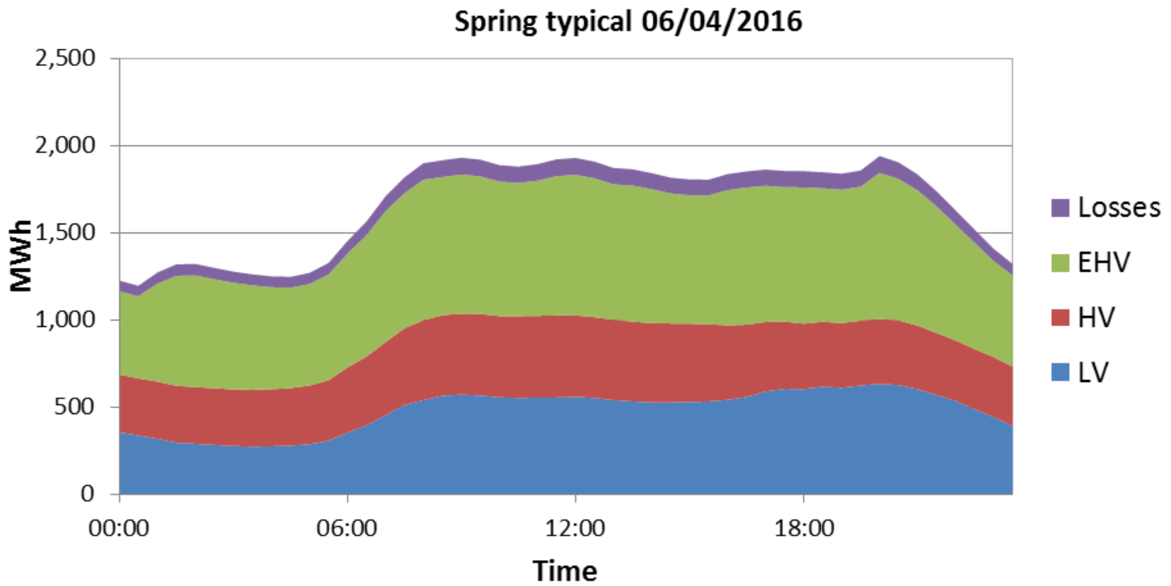

Figure 4: Typical spring day energy usage profile, MWh per half hour

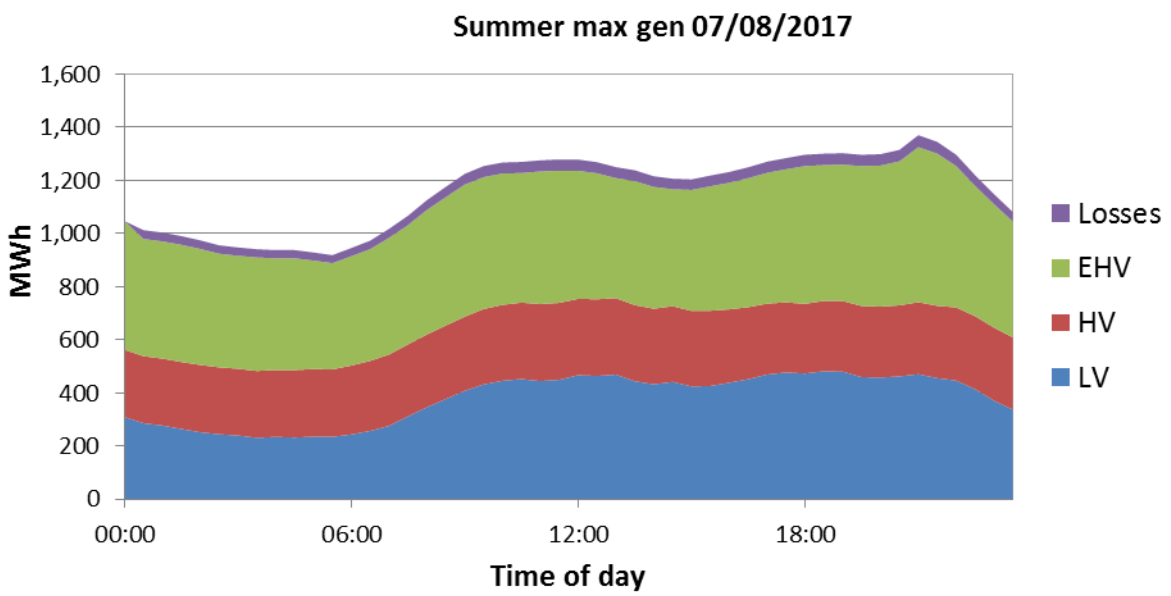

Figure 5: Typical summer day energy usage profile, MWh per half hour

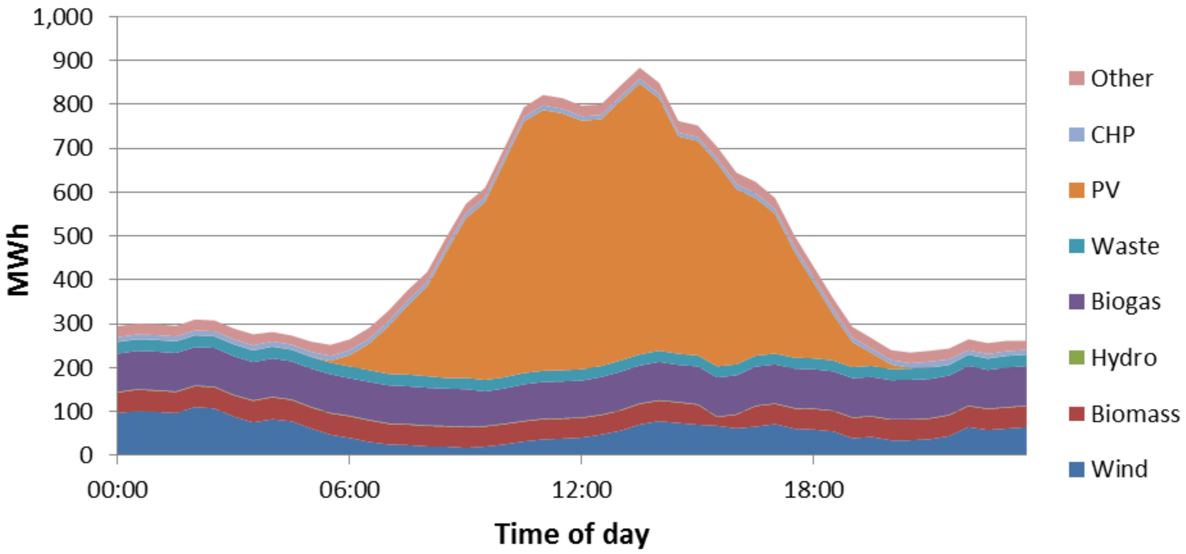

Figure 6: Breakdown of summer day generation mix by technology, MWh per half hour, 07/08/2016

The results in Figure 3, Figure 4 and Figure **5** show the demand on the HV network is relatively constant through the daily and annual period. The LV network demand is highest during the winter peak demand and lowest in summer. In winter, the daily peak demand tends to occur in the evening hours (17:00-19:00). The losses are calculated as a percentage of the total take, based off the DPRC4 losses calculation for that month. Total network losses vary between 3% and 6% depending on the time of year and network loading.

Figure 6 shows the output of the distribution connected generation for the 24 hour period of 07/08/2016. This shows that whilst many of the generation technologies have reasonably static outputs, the intermittent technologies can vary significantly and dominate the overall output.

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 Demand Side Response (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

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 wind generation supported by various subsidy arrangements, and a few large gas turbine connections.

In addition, NGET have developed various contracted services which has led to the growth in diesel and gas fuelled distribution connected plant to provide these services, generally being required to operate at or around times of peak national demand. Since around 2010, there has been a significant growth in solar Photovoltaic (PV) connections, both in the volume of small roof top systems and large, MW scale, ground mounted systems. More recently 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 East 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 East Midlands at the end of May 2017

Generator type	**Connected [MVA]**	**Accepted [MVA]**	**Offered [MVA]**	**Total [MVA]**
Photovoltaic	1,248.3	490.8	37.6	1776.7
Wind	591.6	116.8	41.5	749.9
Landfill Gas, Sewage Gas, Biogas and Waste Incineration	237.1	65.7	21.2	324
Combined Heat and Power (CHP)	151.8	36.8	1.2	189.8
Biomass and Energy Crops	85.4	102.9	9.9	198.2
Hydro, Tidal and Wave Power	1.9	2.0	1.1	5
Storage	0	218.5	271.6	490.1
All Other Generation	991.6	994.2	441.6	2427.4
Total	**3307.7**	**2027.7**	**825.7**	**6161.1**

Issues resulting from the growth of DG and demand in East Midlands to 2017

Distribution network constraints

Some parts of the East 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 Corby BSP and Skegness BSP. Further ANM zones are open to application in the networks associated with Northampton BSP and Horncastle primary substation..

In addition, the reinforcement of networks including the circuits between Grendon GSP and Corby BSP and 132kV running arrangements at Tamworth and Bourne BSPs is planned in response to projected demand growth.

Transmission network constraints

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

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

Individual SoW applications have been made to NGET for Grid Supply Points in East 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 Staythorpe GSP areas will be required to participate in an ANM scheme to manage reverse power flow through the Super Grid Transformer.

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

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

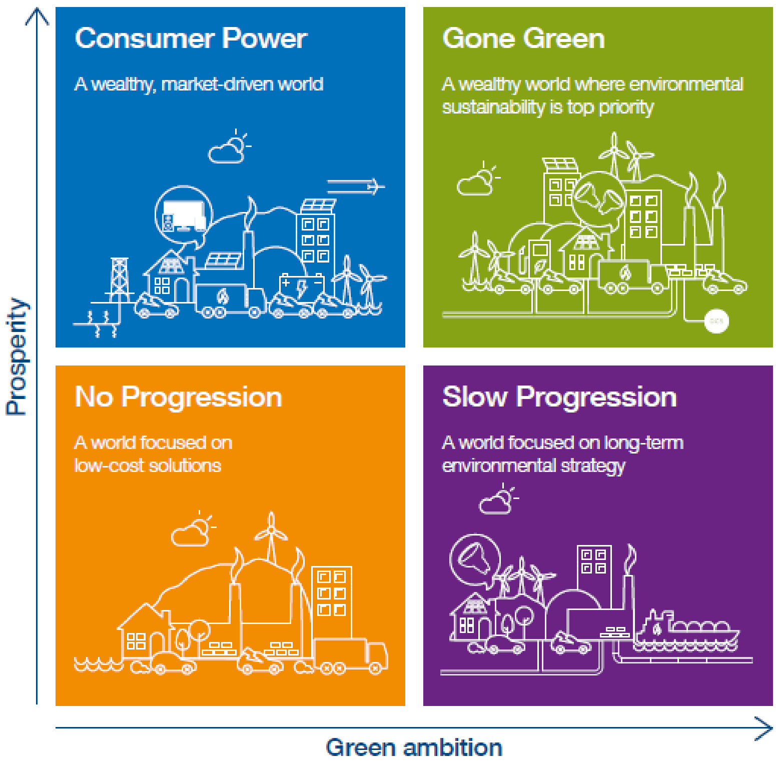

Figure 7: National Grid's Future Energy Scenarios[1]

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

These scenarios are named after and correspond to those developed by National Grid in the FES. 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 2016 to 2030.

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

Key Distributed Generation, storage and demand technologies assessed	

Electricity Generation Technologies
• Solar PV – ground mounted
• Solar PV – roof mounted
• Onshore wind – large scale
• Onshore wind – small scale
• Anaerobic digestion – electricity production
• Hydropower
• Energy from waste (EfW)
• Offshore energy:
  - Offshore wind
  - Wave energy
  - Tidal stream
	New Demand Technologies
	• Electric vehicles
	• Heat pumps (domestic)
	Conventional Demand Technologies
	• Domestic
	• Industrial and Commercial (I&C)
	Energy (electricity) storage
	• I&C behind the meter
	• Domestic and community own use
	• 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 September 2016 with a high degree of accuracy;
2. Pipeline – WPD's database of Accepted-not-yet-Connected DG was combined with an assessment of the BEIS Renewable Energy Planning Database, current market conditions and recent policy changes, to give a forecast shared between all scenarios of what is expected to connect by 2017 or 2020 depending on technology; and
3. Scenario projection – each FES scenario was assessed and interpreted to take into consideration the specific local resources, constraints and opportunities for that technology in WPD's East 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 2016 to 2030.

Conventional Demand Forecasting

As the East Midlands was highlighted as a licence area with higher levels of proposed demand growth than in previous South West and South Wales studies, 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 East Midlands study, Regen and Western Power Distribution hosted a demand stakeholder engagement event to gain feedback from local authorities. The forecast data did not include a pipeline; instead the forecasts were based on two different scenarios from 2016 to 2030. The two scenarios chosen were based wholly on the 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 East Midlands licence area was divided into 119 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); or
- A customer directly supplied at 132kV or by a dedicated BSP.

The BSP ESAs are shown geographically in Figure 8. Additional ESAs outside the East Midlands licence area have been included to represent area of neighbouring licence areas which interconnect with the Subtransmission network. These include;

- Buxton BSP, which is located in Electricity North West's Stalybridge GSP area but supplies a geographic area in the north west of the East Midlands licence area and north east of WPD's West Midlands licence area;
- Banbury BSP in WPD's West Midlands licence area. Banbury is supplied from East Claydon GSP in the East Midlands licence area.
- Ten ESAs in the Eastern Power Networks licence area covering the Peterborough, Walsoken and March area; which are supplied from Walpole

GSP. UKPN and WPD agreed to a data sharing agreement as a similar project is being undertaken by UKPN.

Figure 8: Geographical ESAs

Scenarios were developed for each ESA, taking into account historic and planned DG developments, local industry, population and natural resources.

The results of the assessment are presented in each of the technology chapters in the Regen report and provide a projection of annual capacity deployment, by technology and scenario, for the period from 2016 to 2030. The complete Regen report, *Distributed generation and demand study -Technology growth scenarios to 2030, East Midlands licence area* is available from our website at: https://www.westernpower.co.uk/About-us/Our-Business/Our-network/Strategic-network-investment/East-Midlands.aspx

A summary of the DG forecasts is shown in Figure 9. From the baseline capacity of circa 3,264MW in spring 2016, capacity grows to 6,653MW 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 4,924MW of DG capacity by 2030. There is a sharp rise in all scenarios between 2016 and 2017, due to the customer-proposed connection dates within the DG category 'Other Generation'. Whilst this represents a significant rise within one year, it does not affect the network studies as the network is studied at 2016, 2020, 2025 and 2030.

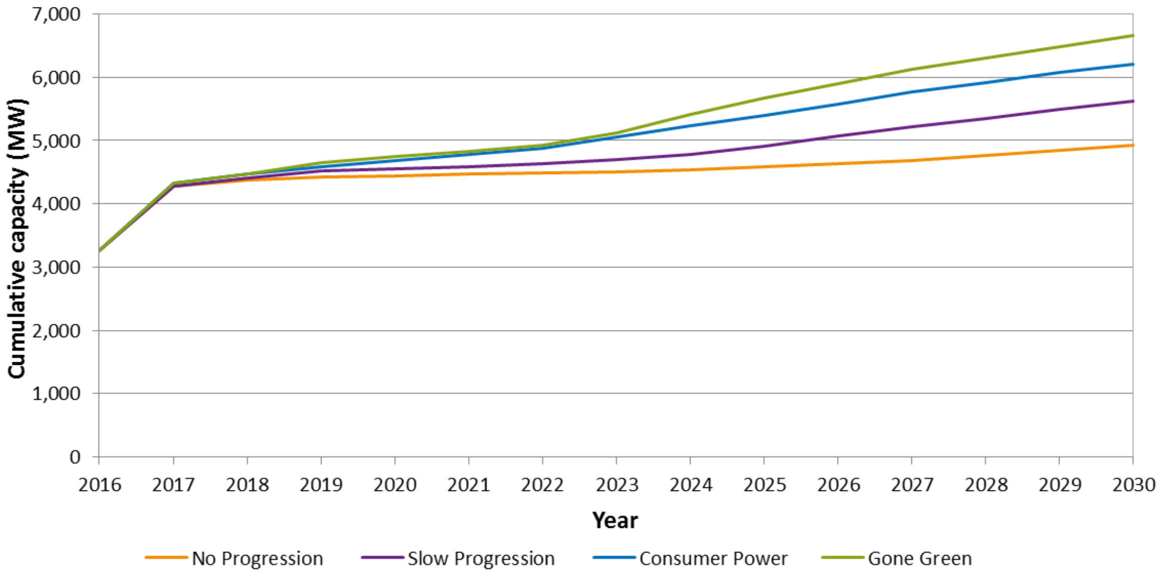

Figure 9: Total Distributed Generation capacity growth in WPD East Midlands licence area from 2016 to 2030 under each scenario

A summary of demand forecasts is shown in Figure 10. This demand growth is based on the growth of EVs and HPs and also conventional demand growth. The total demand at 2016 was around 5GW; demand is projected to increase to as much as 7.8GW by 2030, which is diversified against the peak demand at the BSP level. Figure 10 shows that the demand growth forecasts in the region are significant and may have a significant effect on the distribution network.

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.

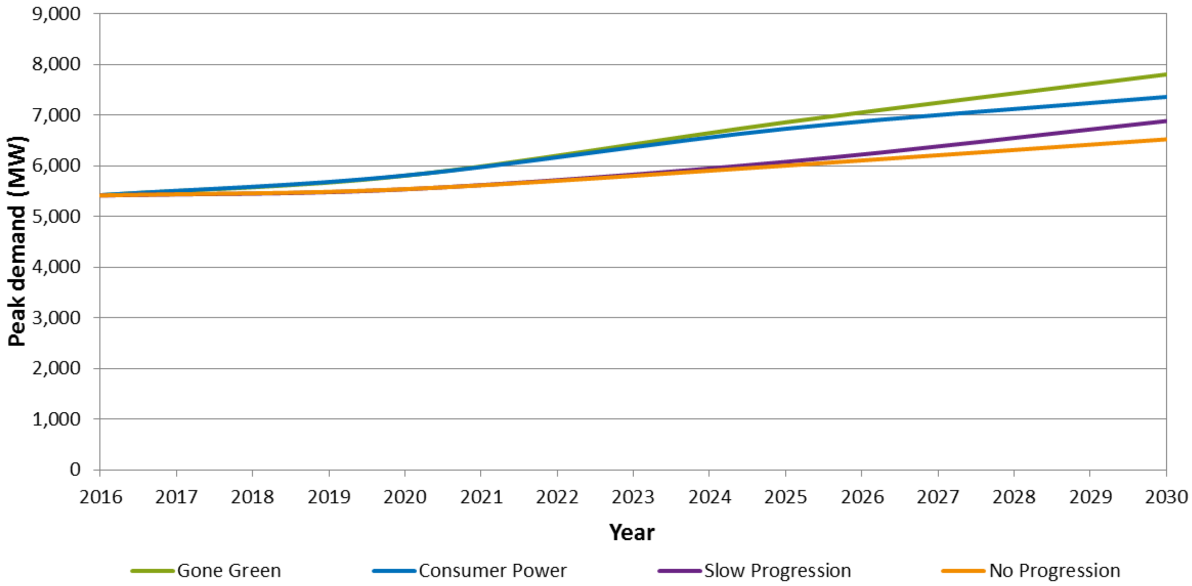

Figure 10: Total Demand growth in WPD East Midlands licence area from 2016 to 2030 under each scenario

5 – Network modelling technique and inputs

An analysis technique was devised to assess the impact of the four scenarios on WPD East 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 both demand and DG 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 for each of the four scenarios, for 2016, 2020, 2025 and 2030. To cover a range of likely onerous cases, each half-hour of three representative days was assessed for:

- **Winter Peak Demand**, with minimum coincident generation,
- **Summer Peak Generation** with minimum coincident demand, and
- **Spring/Autumn Typical** with average demand and generation for the arranged outage period.

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

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

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

Demand and Generation Profiles

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

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

- Underlying demand is measured in MW of peak demand;
- EVs and heat pumps are measured in number of units installed;

- 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 East 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 East 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 East 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, three different BSP profile types where produced to represent different levels of population density and are listed below. Each BSP was assessed against the population density in the area it supplies electricity to (its ESA).

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

Each BSP type was assessed for each representative day to make nine real and reactive power demand profiles which could be applied to the network model. These normalised profiles shown in Figure 11 through Figure 16 show the 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 particular BSP.

Demand Profiles – Methodology

The BSP demand profiles are based on measured date from 2016 and early 2017. For each of the BSP categories (urban, rural and mixed), three BSP's from the East 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	• Nuneaton • Northampton West • Bradwell Abbey
Rural	• Warwick • Checker House • Sleaford
Mixed	• Rugby 11kV • Coventry North • Whitwell

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 three 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 Generation day:** The 24 hour demand data was selected from the annual demand data for the day where the peak DG export 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.

- **Spring/Autumn Typical day:** This day was harder to select as there are no distinct behaviours in either the demand or DG output – it is a 'typical day'. To determine a typical day, the demand over a 24 hour period had to be considered. This was done by assessing the megawatt hours or total energy that passed through the BSP for a 24 hour period. For each of the days in spring and autumn the megawatt hours were calculated and the median day was selected from the annual demand data. Only data from the months March, April, September, October and November was considered. These months are defined as spring and 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.

Table 5: Dates selected for underlying demand representative days

Representative Day	**Dates**
Winter Peak Demand	• Urban - 05/01/2017 • Rural - 26/01/2017 • Mixed - 20/12/2016
Summer Peak Generation	• Urban - 12/08/2016 • Rural - 12/08/2016 • Mixed - 10/07/2016
Spring/Autumn Typical	• Urban - 12/03/2016 • Rural - 06/04/2016 • Mixed - 27/04/2016

To create demand profile curves for each BSP, a multiplying factor was applied to the normalised demand profiles. For each BSP in the East Midlands the real power demand for the 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 different BSP in the network model. These normalised profiles are shown in Figure 11 through Figure 16.

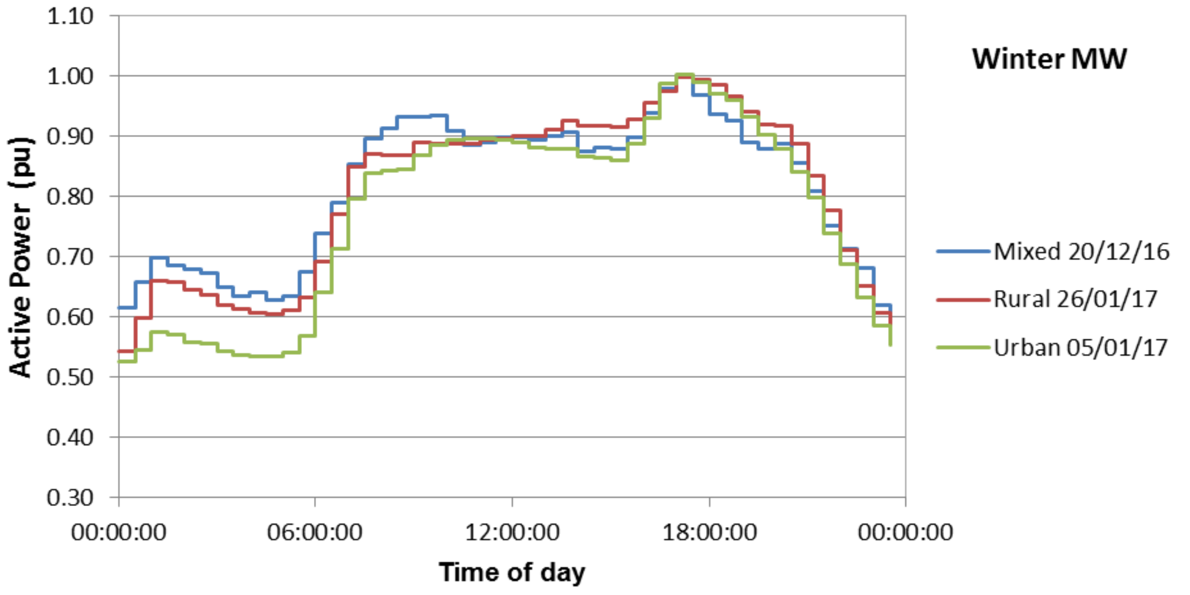

Figure 11: Real power underlying demand profiles for the Winter Peak Demand day, normalised over the peak real power annual demand

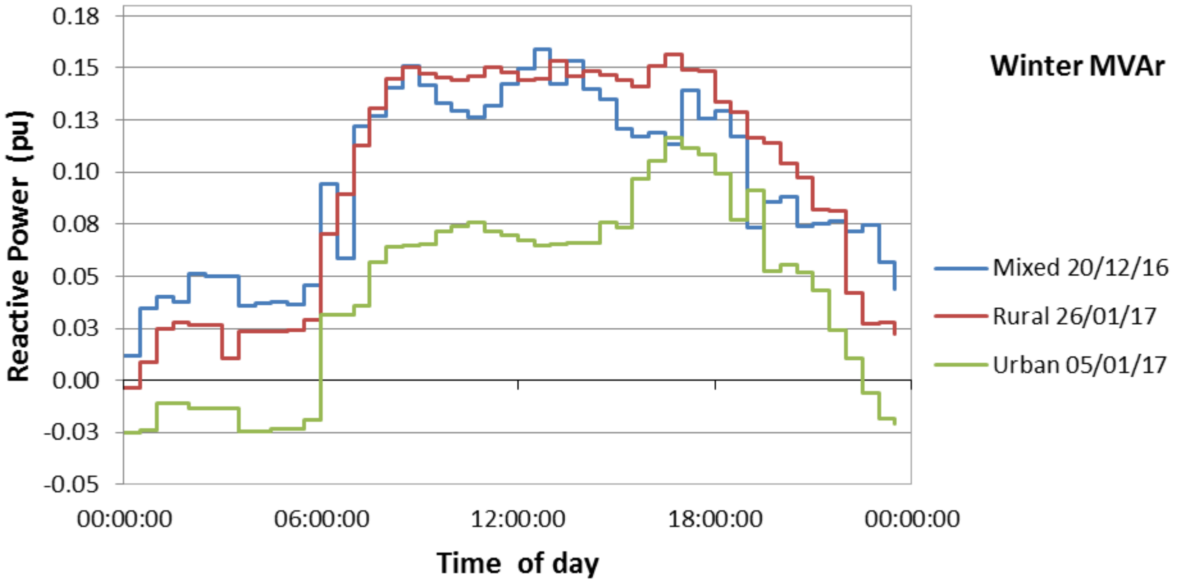

Figure 12: Reactive power underlying demand profiles for the Winter Peak Demand day, normalised over the peak real power annual demand

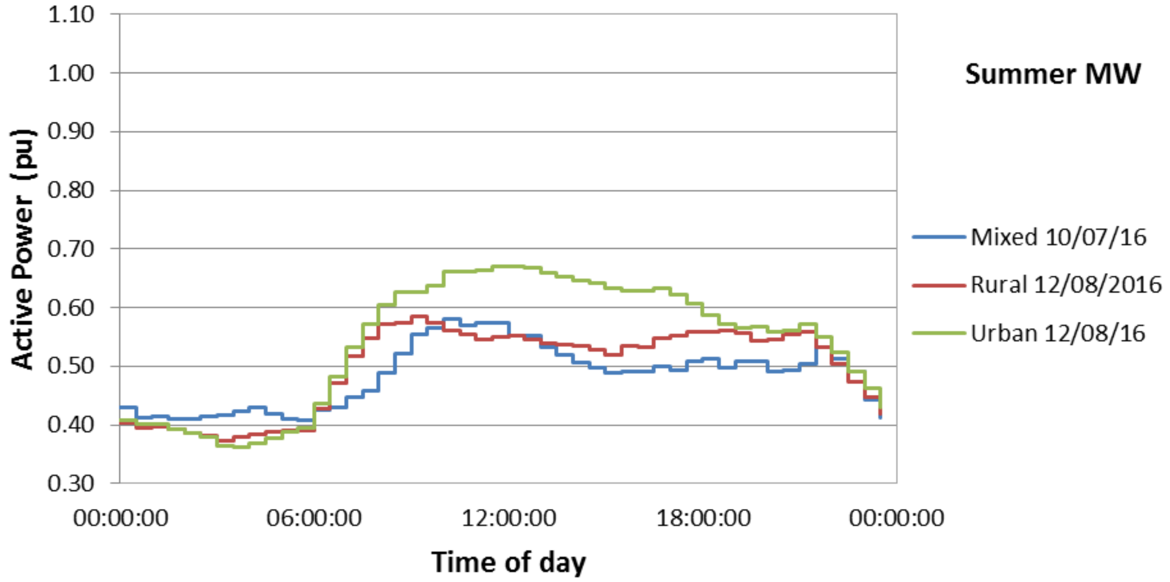

Figure 13: Real power underlying demand profiles for the Summer Peak Generation day, normalised over the peak real power annual demand

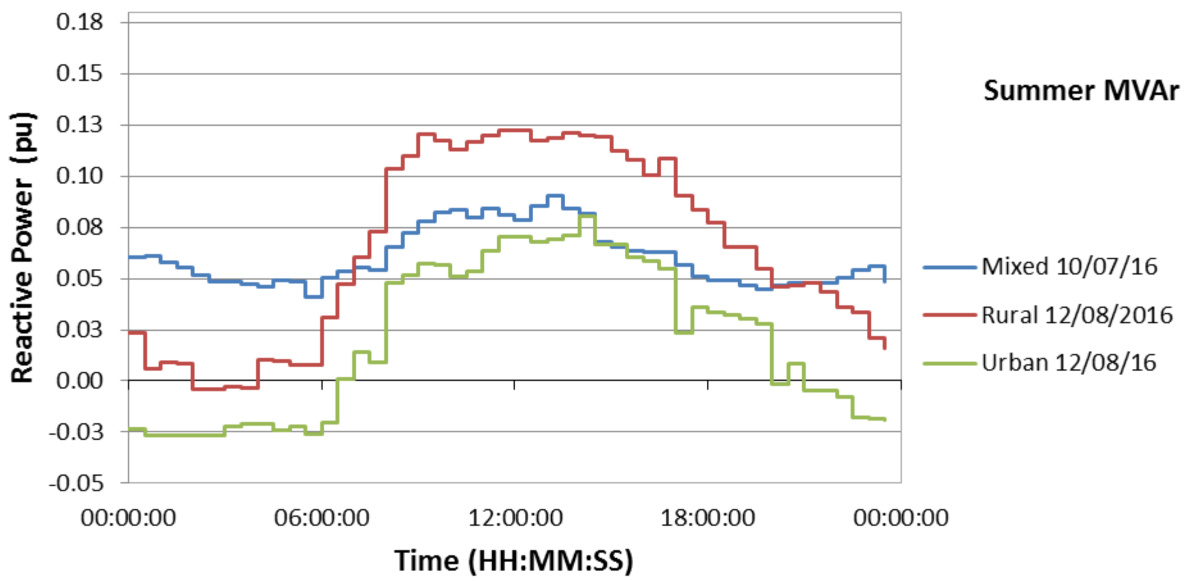

Figure 14: Reactive power underlying demand profiles for the Summer Peak Generation day, normalised over the peak real power annual demand

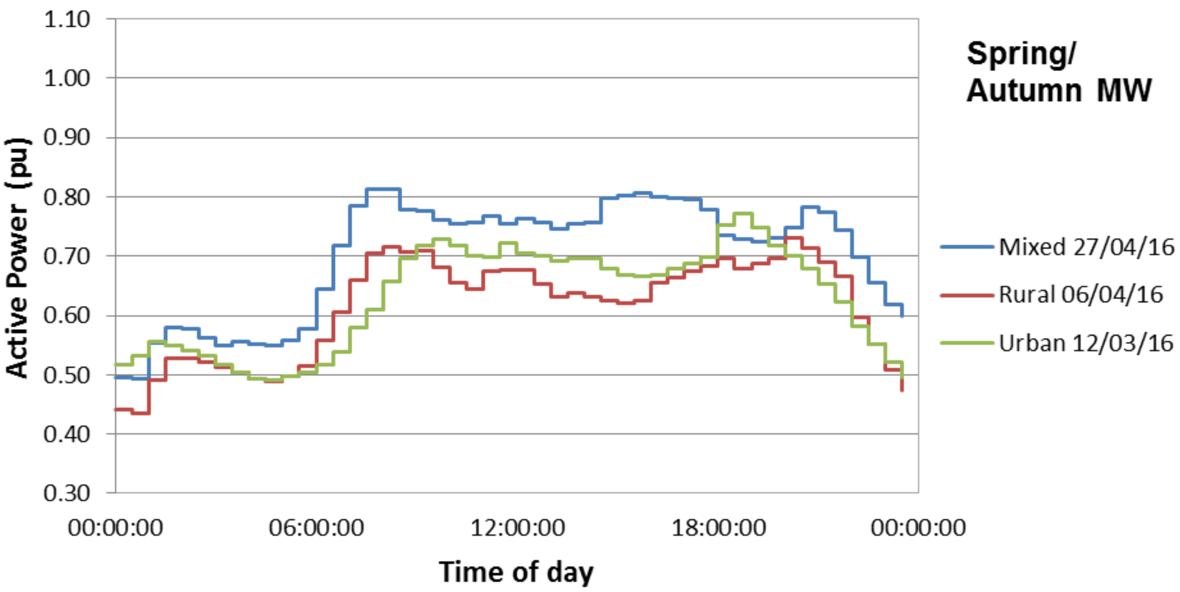

Figure 15: Real power underlying demand profiles for the Spring/Autumn Typical day, normalised over the peak real power annual demand

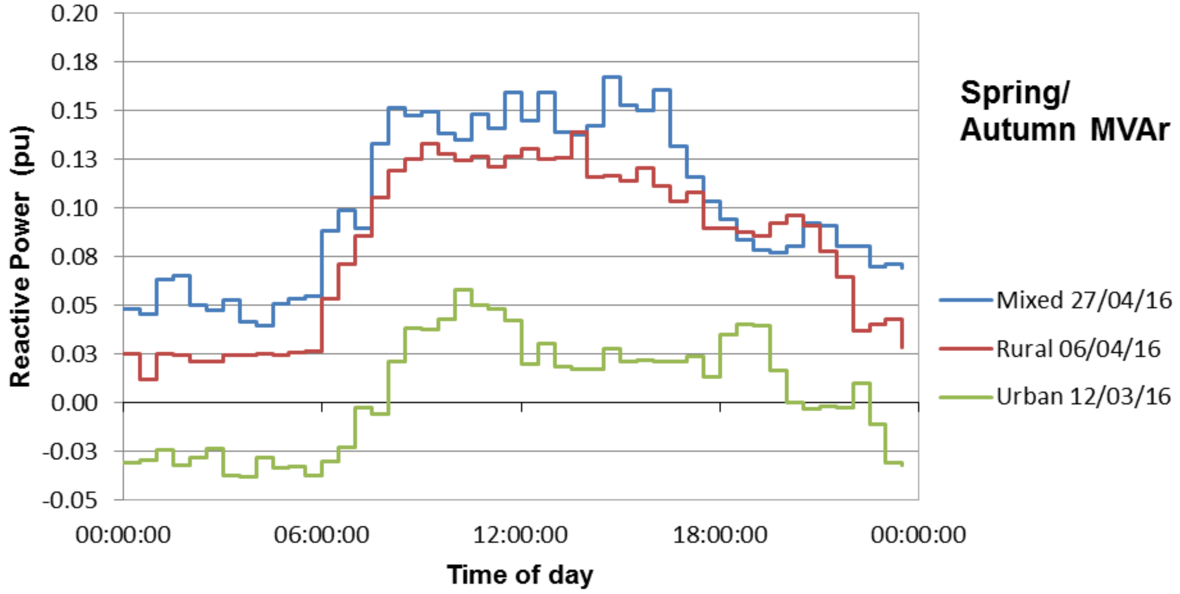

Figure 16: Reactive power underlying demand profiles for the Spring/Autumn Typical day, normalised over the peak real power annual demand

Heat Pumps

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

The study considered various types of heat pump as follows:

- Lower temperature Air Source Heat Pump (ASHP)

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

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

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

Electric Vehicles

EV charging profiles were derived from the Electric Vehicles Insight Report of the Customer-Led Network Revolution project. This was based on a trial involving 143 domestic EV owners that took place in 2014. The profiles are shown in Figure 17.

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

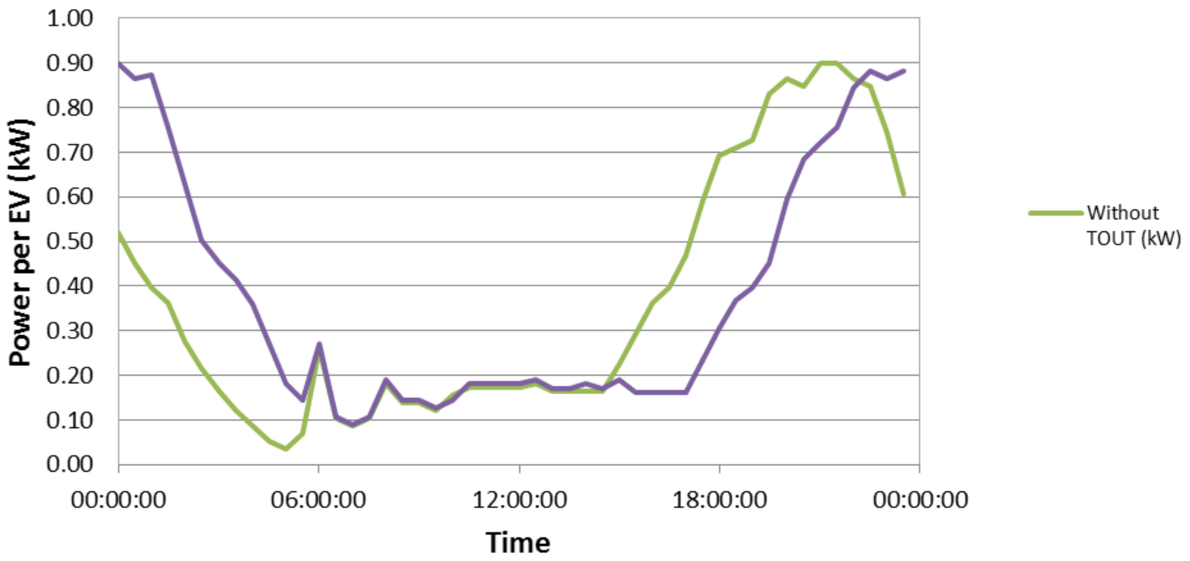

Figure 17: EV Winter Profile (per EV)

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 East Midlands strategic studies included forecasts for conventional demand growth, including domestic and 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. The domestic profile applied to the growth forecasts is based on a Class 1 Elexon domestic profile, with a seasonality factor applied to represent the three representative days studied. The seasonal profiles were taken from the ‘LV Networks Template’ innovation project run by Western Power Distribution. The domestic profiles used are shown in Figure 18.

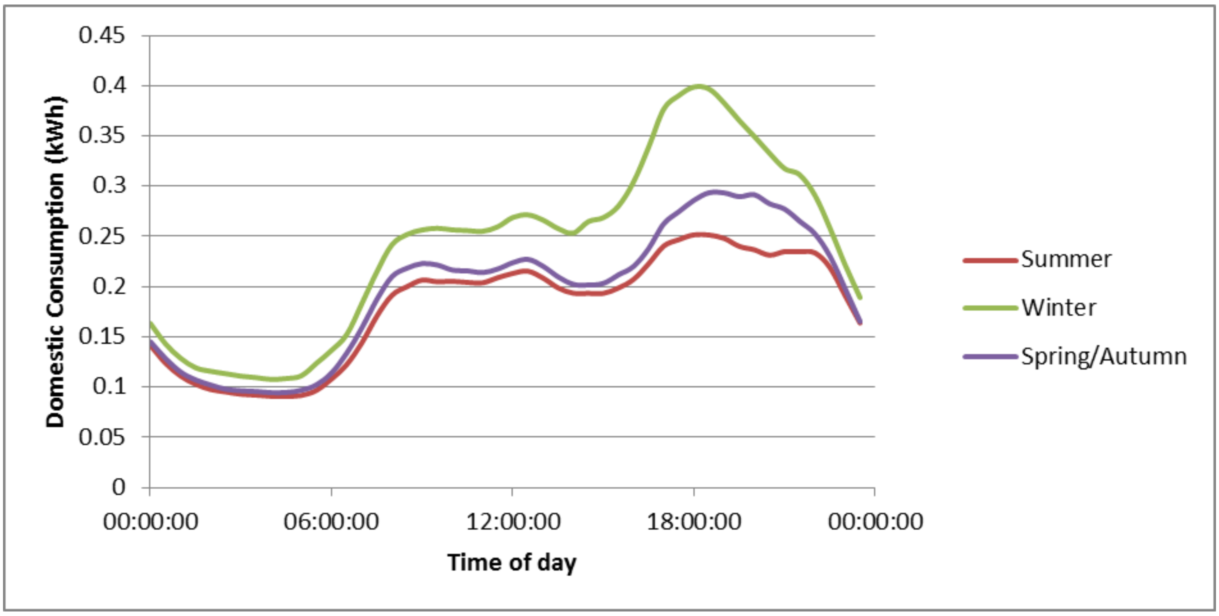

Figure 18: Domestic profile (per house, diversified to BSP level)

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 calculate the half hourly profile in kWh from the development size in m^2. Each individual development in the Regen forecast was assigned a profile and overlaid onto the network model.

The 'Modelling Demand Profiles in the I&C Sector' innovation project produced an average daily profile for each demand category. Further work was undertaken to model the seasonality of the industrial and commercial profiles orthe three representative days studied. A sample of connected customer's metering data over an annual period was examined to ascertain a scaling factor from the average daily profile to a 'summer minimum demand' and 'winter maximum demand' scenario. An example of the seasonality factors is the factory and warehouse profile shown in Figure 19. In the summer the profile used is near zero for the whole day, which could represent a factory summer shutdown, which could also coincide with the maximum generation output day. Further graphs of the profiles used for all fifteen industrial and commercial demand categories are shown in the Appendix of this report.

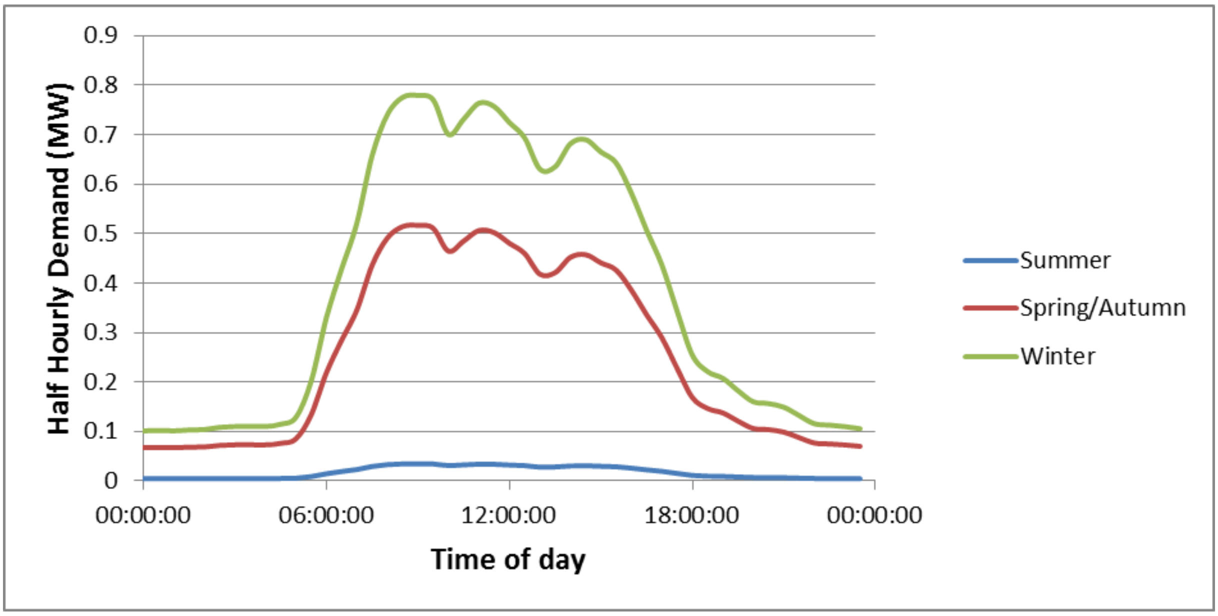

Figure 19: A typical half hourly profile used in the studies in the 'Factory and Warehouse' category of a typical size of 2000m^2, showing seasonal variation

132kV demand customers

The East Midlands networks supplies a number of large demand customers with 132kV connections or dedicated grid transformers (GTs) at WPD BSPs, 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 customers is:

- Winter Peak Demand day: continuous demand at agreed supply capacity,
- Summer Peak Generation day: zero demand, and
- Spring/Autumn Typical day: continuous demand at 20% of agreed supply capacity.

Generation Profiles

Profiles for Solar PV, Onshore Wind and Offshore Wind generation were derived from the measured output of existing generators connected to the East Midlands network. The other profiles were derived from various sources as described below. A particular focus was placed on the Solar PV and Onshore Wind due to the high level currently installed on the network and forecast out to 2030 under all scenarios.

Solar PV

Real power output data from all Solar PV generation sites in the East Midlands licence area was collected and aggregated by each half hour for 2016 and early 2017. Only PV sites with an installed capacity greater than or equal to 1 MW were considered. The PV generator data sample comprised 138 sites, with an installed capacity of 950MW. The geographical spread of solar PV sites in the data sample is shown in Figure 20.

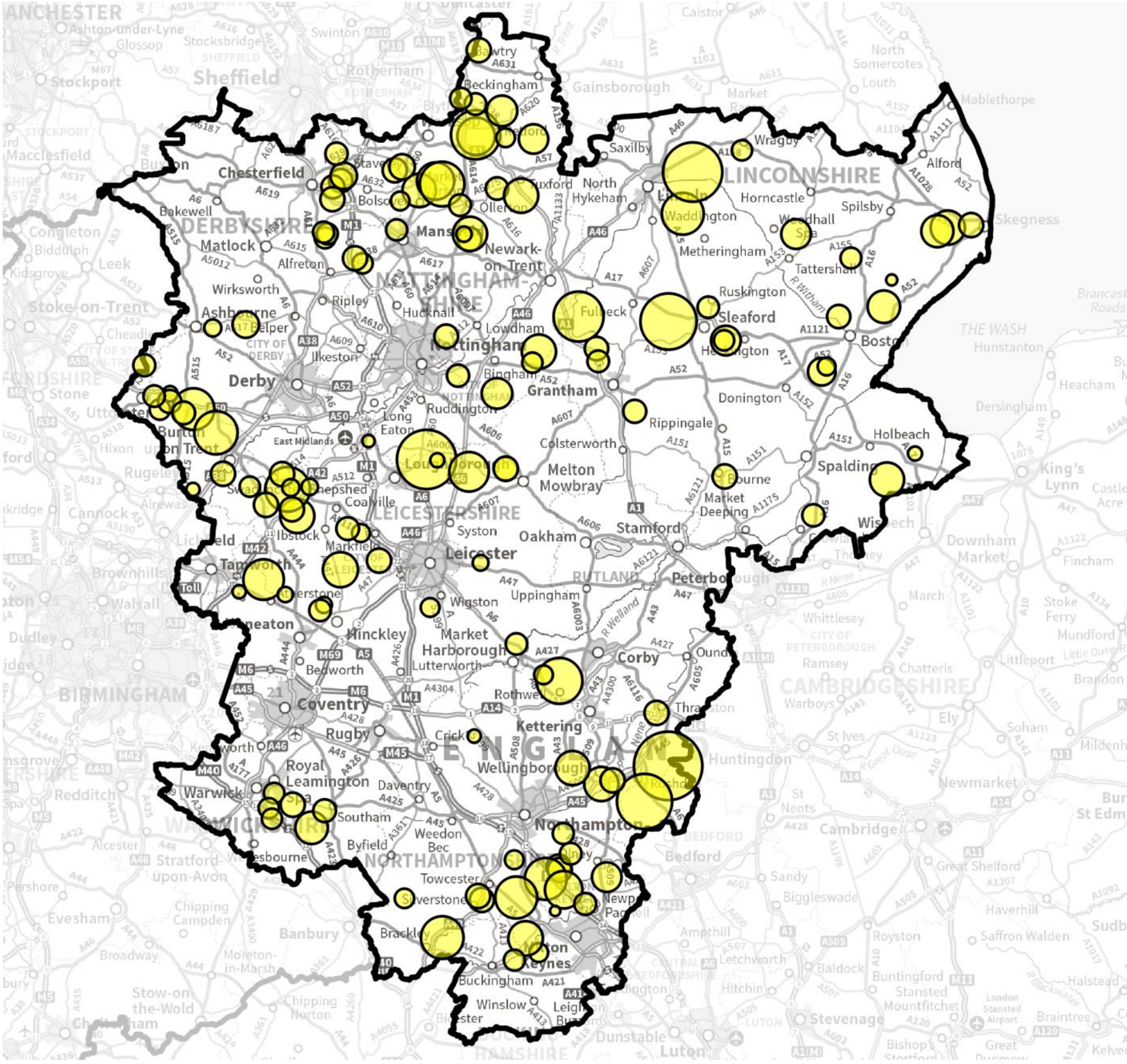

Figure 20: Map of Solar PV sites contributing to generation profiles; symbol area proportional to installed capacity [MW]

The generation output profiles are for a 24 hour period and consist of 48 data point (48 half hourly readings). Maximum, Minimum and average generation output profiles where created for each season and were normalised against the PV total installed capacity. Figure 21 shows the PV generation output profiles that were created. Finally the Generation output profiles were applied to the network model in the following way:

- The Summer Maximum profile was used for the Summer Peak Generation day;
- The Spring/Autumn Average profile was used for the Spring/Autumn Typical day; and
- The Winter Minimum profile was used for the Winter Peak Demand day.

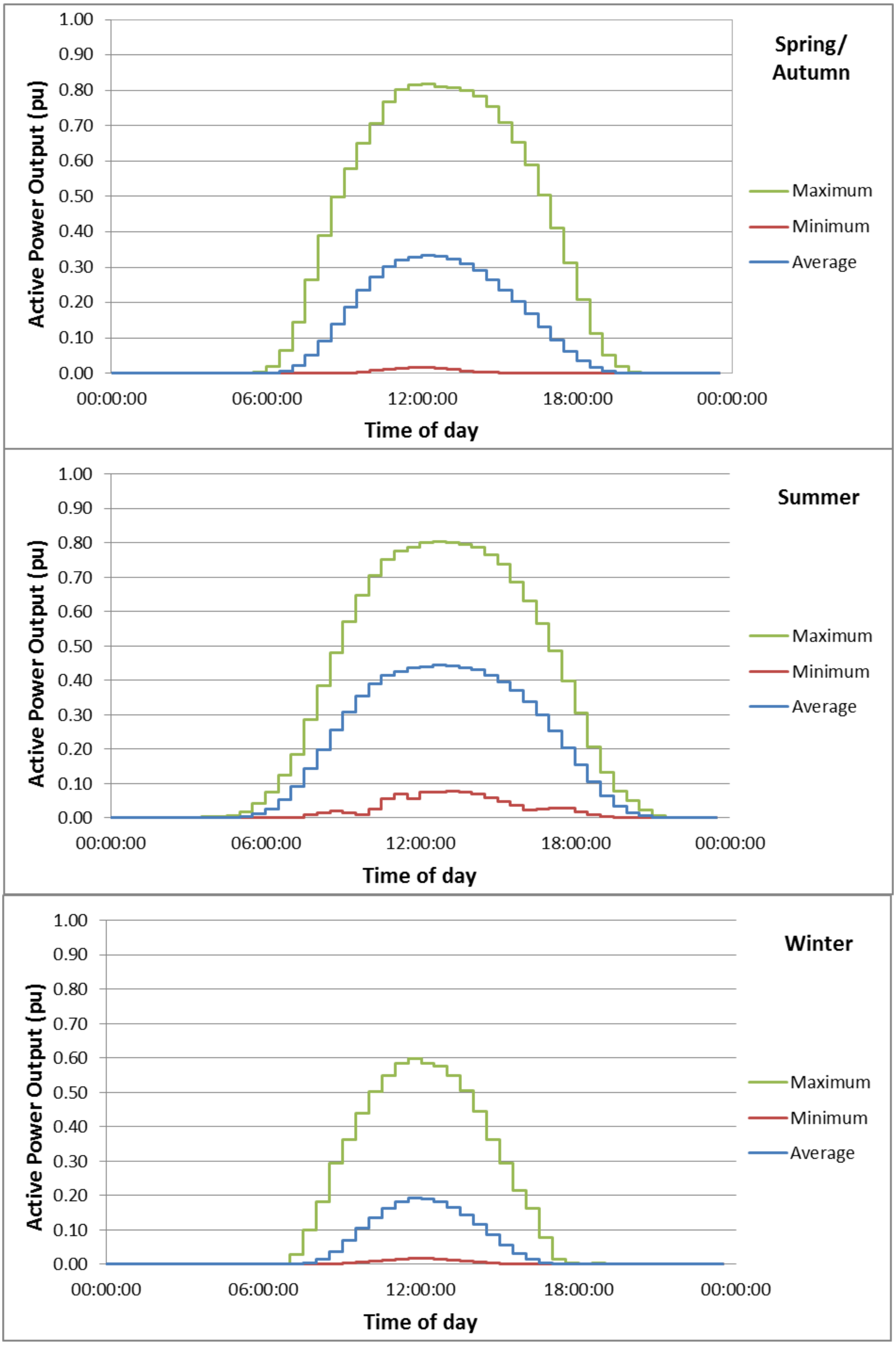

Figure 21: Normalised PV profiles based on the three representative day seasons

Onshore Wind

A similar process used for the PV was used to generate the Onshore Wind profiles. The generation output profiles, in this case solar onshore wind, were created in a similar way to the underlying demand profiles. Meter reading data from all of installed onshore wind generation sites in the East Midlands licence area was collected and aggregated by each half hour for 2016 and early 2017. Only onshore wind sites with an installed capacity greater than or equal to 1 MW were considered. The onshore wind generator data sample comprised 36 sites, with an installed capacity of 368.2MW. The geographical spread of solar onshore wind sites in the data sample is shown in Figure 22.

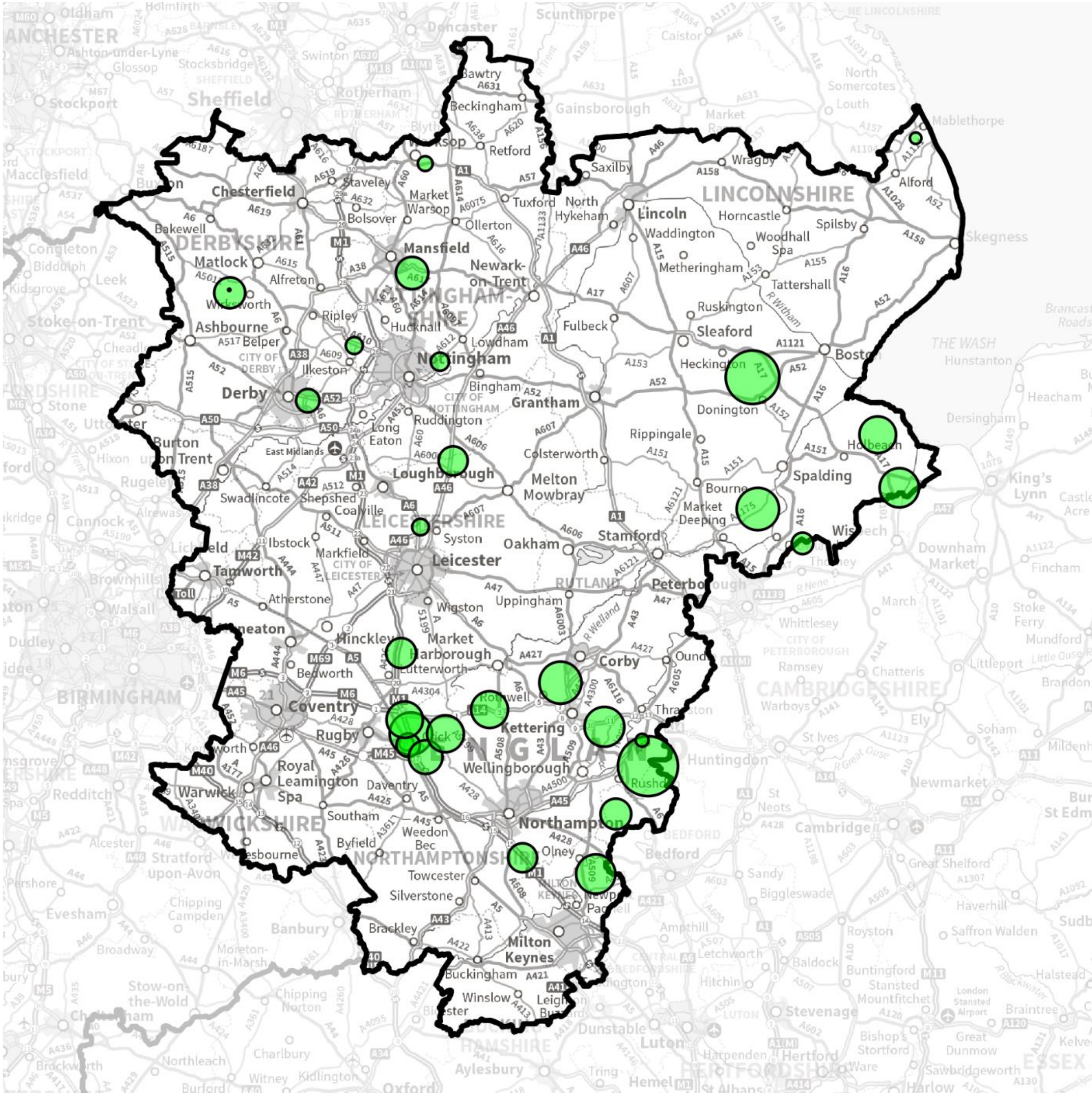

Figure 22: Map of Onshore Wind sites contributing to generation profiles; symbol area proportional to installed capacity [MW]

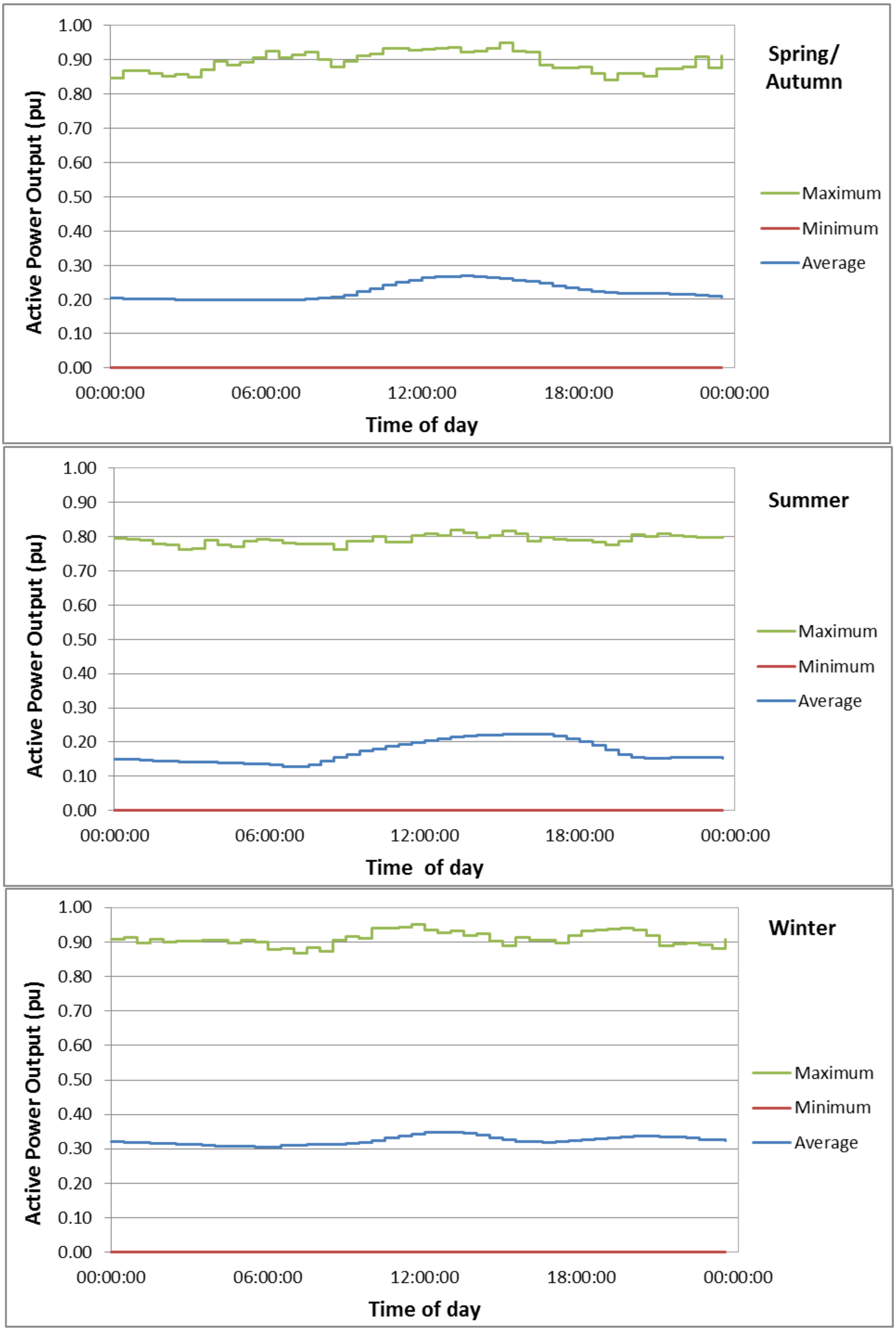

Figure 23: Normalised wind profiles based on the three representative day seasons

The generation output profiles are for a 24 hour period and consist of 48 data point (48 half hourly readings). Maximum, Minimum and average generation output profiles where created for each season and were normalised against the PV total installed capacity. Figure 21 shows the PV generation output profiles that were created. Finally the Generation output profiles were applied to the network model in the following way:

- The Summer Maximum profile was used for the Summer Peak Generation day;
- The Spring/Autumn Average profile was used for the Spring/Autumn Typical day; and
- The Winter Minimum profile was used for the Winter Peak Demand day.

Other Generation

Profiles for Offshore Wind were derived using a similar process to Solar PV and Onshore Wind.

The remaining DG types modelled were:

- Anaerobic Digestion (AD)
- Energy from waste
- Hydropower
- Other generation (non-renewable Distributed Generation)
- STOR, non-renewable Distributed Generation operating under a Short Term Operating Reserve (STOR) contract or other similar contract

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

STOR

- Summer Peak Generation day: continuous output at installed capacity;
- Winter Peak Demand day: zero output;
- Spring/Autumn Typical day: continuous output at 0.2 times installed capacity.

All other types

- Summer Peak Generation day: continuous output at installed capacity;
- Winter Peak Demand day: zero output;
- Spring/Autumn Typical day: continuous output at 0.8 times installed capacity

Fault Level modelling

One of the main drivers for network reinforcement and running arrangement restrictions in the East Midlands is fault level. Fault levels must be managed carefully to ensure that:

- Switchgear and other equipment are not overstressed and at risk of failure during faults;
- Protection schemes operate correctly in the event of faults;
- Dangerous voltages do not occur during earth faults; and
- Customers do not receive poor power quality.

Of these, switchgear overstressing is the most common driver for fault level-related reinforcement. Switchgear overstressing can be resolved by reducing fault levels (usually by changing network running arrangements) or by increasing plant ratings (usually by replacement, but sometimes by modification). Switchgear stressing is assessed both periodically and for all new demand, generation and storage connections.

Fault levels are usually calculated using specialist network analysis software. There are several analysis routines applied to different fault level problems. Fault levels for the determination of switchgear stressing are calculated in accordance with Engineering Recommendation G74, *Procedure to Meet the Requirements on IEC 909 for the Calculation of Short-Circuit Currents in Three-Phase AC Power Systems*. G74-compliant analysis has stringent data requirements and is computationally intensive.

For these studies, a simpler steady-state three-phase fault analysis routine was used to calculate a high-level overview of how fault level could change out to 2030 under the four scenarios. The stressing of individual network components was not assessed. The studies assumed that the fault infeed from the transmission network did not change over time; at and near GSPs changes in transmission infeed normally dominate switchgear stressing assessment. Instead the studies concentrated on how contribution to fault level from distribution-connected generation and demand.

Studies were run for intact network conditions only, taking into account changes in network topology due to reinforcement. Only three-phase faults were assessed, some networks are constrained by single-phase-to-earth rather than three-phase fault levels. Generic fault infeed assumptions were determined for each type of existing and forecast demand and generation. All networks at 33kV and below were deenergised, with the demand and generation fault infeeds modelled at BSP 33kV and 11kV bars. This increases their contribution to 132kV fault levels.

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 9 – Definitions and references.

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

A map of the geographic area supplied by each GSP is included with the 2020 results for that GSP.

2016

In 2016 all four scenarios are identical, representing the demand and DG connected to the network as of 2016. The 2016 studies were used to benchmark the future years. The 2016 results did not reveal any network deficiencies, but they did highlight that, during planned outages, several areas of the East Midlands 132kV network are reliant upon pre-fault transfers to prevent the overload of SGTs and circuits from GSPs to remote 132kV bussing points.

Post-fault Corrective Actions

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

2020

Between 2016 and 2020, the growth in generation is dominated by the pipeline of Accepted-not-yet-Connected generators, with very little difference between scenarios. Demand growth is dominated by new housing, industry and commercial premises; Gone Green and Consumer Power show significantly stronger growth than Slow Progression and No Progression.

Berkswell GSP

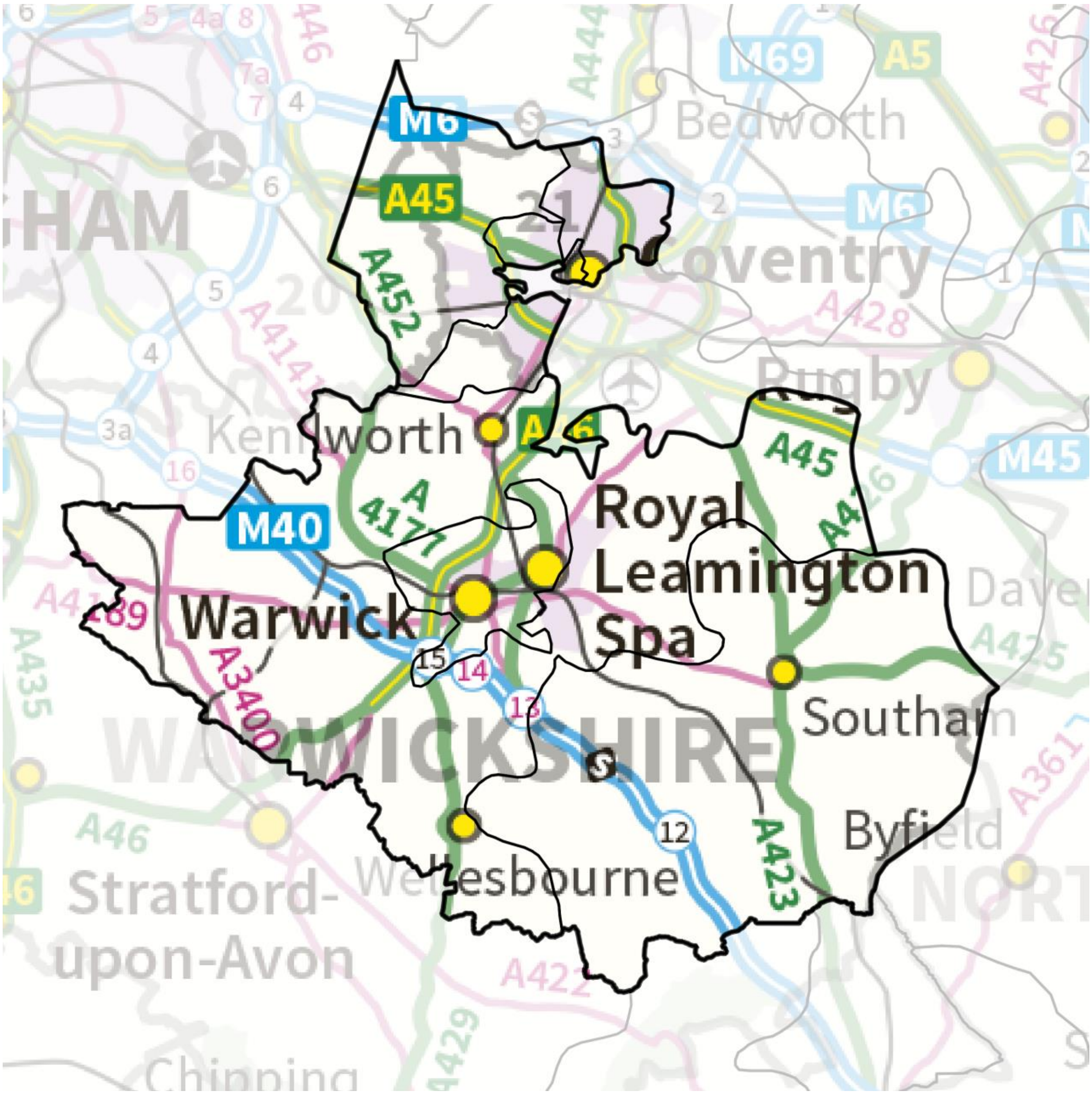

Figure 24: Area supplied by Berkswell GSP

SGT capacity

GG CP SP NP

Berkswell GSP has three SGTs, and is normally operated split into two sections to keep fault levels within plant ratings:

1. SGT1 and SGT2 supply main bar sections 1 and 2
2. SGT3 supplies reserve bar sections 1 and 2

The two bar sections are remote-coupled at 132kV by the 132kV mesh at Warwick, and loose-coupled by the 33kV and 11kV bars of other BSPs supplied from Berkswell.

An arranged outage of one SGT at Berkswell, followed by a fault outage of a second leaves the remaining SGT supplying all of Berkswell. Demand growth to 2020 overloads the remaining SGT. It is possible to transfer Coventry South BSP 33kV and Coventry West BSP onto Coventry GSP via Whitley BSP at 132kV. To prevent overloading of the remaining SGT, the transfer should be made as part of the arranged outage of the first SGT. If a Coventry/Whitley/Coventry South 132kV circuit were to fault while Coventry South BSP 33kV and Coventry West BSP were transferred, the remaining circuit would overload on the HK-route between Coventry GSP and Whitley BSP.

It is recommended that the existing 175mm² ACSR (Lynx) conductor on the HK-route between Coventry GSP and Whitley BSP is replaced with 300mm² AAAC (Upas) profiled for operation at 75°C. Cable sections should be overlaid as necessary to allow full use of the increased rating of the overhead sections; it may be possible to defer the overlay of some cable sections under Slow Progression and No Progression. Alternatively, a fourth SGT could be established at Berkswell GSP to reduce the transfer requirement; the results for 2025 suggest that the fourth SGT will eventually be required despite load transfers and the reinforcement of the HK-route.

WPD has an ongoing innovation project, Project ENTIRE, focusing on the use of Demand Side Response (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. Berkswell GSP is included in Project ENTIRE. For more information on Project ENTIRE visit https://www.westernpowerinnovation.co.uk/Projects/Current-Projects/Project-ENTIRE.aspx

Harbury BSP

Both 22.5/45MVA GTs at Harbury BSP are currently being replaced with 60/90 GTs to provide sufficient capacity for new demand connections.

Bicker Fen GSP

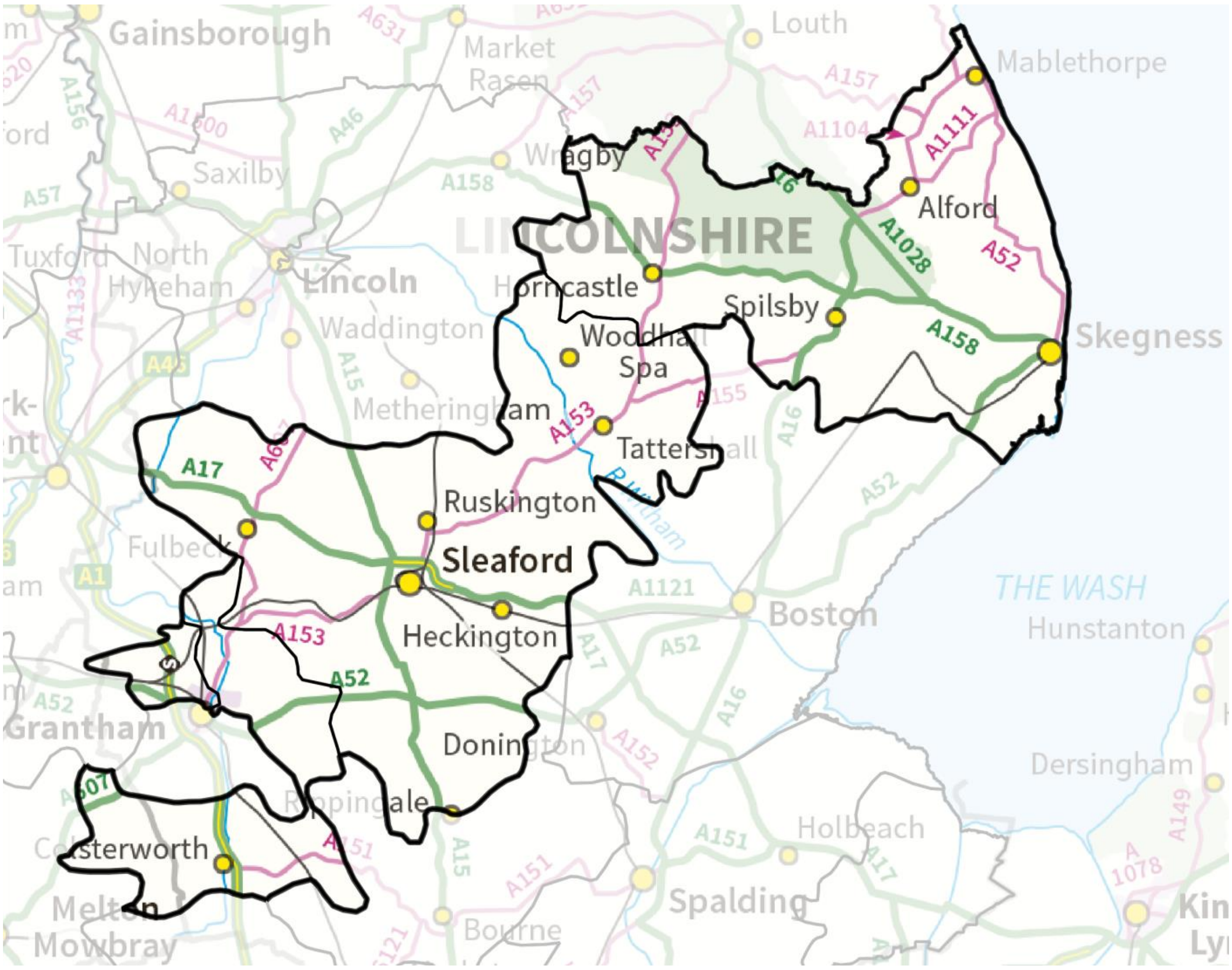

Figure 25: Area supplied by Bicker Fen GSP

No reinforcement requirements were identified in the 2020 scenarios.

Chesterfield GSP

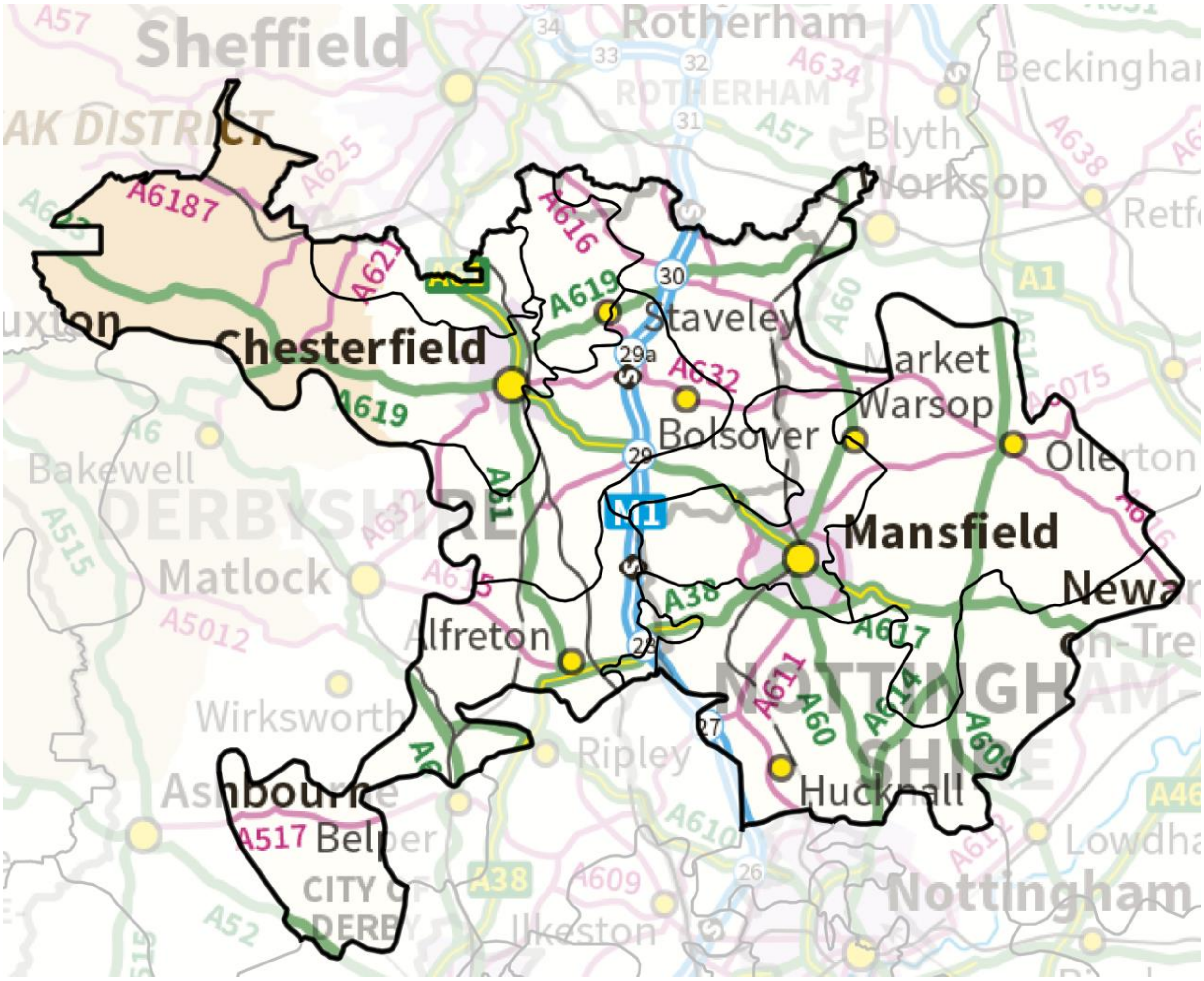

Figure 26: Area supplied by Chesterfield GSP

Alfreton BSP

GG CP SP NP

Alfreton BSP has two 30/60MVA GTs. The arranged or fault outage of either GT leaves all of Alfreton supplied by the remaining GT. The growth of generation to 2020 overloads the remaining GT, as shown in Figure 27.

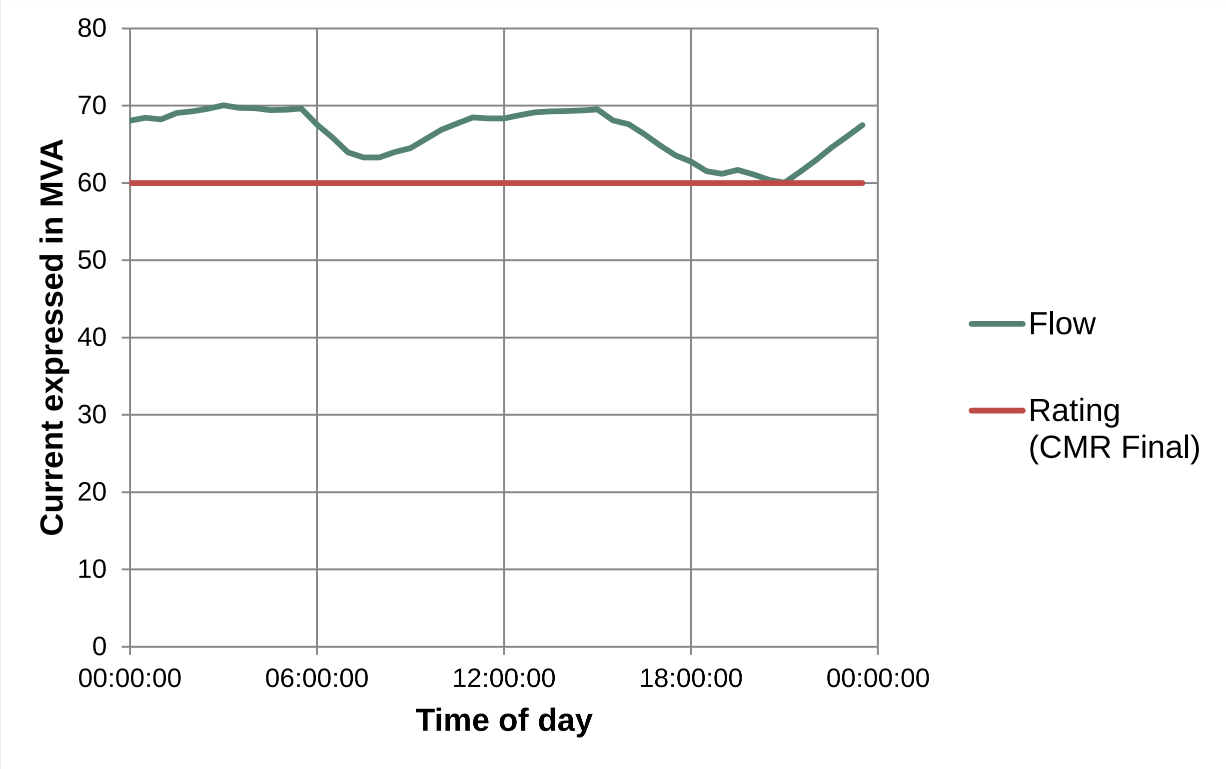

Figure 27: Summer Peak Generation day flow through Alfreton GT1 during outage of Alfreton GT2, Gone Green 2020.

It is recommended that both GTs at Alfreton BSP are replaced with 60/90MVA units.

Clipstone BSP

Clipstone BSP has two 132/33kV 45/90MVA GTs, GT1 and GT2. A third GT is planned to be commissioned, double-banked with GT2 at 132kV, to supply new generation connections in the vicinity of the BSP separately from the existing Clipstone 33kV network.

Coventry GSP

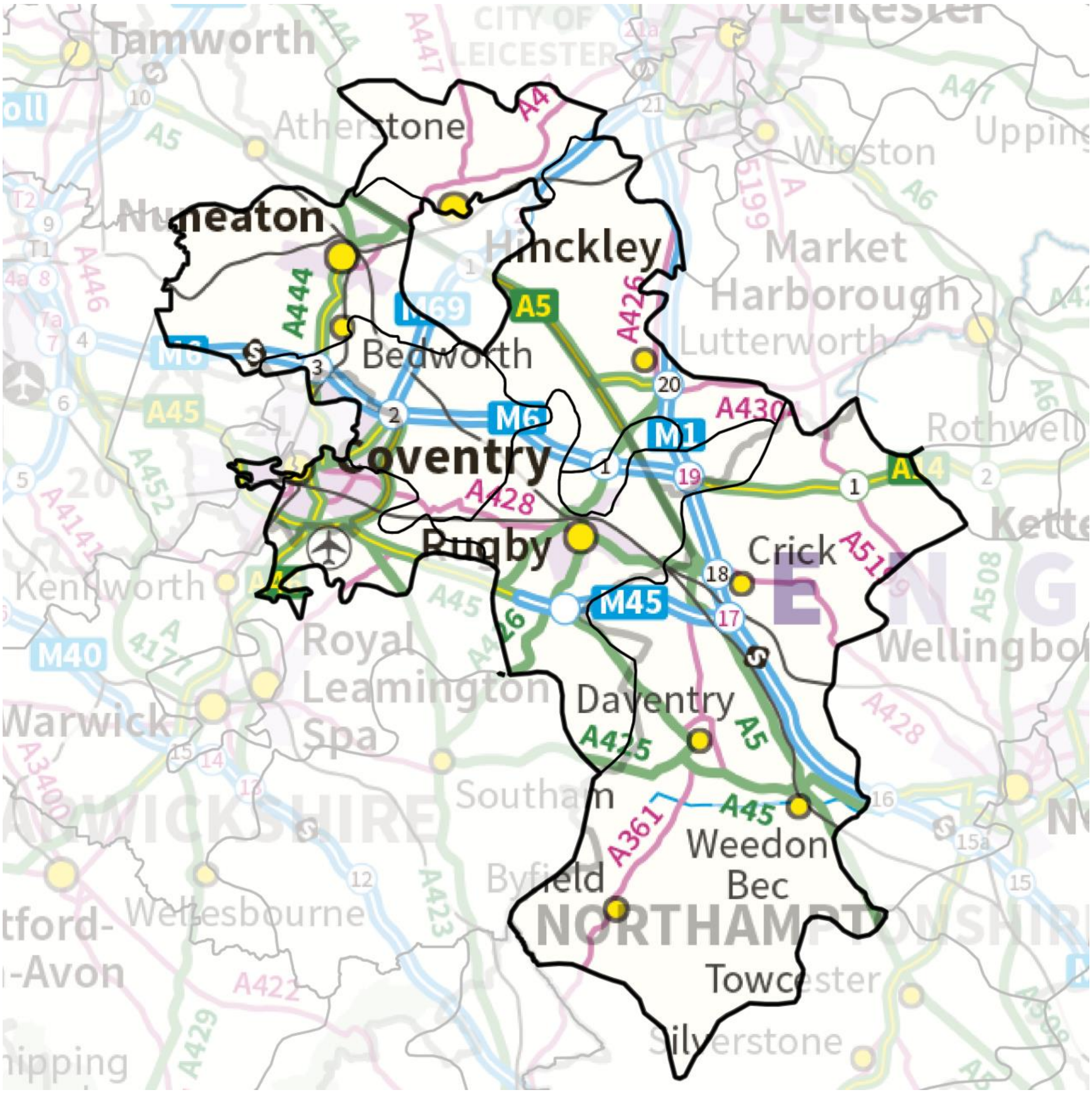

Figure 28: Area supplied by Coventry GSP

SGT capacity

GG CP

Coventry GSP has four SGTs, and is normally operated split into two to keep fault levels within plant ratings:

1. SGT1 and SGT2 supply main bar sections 1 and 2
2. SGT3 and SGT4 supply reserve bar sections 1 and 2

There is a section breaker 120 between main bar sections 1 and 2, but no section breaker between reserve bar sections 1 and 2. This means that a fault on either reserve bar section results in both being deenergised, with all Coventry supplied by

SGT1 and SGT2. Demand growth to 2020 under Gone Green and Consumer Power overloads SGT1 and SGT2 in this condition.

It is recommended that a section breaker 160 is installed between reserve bar sections 1 and 2 at Coventry GSP. A fault on either reserve bar section will only deenergise that section, leaving three SGTs in service and within their ratings.

Drakelow GSP

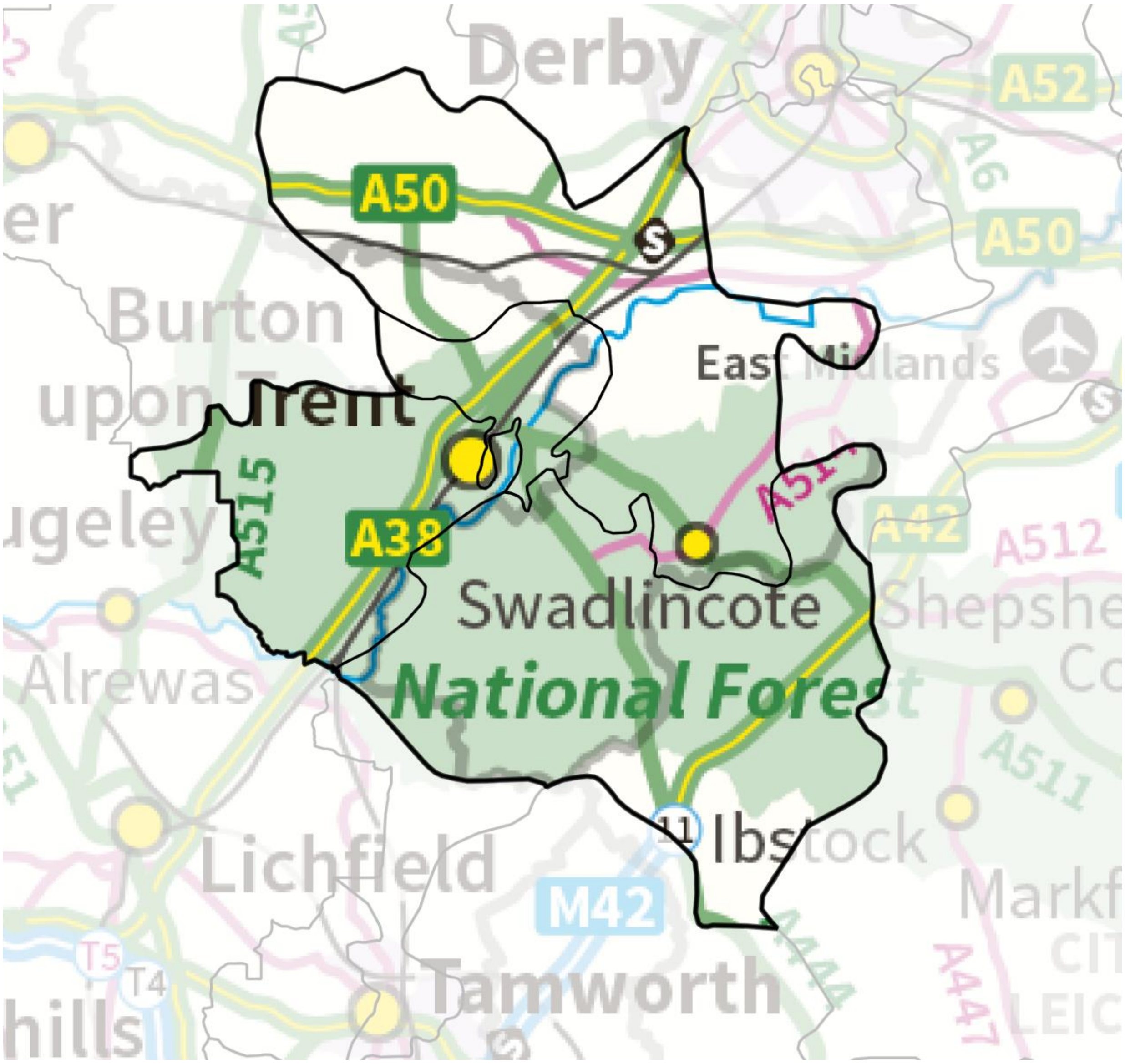

Figure 29: Area supplied by Drakelow GSP

SGT capacity

GG CP SP NP

Following asset replacement by National Grid, Drakelow GSP has only two SGTs. Under SCO of both SGTs, it is reliant on WPD's network for P2/6 compliance. A normally-open single circuit 132kV OP-route from Willington GSP to Burton BSP (normally fed from Drakelow GSP) is already available.

The normally-open single-circuit 132kV AE-route runs between Tamworth BSP (normally fed from Hams Hall GSP) and a tee from the DG-route between Drakelow GSP and Gresley BSP. The normal-open point is currently held on isolators at Tamworth BSP. This provides SCO support to Tamworth group, but not to Drakelow GSP. Tamworth BSP is currently undergoing a wider reinforcement and asset replacement project that will transfer the normal-open point onto circuit breakers at Tamworth BSP, allowing the AE-route to provide further SCO support to Drakelow GSP.

East Claydon GSP

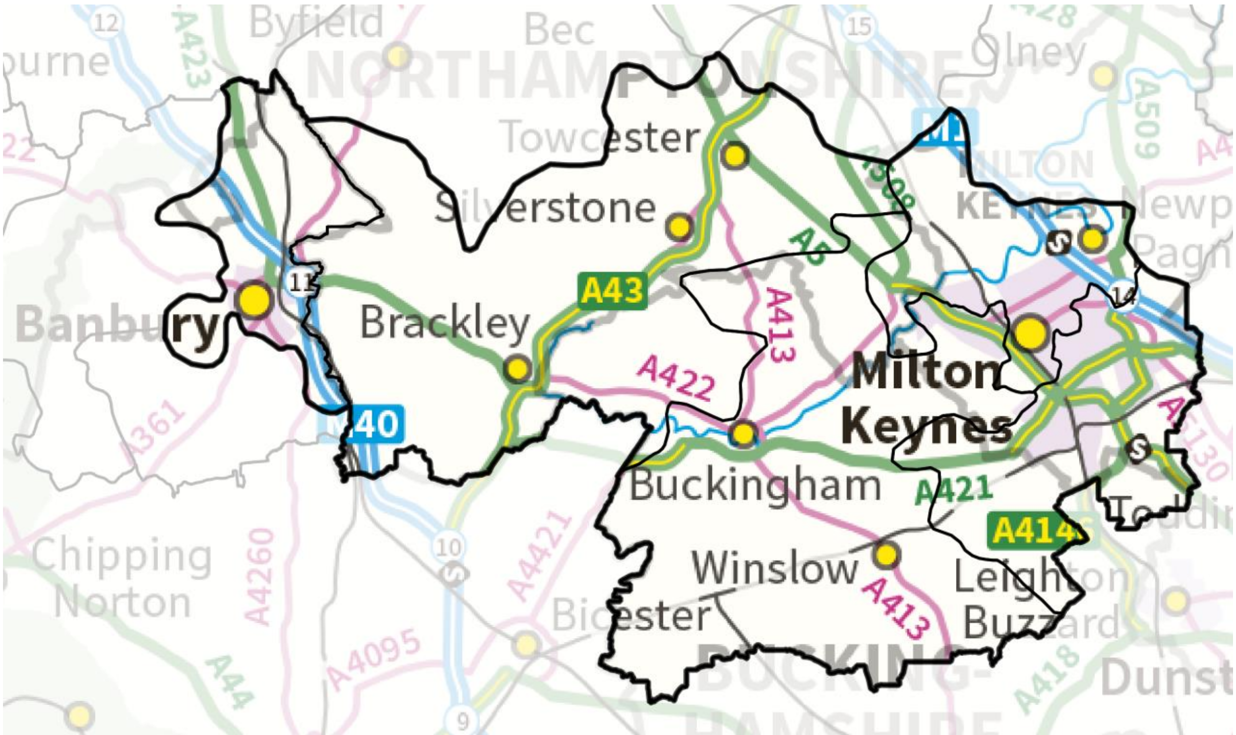

Figure 30: Area supplied by East Claydon GSP. Banbury BSP is in WPD's West Midlands licence area.

Stony Stratford BSP

Stony Stratford BSP is currently being rationalised from two 30/60MVA GTs and one 45/90MVA GT to a pair of 45/90MVA GTs.

No further reinforcement requirements were identified in the 2020 scenarios.

Enderby GSP

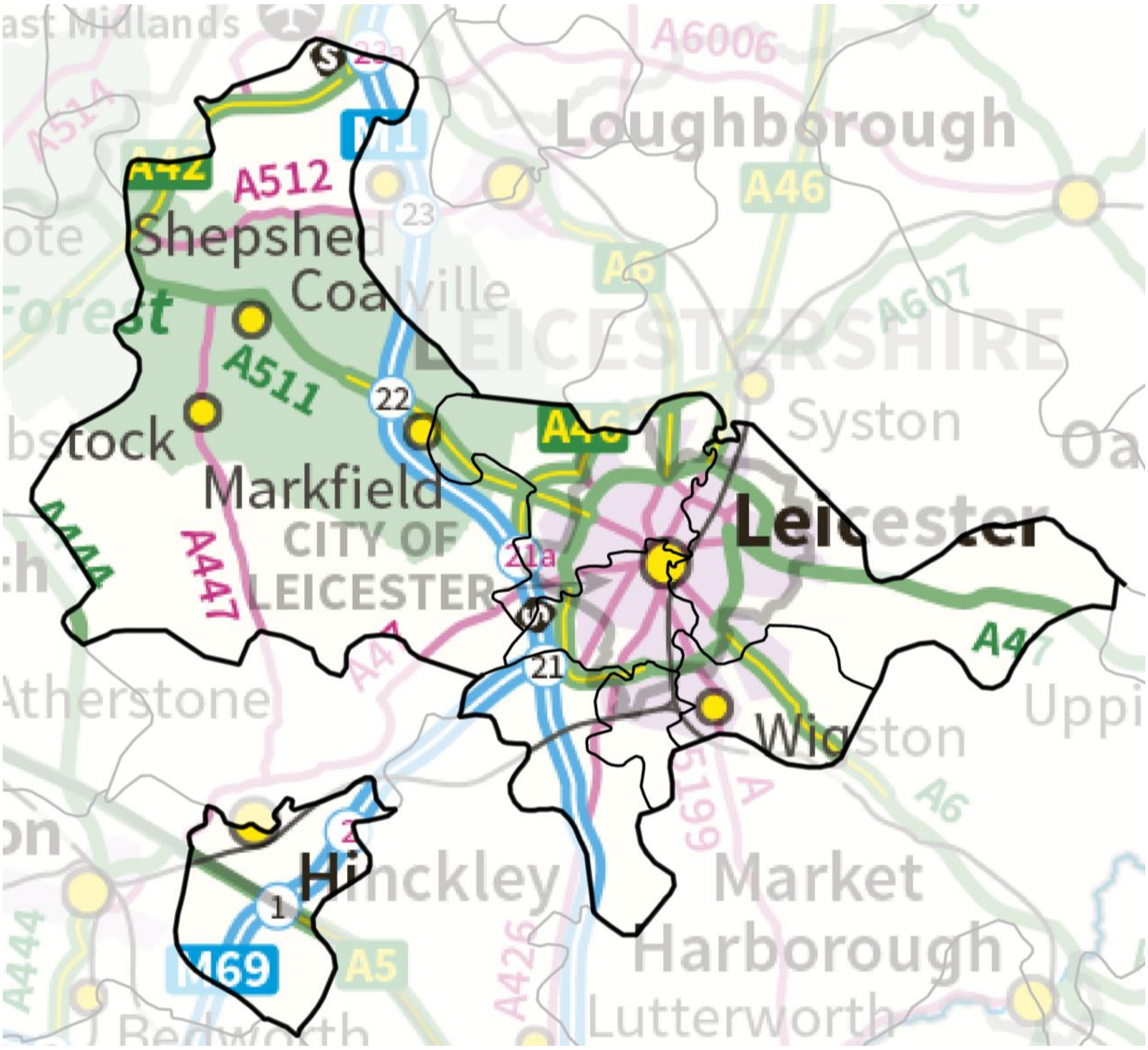

Figure 31: Area supplied by Enderby GSP

SGT capacity

GG CP

Enderby GSP has four SGTs. The 132kV bar is normally operated solid, fed by SGT1, SGT3 and SGT4. SGT2 is held on hot-standby to control fault level; its 132kV breaker is closed for the outage of any other SGT. Following completion of the ongoing replant of Leicester BSP 132kV, it is intended to operate all four SGTs in parallel at Enderby GSP.

An arranged outage of any SGT followed by the fault outage of a second SGT would overload the two remaining SGTs. To prevent this overload, it is necessary to transfer load out of Enderby GSP pre-fault. Transferring Wigston BSP onto Grendon GSP via Kibworth and Corby alleviates the overload. A fault on the AZ-route between Kibworth and Corby whilst Wigston is transferred leaves all of Kibworth and Wigston supplied by the remaining circuit of the AZ-route. Demand growth to 2020 under Gone Green and Consumer Power overloads that circuit.

It is recommended that a reinforcement scheme is developed to reprofile the existing 175mm² ACSR (Lynx) conductors on each circuit of the AZ-route between Corby and Kibworth for 75°C. Given the age of the existing conductors, it may prove more cost effective to combine this reinforcement with the condition-driven replacement of the conductors with single 300mm² AAAC (Upas). It would also be necessary to overlay around 400m of small-section 132kV cables between tower AZ158 and line breakers 905 and 1005 at Corby. This reinforcement scheme can then be triggered as necessary in response to demand growth.

Leicester 132kV rings

GG CP

Leicester BSP is supplied by four 132kV circuits from Enderby GSP. There are two GTs at Leicester, and six outgoing 132kV circuits to other BSP. Leicester 132kV board is currently undergoing asset replacement. Once this is complete, it will be operated as two independent 132kV bars, each supplied by two circuits from Enderby GSP, one from each of the CN- and CC-routes. The GTs and outgoing circuits will be distributed so that every BSP has supplies from both 132kV bars at Leicester.

An arranged outage followed by a fault (in either order) of one CC-route circuit and the GT at Leicester fed from the other 132kV bar leave a CN-route circuit feeding all of one 132kV bar at Leicester and all of the 33kV bar at Leicester. Demand growth to 2020 under Gone Green and Consumer Power overloads that circuit.

It is recommended that the existing twin 175mm² ACSR (twin Lynx) conductors on each circuit of the CN-route are reprofiled for 75°C. Given the age of the existing conductors, it may prove more cost effective to combine this reinforcement with the condition-driven replacement of the conductors with single 500mm² AAAC (Rubus) or 570mm² AAAC (Sorbus). It may be possible to defer this reinforcement by transferring Wigston BSP onto Grendon GSP via Kibworth and Corby for planned outages including GTs at Leicester and circuits between Leicester and Enderby.

Grendon GSP

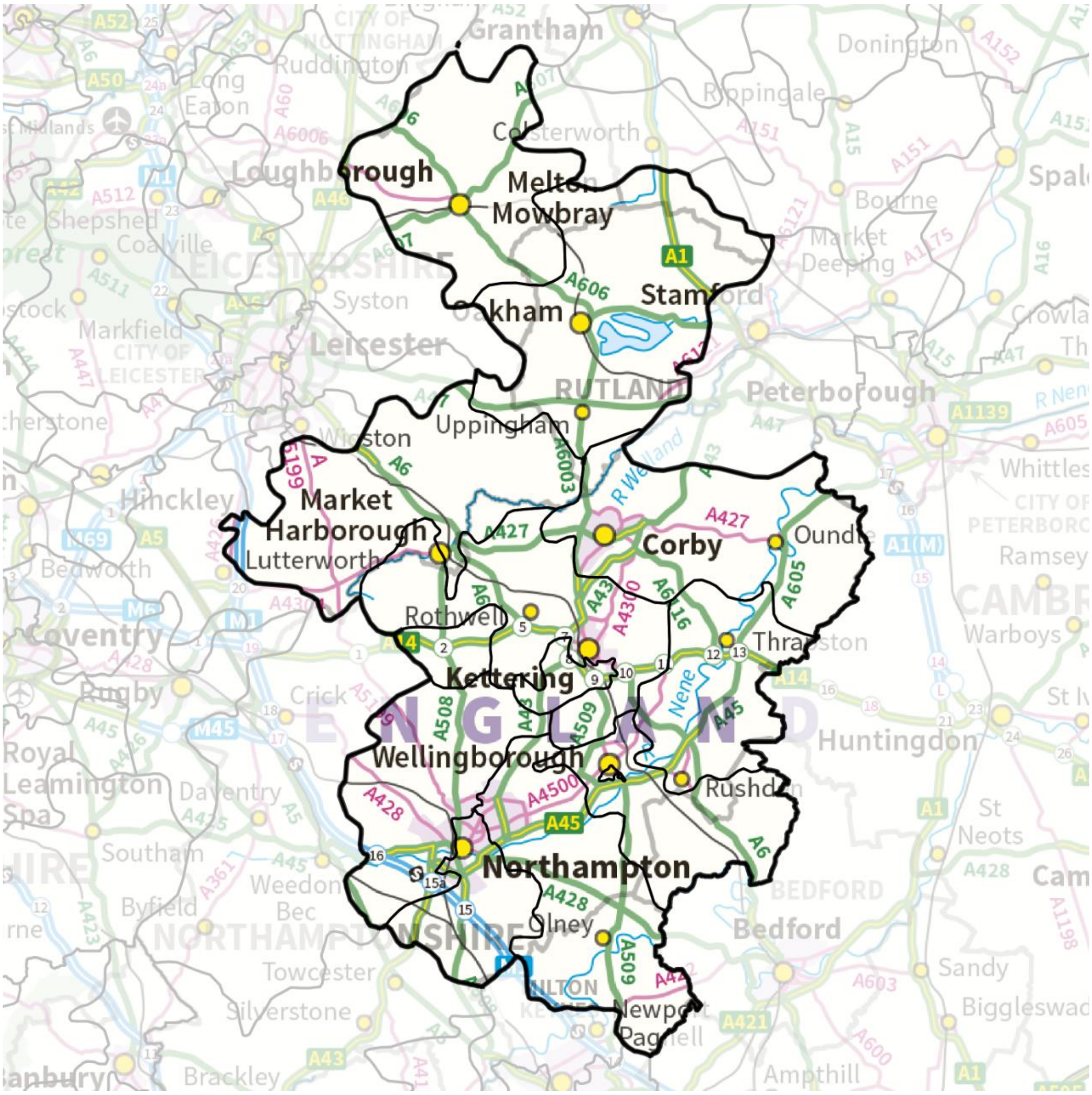

Figure 32: Area supplied by Grendon GSP. Supplies are also provided to UKPN's EPN licence area both directly from Grendon GSP and via WPD's 132kV bar at Corby BSP.

SGT capacity

GG CP SP NP

Grendon GSP is shared between WPD East Midlands and UKPN's EPN network. As such, SGT capacity is National Grid's responsibility. Grendon has five SGTs, and is normally operated split into two sections to keep fault levels within plant ratings:

- SGT2 and SGT3 supply section 1 of the main and reserve bars;
- SGT1 and SGT4 supply section 2 of the main and reserve bars;
- SGT5 is a hot-standby SGT with two 132kV circuit breakers so that it can be quickly and automatically connected to section 1 or section 2 in the event of a fault disconnecting one of the other SGTs. It does not normally supply load.

Since each 132kV circuit breaker associated with SGT5 has to be selected to either the main or reserve bar, it is only immediately available for two out of the four possible 132kV busbar faults at Grendon. Each of the two remaining busbar faults leaves a single SGT supplying a section of bar, heavily overloading that SGT. Demand growth to 2020 exacerbates the busbar-fault overload, and introduces difficulties in managing SGT loading during planned SGT outages despite load transfers to other GSPs.

It is recommended that Grendon GSP 132kV bar is replanted to remove fault level constraints in coordination with National Grid and UKPN. This will allow Grendon 132kV bar to be operated with four SGTs in parallel ('solid'), with SGT5 available as standby for any SGT or busbar fault.

Corby group generation

GG CP SP NP

Grendon 132kV bar's two sections are remote-coupled at 132kV at Corby BSP. The two circuits from Grendon section 1 to Corby are teed to supply Kettering BSP; the two circuits from Grendon section 2 to Corby are teed to supply Irthlingborough BSP. Differences in net demand at Kettering and Irthlingborough result in poor load share between the four circuits. Generator connections to date have resulted in these circuits reaching their rating at peak generator output. Further generator connections are being facilitated in two ways:

1. Circuit reinforcement:
    a. The overhead sections from Grendon to the Irthlingborough and Kettering tees are being reconductored with 500mm² AAAC (Rubus) profiled for operation at 75°C;
    b. The overhead sections from the Irthlingborough and Kettering tees to Corby are being reconductored with 300mm² AAAC (Upas) profiled for operation at 75°C. This is the highest-rated conventional conductor system suitable for the existing towers;
    c. Cable sections in all four circuits are being overlaid as necessary to allow full use of the increased rating of the overhead sections.
2. An ANM system has been commissioned to manage the output of generators that contribute to the loading on the four circuits. New generator customers are given the option to not contribute to the cost of circuit reinforcement but instead accept curtailment on a non-compensatory basis to prevent circuit overloads. ANM customers are still required to contribute to fault level reinforcement.

Despite the extensive reinforcement, the growth of generation to 2020 increases the curtailment of generators connected using the ANM system – to the extent that some generators are curtailed even when the network is intact. This is likely to deter customers from submitting to ANM control.

The proposed replanting and solid running of Grendon 132kV bar will also improve load share on the four circuits between Grendon GSP and Corby BSP, unlocking capacity for generation connections in the Corby area.

Northampton group

GG CP SP NP

The Northampton group consists of three BSPs: Northampton, Northampton East, and Northampton West. They are supplied by three 132kV circuits from Grendon:

- Northampton 132kV bar is supplied by both circuits of the double-circuit CK-route from Grendon.
- Northampton West is supplied by two 132kV cables from Northampton
- Northampton East GT1 is supplied by the single-circuit DL-route from Grendon
- Northampton East GT2 is supplied by one circuit of the double-circuit DR-route from Northampton. It can be connected via circuit breakers 120 and 220 at Northampton to either circuit of the CK-route or (within the bounds of fault level constraints) to both circuits of the CK-route.

The second circuit of the DR-route is currently operated as a normally-open 33kV interconnector between Northampton and Northampton East, but is suitable for future operation at 132kV.

An arranged outage of one circuit of the CK-route followed by a fault outage of the other circuit of the CK-route deenergises Northampton and Northampton West. Northampton and Northampton West form a P2/6 group of class D, with a requirement to restore one-third of group demand within three hours. This requirement is currently met by 33kV demand transfers to other BSPs, including Northampton East. Demand growth to 2020 exhausts the capacity of these demand transfers.

It is recommended that the second circuit of the DR-route between Northampton and Northampton East is reenergised at 132kV. At Northampton East it should be teed to GT1. At Northampton it should be connected by normally open circuit breakers so that it can reenergise GTs at Northampton and/or Northampton West following the fault. This will transfer additional demand onto the DL-route, triggering its reinforcement.

It will be necessary to reprofile the existing 175mm² ACSR (Lynx) conductors on the DL-route for a minimum of 65°C in No Progression and Slow Progression, and 75° in Consumer Power and Gone Green. Given the age of the existing conductors and the requirement for a fourth 132kV circuit into the Northampton group identified in 2025, it may prove more cost effective to rebuild the DL-route from Grendon GSP to Northampton East BSP using double-circuit L7 towers strung with single 500mm² AAAC (Rubus) or 570mm² AAAC (Sorbus) conductors.

An arranged outage followed by a fault (in either order) of one CK-route circuit and the DL-route circuit leaves all of Northampton, Northampton West and Northampton East fed via the remaining circuit of the CK-route. Demand growth to 2020 overloads that circuit.

It is recommended that the existing twin 175mm² ACSR (twin Lynx) conductors on each circuit of the CK-route is reprofiled for 75°C. Given the age of the existing conductors, it may prove more cost effective to combine this reinforcement with the condition-driven replacement of the conductors with single 500mm² AAAC (Rubus) or 570mm² AAAC (Sorbus).

Hams Hall/Lea Marston GSP

Figure 33: Area supplied by Hams Hall/Lea Marston GSP. Supplies are also provided to several BSPs in WPD's West Midlands licence area.

Hams Hall/Lea Marston GSP supplies the Tamworth area in the East Midlands, and part of WPD's West Midlands network. The supplies to the West Midlands were not considered in this project.

As part of the reinforcement mentioned above in the section on Drakelow GSP, both GTs at Tamworth BSP are being reinforced by replacement with 60/90MVA units. It is also intended to split the 33kV parallel between Tamworth BSP and Tamworth Town BSP. No further reinforcement requirements were identified in the 2020 scenarios.

Hams Hall/Lea Marston GSP will be studied in further detail as part of the West Midlands counterpart to this project in the second half of 2017.

Ratcliffe GSP

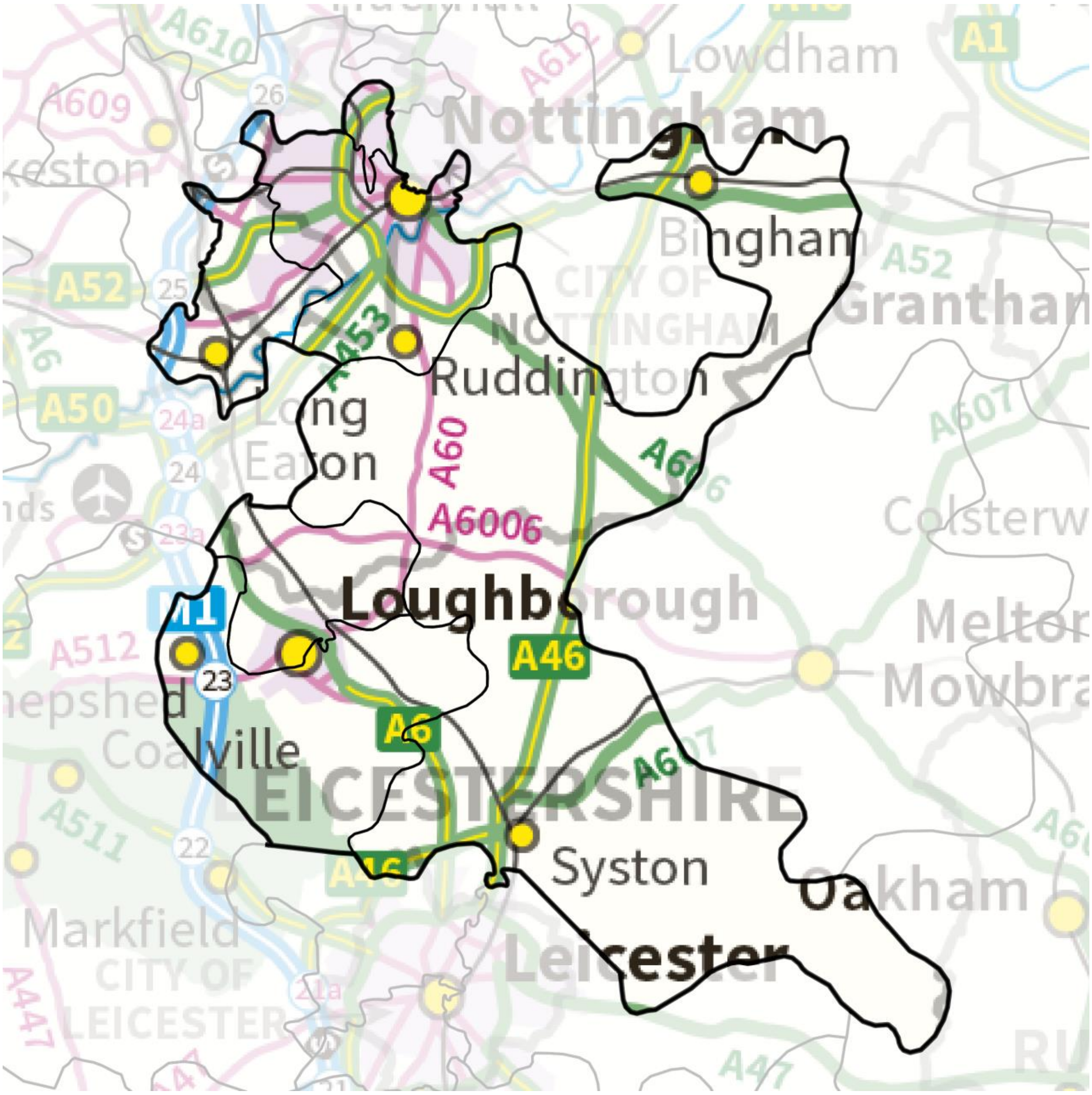

Figure 34: Area supplied by Ratcliffe GSP

The SZ-route from Ratcliffe GSP to the HT-route tee is due to be reconductored with 300mm² AAAC (Upas) before 2020. No further reinforcement requirements were identified in the 2020 scenarios.

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Staythorpe GSP

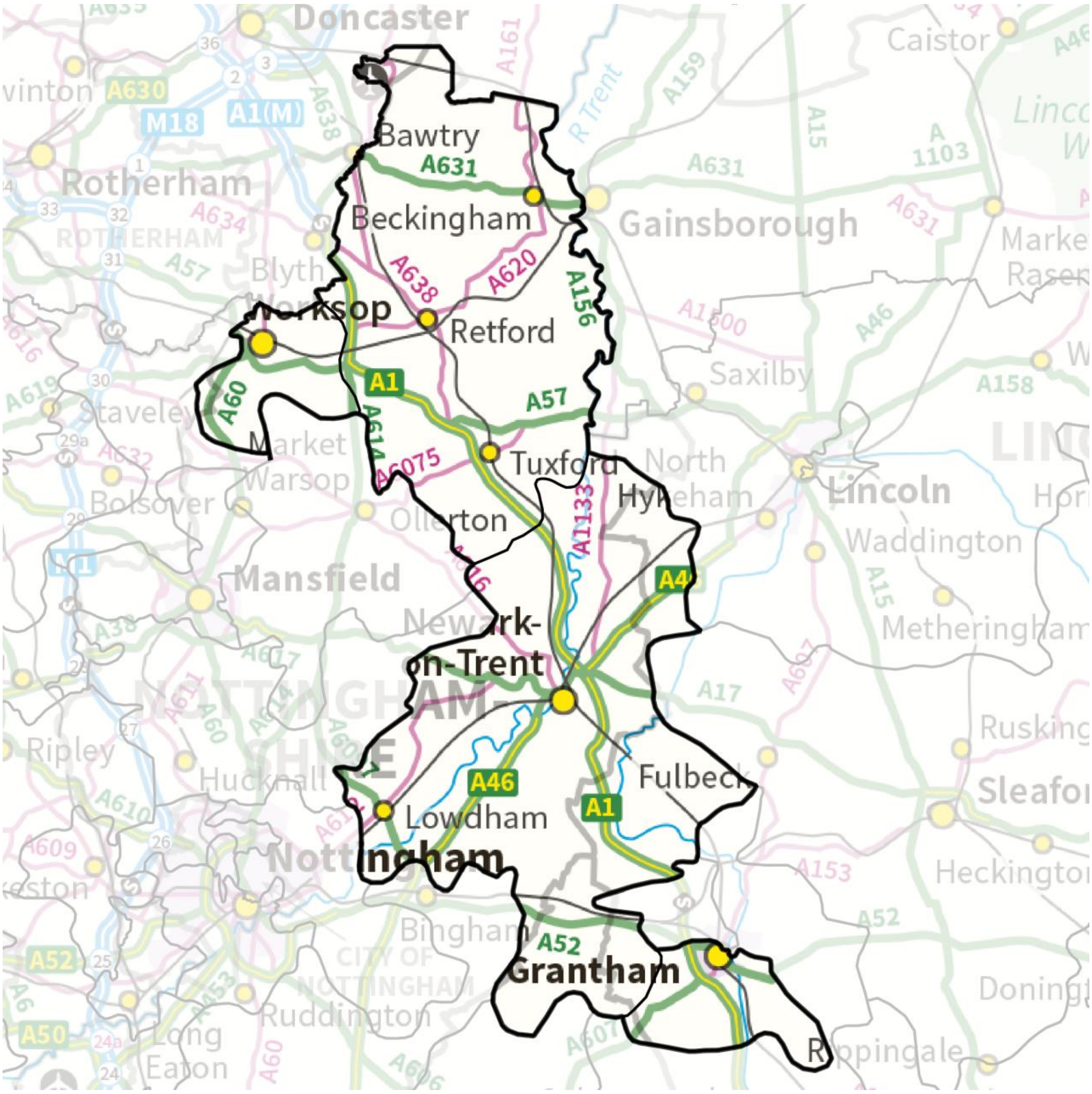

Figure 35: Area supplied by Staythorpe GSP

SGT capacity

GG CP SP NP

Staythorpe GSP has two SGTs. There are two separate 132kV bars at Staythorpe:

- Staythorpe B, the 132kV bar of the former Staythorpe B coal-fired power station built in the 1960s; and
- Staythorpe C, the 132kV bar built to establish Staythorpe GSP in the 1990s. Staythorpe C was laid out to allow future expansion

Outgoing circuits are distributed between the two 132kV bars; both SGTs are connected to Staythorpe C. Staythorpe B is supplied by two 132kV interconnector circuits from Staythorpe C.

Staythorpe 132kV is normally operated split into two sections to keep fault levels within the plant ratings of Staythorpe B:

- SGT1 supplies both reserve bars at Staythorpe C and both reserve bars at Staythorpe B
- SGT2 supplies both main bars at Staythorpe C and both main bars at Staythorpe B

The two bar sections are loose-coupled by the 33kV and 11kV bars of the BSPs supplied from Staythorpe.

The arranged or fault outage of either SGT leaves all of Staythorpe supplied by the remaining SGT. Demand growth to 2020 overloads the remaining SGT.

It is recommended that a third SGT is established at Staythorpe GSP. To connect the third SGT and allow it to operate in parallel with the existing SGTs, it is recommended that Staythorpe B is decommissioned, and Staythorpe C 132kV bar expanded with the following new bays to allow all circuits to be transferred from Staythorpe B:

- **One SGT breaker**
- **Four line breakers**
- **One bus section breaker**
- **One bus coupler breaker**
- **One GT breaker**

As a former major power station, Staythorpe has normally-open 132kV interconnection with six other GSPs. A third SGT at Staythorpe will have the additional benefit of improving Staythorpe's ability to support load transfers from other GSPs.

Hawton BSP

GG CP

Hawton BSP has two 45/90MVA 132/33kV GTs, each supplied by a circuit of the DE-route from Staythorpe GSP. Each circuit of the DE-route is currently teed from a circuit of the TZ-route on the approach to Staythorpe. The outage of either GT or circuit leaves all of Hawton supplied by the remaining GT and circuit. Demand growth to 2020 under Gone Green and Consumer Power overloads the remaining GT and circuit, as shown in Figure 36. There is a 33/11kV primary substation at Hawton supplied from the BSP 33kV bar.

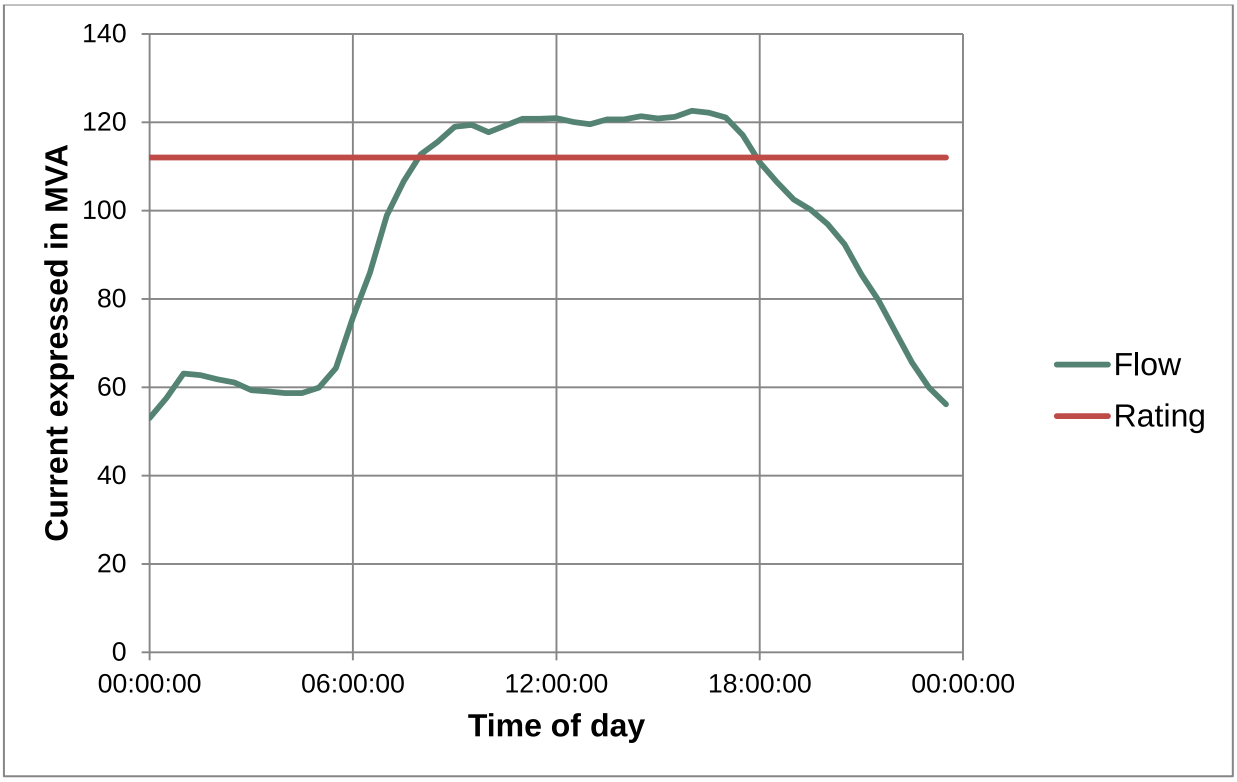

Figure 36: Winter Peak Demand day flow through the circuit from Staythorpe GSP to Hawton BSP GT1 during outage of the circuit from Staythorpe GSP to Hawton BSP GT2, Gone Green 2020.

It is recommended that a reinforcement scheme is developed to establish a pair of 132/11kV 15/30MVA GTs at Hawton BSP, each double-banked with one of the existing 132/33kV GTs. The 11kV load would be transferred from the existing primary substation to the 132/11kV GTs to deload the 132/33kV GTs. The DE-route between Hawton and Staythorpe (~5km circuit length) would need to be reconductored with 300mm² AAAC (Upas) profiled for 50°C. This reinforcement scheme can then be triggered as necessary in response to demand growth.

The cables that tee the DE-route to the TZ-route on the approach to Staythorpe (~200m circuit length) would need to be overlaid with 1000mm² Cu XLPE Pb cable in trefoil. It may prove more cost-effective to establish two additional bays at Staythorpe C for the DE-route circuits as part of the expansion of the GSP (see above) and connect the DE-route overhead rather than overlay the cables. This would have the added benefit of removing the interdependence between the DE-route and the TZ-route, which supplies Asforby BSP and provides normally-open interconnection with Grendon GSP.

Checkerhouse BSP

GG CP SP NP

Checkerhouse BSP has two 30/60MVA GTs. The arranged or fault outage of either GT leaves all of Checkerhouse supplied by the remaining GT. The growth of generation to 2020 overloads the remaining GT.

Both GTs at Checkerhouse are due to be replaced with 60/90MVA units by 2020, triggered by new generation connections. This will alleviate the projected overloads.

Stoke Bardolph GSP

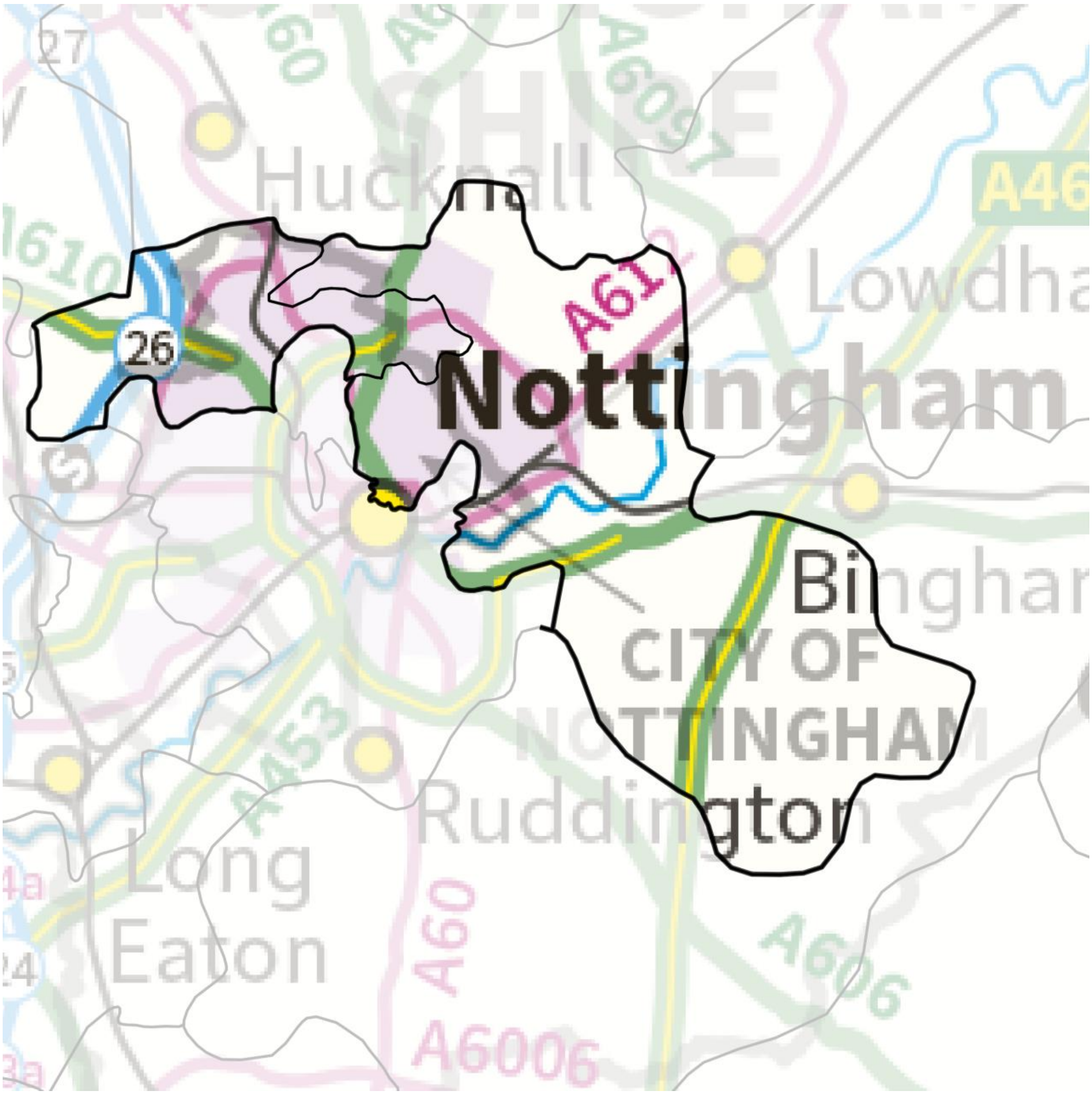

Figure 37: Area supplied by Stoke Bardolph GSP

No reinforcement requirements were identified in the 2020 scenarios.

Walpole GSP

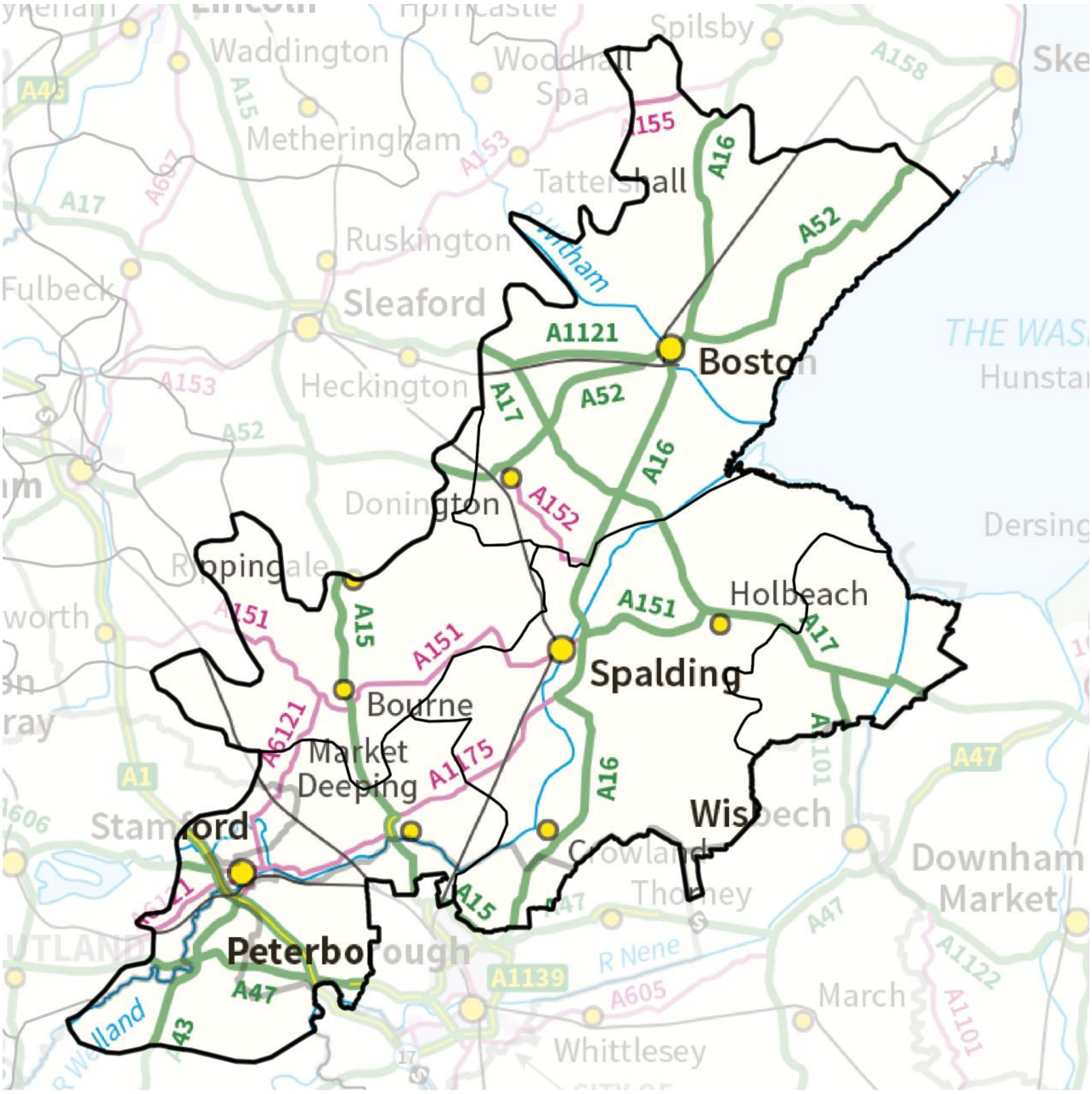

Figure 38: Area supplied by Walpole GSP. Supplies are also provided to UKPN's EPN licence area.

Walpole GSP is shared between WPD East Midlands and UKPN's EPN network. The 132kV bar is currently being replaced using GIS equipment.

WPD's Bourne area network is supplied from Walpole by two 132kV circuits, and UKPN's Peterborough area network is supplied from Walpole by four 132kV circuits. A 132kV circuit between WPD's Stamford BSP and UKPN's Peterborough North BSP interconnects these two networks, and is operated normally closed.

Bourne 132kV network

GG CP SP NP

For the arranged outage followed by fault outage of any two circuits into the Bourne 132kV network, the remaining circuit supplies the whole Bourne 132kV network. Demand growth to 2020 overloads the remaining circuit. The cable sections between Walpole GSP and tower DZ41 (~1km circuit length) are already due to be overlaid with 1000mm² Cu XLPE Pb in trefoil before 2020.

It is recommended that the northern circuit of the DZ-route from Walpole to South Holland BSP (~12km circuit length) and the southern circuit of the DZ- and HB-routes from Walpole to the tee for Spalding BSP (~24km circuit length) are reconductored with 300mm² AAAC (Upas) profiled at 75°C. The existing 175mm² ACSR (Lynx) conductors on the first two spans of the PRA-route from PR61 to PRA1A (~350m circuit length) should be reprofiled for 75°C.

It may be possible to defer some of the circuit reinforcement by transferring Bourne BSP onto Staythorpe GSP via Grantham South BSP pre-fault. This would require two 132kV line breakers (305 and 405) at Bourne to facilitate on-load transfer. Bourne 132kV bar is currently being rebuilt under asset replacement. Provision has been made in the new layout for installing these breakers in future. More of the circuit reinforcement could be deferred if a second GT were established at South Holland BSP.

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

West Burton GSP

Figure 39: Area supplied by West Burton GSP. Supplies are also provided to West Burton Power Station.

SGT capacity

GG CP SP NP

West Burton GSP is shared between WPD East Midlands and auxiliary supplies to West Burton Power Station. As such, SGT capacity is National Grid's responsibility. West Burton has two SGTs, and is normally operated split into two halves to keep fault levels within plant ratings. The two halves are remote-coupled via Lincoln BSP 132kV bar. An auto-close scheme on bus coupler breaker 230 couples the two halves of West Burton for the loss of either SGT.

National Grid intends to install a third SGT by 2020 to alleviate demand-related constraints. WPD has temporarily transferred Retford and Worksop BSPs from West Burton GSP to Staythorpe GSP to assist National Grid in preventing overloads.

Despite the commissioning of the third SGT, it may prove necessary to transfer Retford and Worksop BSP onto Staythorpe GSP during arranged SGT outages to prevent the overloading of the remaining SGT in the event of an SGT fault outage.

Willington GSP

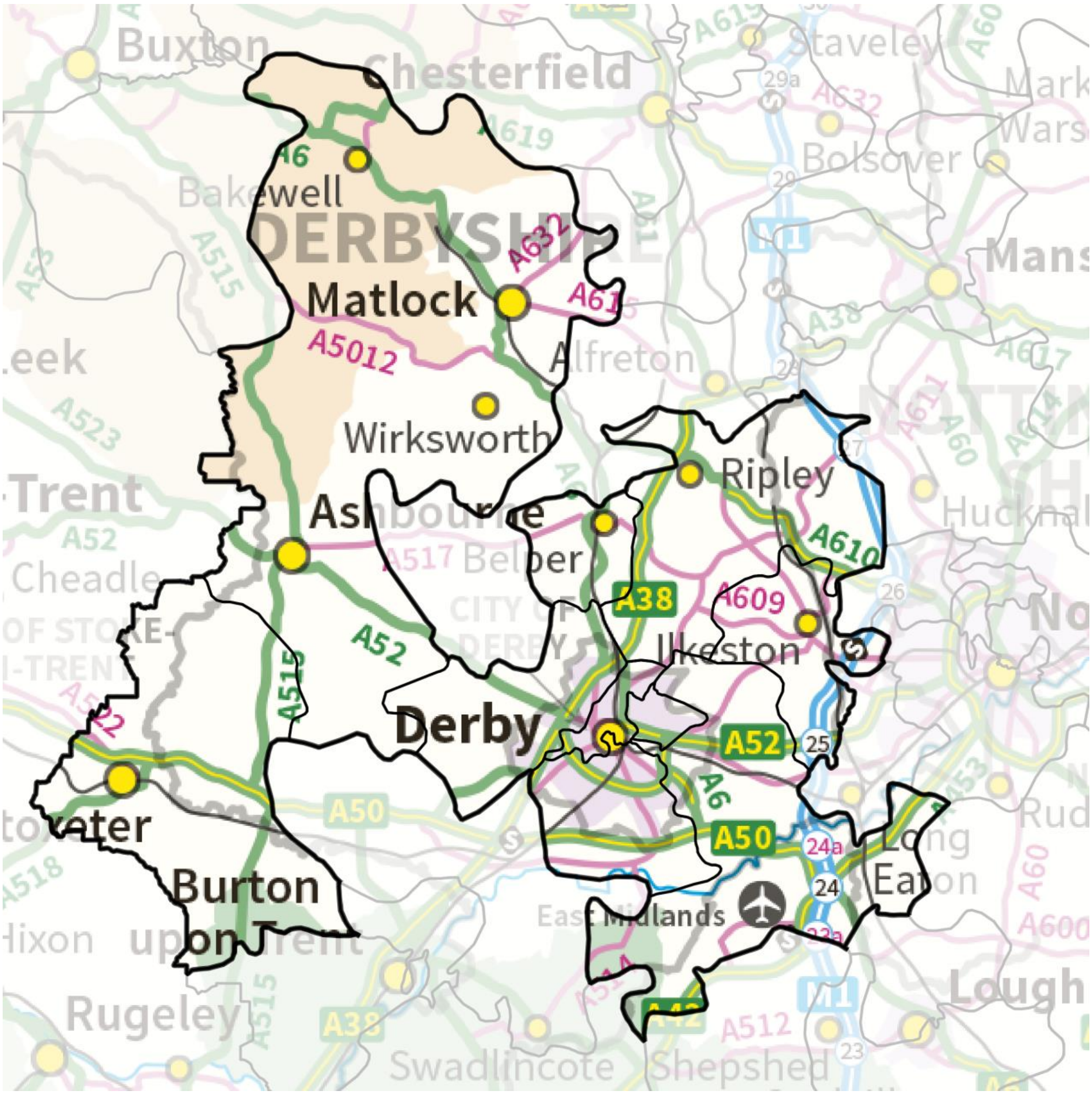

Figure 40: Area supplied by Willington GSP

SGT capacity and Spondon 132kV network

GG CP SP NP

Willington GSP has five SGTs, and is normally operated split into two to keep fault levels within plant ratings:

1. SGT4 (120MVA), SGT6 (240MVA) and SGT7 (240MVA) supply main bar sections 1 and 2, and reserve bar section 2
2. SGT1 (240MVA) and SGT5 (120MVA) supply reserve bar section 1

The two halves are remote-coupled by the 132kV bar at Spondon, and loose-coupled by the 33kV and 11kV bars of other BSPs supplied from Willington.

Following demand growth to 2020, an arranged outage of one 240MVA SGT followed by the fault outage of a second 240MVA SGT overloads various SGTs and 132kV circuits to Spondon, depending on the particular outage combination.

It is recommended that Willington 132kV bar is operated with all SGTs in parallel to improve load share on the SGTs and the 132kV circuits. This will alleviate some but not all overloads. This would cause switchgear overstressing, and so trigger the replanting of Willington 132kV bar which would need to be carried out in coordination with National Grid.

The pre-fault transfer of Heanor BSP, Stanton BSP and part of the power station at Spondon onto Staythorpe GSP would also be necessary. In turn, this triggers extensive reconductoring of the HL- and HM-routes between Staythorpe GSP and Loscoe switching station with 300mm² AAAC (Upas) profiled for 50°C.

An alternative reinforcement scheme would also require 132kV replanting, the replacement of both 120MVA SGTs with 240MVA SGTs, and a fourth 132kV circuit from Willington to Spondon (~7km circuit length if an existing circuit can be used from Willington as far as Derby South). Given multiple interrelated reinforcement requirements, detailed studies of several options will be required to determine the most appropriate reinforcement.

Stanton BSP

GG CP

Stanton BSP has two 30/60MVA GTs. The arranged or fault outage of either GT leaves all of Stanton supplied by the remaining GT. Under Gone Green and Consumer Power, the growth of demand to 2020 overloads the remaining GT.

It is recommended that a reinforcement scheme is developed to replace both GTs at Stanton BSP with 60/90MVA units, and triggered as necessary.

2025

Between 2020 and 2025 the four scenarios move beyond the pipeline of Accepted-not-yet-Connected generation schemes and diverge considerably. The growth of EVs and HPs become significant, triggering further demand-related reinforcements.

In 2025, No Progression and Slow Progression trigger all reinforcements that were triggered by Consumer Power and Gone Green in 2020.

Berkswell GSP

SGT capacity

GG CP

Despite reinforcement of the HK-route in 2020 to defer the requirement for a fourth SGT at Berkwell GSP, demand growth to 2025 under Gone Green and Consumer Power exhausts the load transfer capability between Berkswell and Coventry GSPs. Overloads of the SGTs at Berkswell or the HK-route result.

A fourth SGT at Berkswell GSP and reduced transfers to Coventry GSP would alleviate the projected overloads.

Bicker Fen GSP

SGT capacity

GG CP SP

Bicker Fen GSP has two SGTs. The arranged or fault outage of either SGT leaves all of Bicker Fen supplied by the remaining SGT. Under all scenarios except No Progression, the growth of generation to 2025 overloads the remaining SGT.

A third SGT at Bicker Fen would alleviate the FCO overload, but would introduce new overloads for the SCO of two SGTs. It may be possible to manage SCO overloads through pre-fault curtailment or transfer of generation.

Chesterfield GSP

SGT capacity

GG CP

Chesterfield GSP has four SGTs. It is normally operated split into two sections to keep fault levels within plant ratings:

- SGT1 and SGT3 supply reserve bar sections 1 and 2;
- SGT2 and SGT4 supply main bar sections 1 and 2.

Following demand growth to 2025 under Gone Green and Consumer Power, the fault outage of SGT1 or SGT2 overloads its partner SGT. For the SCO of any two SGTs, the two remaining SGTs are overloaded.

If fault level constraints allow, a fast-close scheme on circuit breakers 130 and 230 at Chesterfield GSP could be used run the three remaining SGTs in parallel

following the loss of an SGT. Transferring Clipstone BSP or part of Annesley BSP (see below) onto Staythorpe GSP may assist with the SCO requirement, but would rely on the installation of a third SGT at Staythorpe. Alternatively, additional SGTs could be installed at Chesterfield to alleviate the projected overload.

Annesley BSP

GG CP SP NP

GT1 and GT2 at Annesley BSP are 22.5/45MVA units, supplying one 33kV bar. GT3 and GT4 are 30/60MVA units, supplying a second 33kV bar. Several primary substations are loose-coupled between the two 33kV bars. Following demand growth to 2025, the arranged or fault outage of either of GT1 and GT2 overloads the other.

Replacing GT1 and GT2 with 40/60MVA units would alleviate the FCO overload. An alternative scheme has been proposed to replace the existing GTs with two 132/33kV 60/90MVA units and two 132/11kV 15/30MVA units, transferring the 11kV demand from the existing on-site 33/11kV primary substation. This would simplify the operation of the 33kV network, and allow transfer of a pair of GTs onto Staythorpe GSP permanently or as required by outages. It is recommended that this alternative scheme is considered as GTs and 132kV switchgear at Annesley become due for asset replacement.

Clipstone BSP

GG CP

Clipstone BSP has two 132/33kV 45/90MVA GTs, GT1 and GT2. A third GT is planned to be commissioned, double-banked with GT2 at 132kV, to supply new generation connections in the vicinity of the BSP separately from the existing Clipstone 33kV network.

Following growth to 2025 under Gone Green and Consumer Power, the arranged or fault outage of either of GT1 and GT2 overloads the other.

If new generation is connecting in close proximity to Clipstone BSP, it may be possible to connect it to the third GT rather than the main 33kV bar supplied by GT1 and GT2. If this proves impractical, the third GT could be reconnected using 33kV and 132kV switchgear to provide a third infeed to the main 33kV bar independent of GT1 and GT2. It is recommended that the third GT at Clipstone is sited and connected to allow future reconfiguration.

Whitwell BSP

GG CP

Whitwell BSP has two 132/33kV 30/60MVA GTs. Following demand growth to 2025 under Gone Green and Consumer Power, the arranged or fault outage of either GT overloads the other.

The replacement of both GTs with 60/90MVA units would alleviate the projected overloads.

Coventry GSP

Rugby BSP

GG CP SP NP

Rugby BSP has two 132/11kV 15/30MVA GTs, GT2A and GT2B. Following demand growth to 2025, the arranged or fault outage of either GT overloads the other.

It may be possible to alleviate the projected overload by transferring demand at 11kV onto existing primary substations supplied by the 132/33kV GT1 and GT4 at Rugby. If sufficient transfers are not available, a third 132/11kV GT at Rugby BSP or a new 33/11kV primary substation in the vicinity of the new demand may prove more appropriate.

Whitley BSP

GG CP

Whitley BSP has two 132/33kV 45/90MVA GTs. Following demand growth to 2025 under Gone Green and Consumer Power, the arranged or fault outage of either GT overloads the other.

Establishing a pair of 132/11kV 15/30MVA GTs at Whitley BSP and transferring the load of the existing on-site 33/11 primary substation to the new GTs would alleviate the projected overloads. It may be necessary to install 132kV bus-section breakers between the 132/33kV and 132/11kV GTs to provide SCO compliance and operational flexibility.

Drakelow GSP

SGT capacity

GG CP

Following demand growth to 2025 under Gone Green and Consumer Power, the fault outage of either SGT at Drakelow GSP overloads the other, as shown in Figure 41. No secure 132kV load transfers out of Drakelow currently exist.

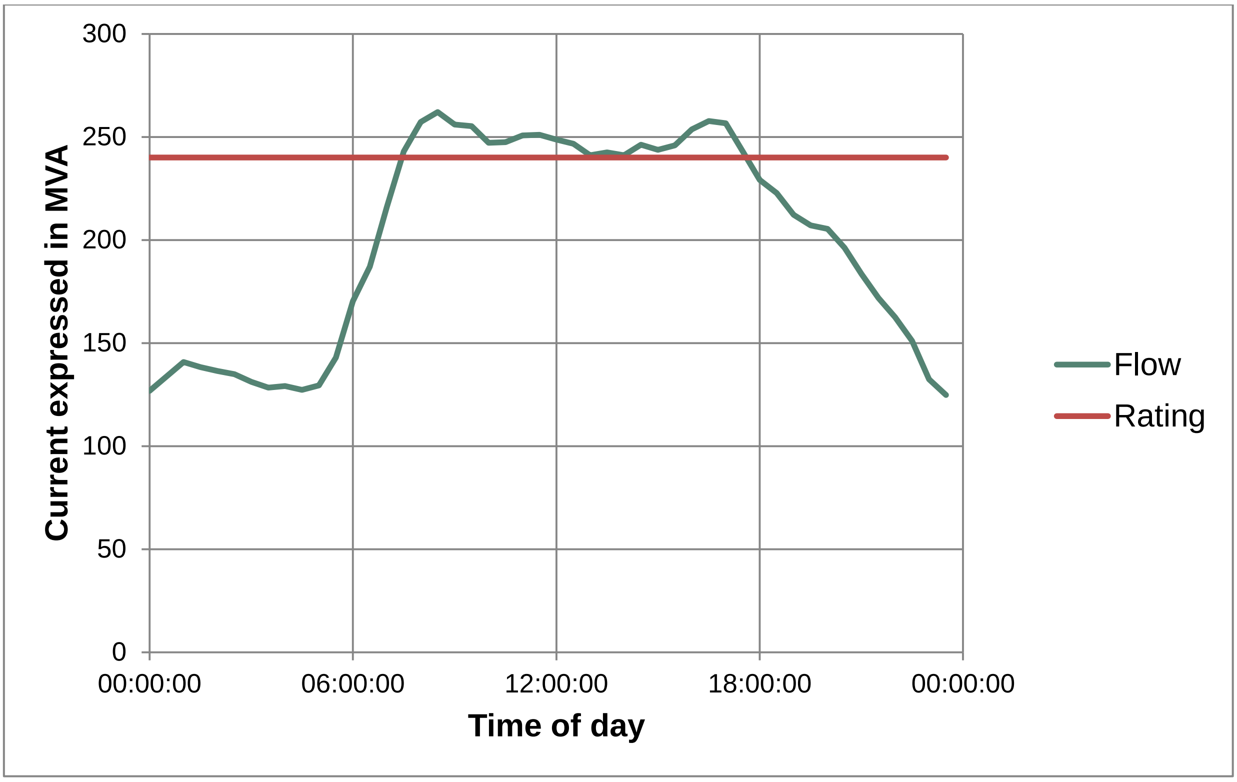

Figure 41: Winter Peak Demand day flow through Drakelow SGT7 during outage Drakelow SGT8, Gone Green 2025.

A third SGT would alleviate the projected overload.

AG-route

GG CP

The AG-route carries both 132kV circuits from Drakelow GSP to Burton BSP. Following demand growth to 2025 under Gone Green and Consumer Power, an outage of either circuit of the AG-route overloads the other.

Reprofiling the existing 175mm² ACSR (Lynx) conductors on the AG-route for at least 65°C would alleviate the projected overloads.

East Claydon GSP

SGT capacity

GG CP

East Claydon GSP has four SGTs. It is normally operated split into two sections to keep fault levels within plant ratings:

- SGT1 and SGT2 supply reserve bar sections 1 and 2;
- SGT3 and SGT4 supply main bar sections 1 and 2.

Following demand growth to 2025 under Gone Green and Consumer Power, the SCO of any two SGTs overloads the two remaining SGTs. No 132kV load transfers are available to the East Claydon network.

Additional SGTs could be installed to alleviate the projected overload.

High demand growth is projected in an area between the M1 and M40 which currently has low load-density. This area is currently supplied by East Claydon GSP (Banbury, Brackley and Stony Stratford BSPs), Berkswell GSP (Harbury and Warwick BSPs), Coventry GSP (Daventry and Rugby BSPs) and Grendon GSP (Northampton and Northampton West BSPs). Existing WPD 132kV and National Grid circuits pass around the edge of the area; supplying major demand growth would require significant new infrastructure. Reinforcement and new connections around this area should be coordinated where possible to provide the best value to consumers.

Milton Keynes 132kV network

GG CP

Following demand growth to 2025 under Gone Green and Consumer Power, the Milton Keynes 132kV network (Bradwell Abbey, Bletchley and Stony Stratford BSPs) becomes a P2/6 class E (>300MW) demand group. Various SCO combinations cause overloads in the following circuits:

- Both circuits of the AH-route between Stony Stratford BSP and Bradwell Abbey BSP
- The 132kV cable between Bradwell Abbey BSP and Bletchley BSP

Reconductoring the AH-route with 300mm² AAAC (Upas) profiled at 75°C and installing an additional 132kV cable circuit from Bletchley BSP to Bradwell Abbey BSP or Stony Stratford BSP would alleviate the projected overloads. Part of this reinforcement could be deferred by installing a second GT at East Claydon BSP and transferring part of the Stony Stratford 33kV network onto East Claydon, deloading the Milton Keynes 132kV network.

Brackley BSP

GG CP

Following extensive demand growth to 2025 under Gone Green and Consumer Power, the outage of either GT at Brackley BSP heavily overloads the other.

Two additional GTs could be installed at Brackley or a new BSP to alleviated the projected overload, but extensive 132kV reinforcement would also be required in the area to maintain P2/6 compliance for the SCO of both 132kV circuits to Brackley and Banbury. A 132kV circuit between Banbury BSP and Harbury BSP is currently under consideration, this would provide SCO infeed to both the Banbury/Brackley group and the Harbury/Warwick group.

Bradwell Abbey BSP

GG CP

Following demand growth to 2025 under Gone Green and Consumer Power, the outage of either GT at Bradwell Abbey BSP overloads the other.

A third, 60/90MVA GT at Bradwell Abbey BSP would alleviate the projected overload. Alternatively, a fourth BSP could be established in the Milton Keynes area.

Enderby GSP

SGT capacity

GG CP

See Grendon GSP below.

Hinckley BSP

GG CP

Hinckley BSP has two 132/33kV 22.5/45MVA GTs and two 132/11kV 15/30MVA GTs. Following demand growth to 2025, the outage of either 132/33kV GT overloads the other.

Replacing both 132/33kV GTs with 40/60MVA units would alleviate the projected overloads.

Wigston BSP

GG CP

Wigston BSP has two 132/33kV 30/60MVA GTs and two 132/11kV 15/30MVA GTs. There is no 132kV SCO capability, and limited transfers at lower voltages. Following demand growth to 2025, the outage of either 132/33kV GT overloads the other.

A new BSP connected to the 132kV cables from Enderby GSP to Carlton Park BSP could be used to deload Wigston 33kV network, alleviating both the projected overloads and SCO compliance issues.

Grendon GSP

SGT capacity

GG CP

Despite reinforcement in 2020, demand growth to 2025 under Gone Green and Consumer Power overloads SGTs at Grendon GSP. This happens when load is transferred from Enderby GSP to prevent Enderby SGT overloads during SGT outages. Associated overloads are also seen on the AZ-route between Corby and Kibworth.

Given the size of Grendon and Enderby GSPs and the associated circuit overloads, a new GSP to partially deload both Grendon and Enderby would be an appropriate reinforcement. The AZ-route between Corby BSP and Kibworth BSP crosses National Grid’s 400kV line between Grendon GSP and Staythorpe GSP; a GSP near this crossing would minimise the requirement for new 132kV lines. Depending on the required load transfers from Grendon GSP, it may be necessary to rebuild the AZ-route from the new GSP to Corby as L7 towers to support larger conductors.

Northampton group

GG CP SP NP

Further demand growth to 2025 exhausts the capacity of the three circuits to Northampton despite reinforcement in 2020.

The projected overloads could be alleviated by rebuilding the DL-route from Grendon GSP to Northampton East BSP using double-circuit L7 towers strung with single 500mm² AAAC (Rubus) or 570mm² AAAC (Sorbus) conductors. The first 1.4km out from Northampton East is already on L7 towers; the remaining 6.7km to Grendon GSP would require new towers. Approximately 500m of 132kV cable and a new 132kV bay would be required at Grendon GSP. This would provide a fourth 132kV circuit into the Northampton group, securing it for considerable further demand growth.

It is recommended that the 132kV reconfigurations at Northampton and Northampton East BSPs recommended in 2020 are designed to accommodate the fourth circuit.

Hams Hall/Lea Marston GSP

No reinforcement requirements were identified in the 2025 scenarios.

Ratcliffe GSP

Loughborough BSP, SZ-route and HT-route

GG CP

Loughborough BSP has two 132/33kV 30/60MVA GTs and two 132/11kV 15/30MVA GTs. Each 132/33kV GT is double-banked with a 132/11kV GT; each pair is supplied by a transformer feeder from Ratcliffe GSP carried on the SZ- and HT-routes. Following extensive demand growth to 2025 under Gone Green and Consumer Power, the fault outage of either circuit overloads the lines and transformers in the other circuit.

Given the scale of the overloads, a new BSP on the SZ-route between the HT-route tee and Coalville BSP would be an appropriate reinforcement. 132kV switchgear would be necessary to provide SCO independence from Loughborough BSP. This new BSP is currently in the early stages of planning.

Willoughby BSP and CZ-route

GG

Willoughby BSP has two 45/90MVA 132/33kV GTs, supplied by two transformer-feeders on the CZ-route. Following the growth of both demand and generation to 2025 under Gone Green, the arranged or fault outage of either circuit overloads the other.

Establishing a pair of 132/11kV 15/30MVA GTs at Willoughby BSP and transferring the load of the existing on-site 33/11 primary substation to the new GTs would alleviate the projected transformer overloads. Reprofiling the

existing 175mm² ACSR (Lynx) conductors on the CZ-route for 75°C would alleviate the projected line overloads.

Staythorpe GSP

Checkerhouse BSP

GG CP

Despite reinforcement in 2020, following generation growth to 2025 under Gone Green and Consumer Power the outage of either 132/33kV GT at Checkerhouse BSP overloads the other.

A new BSP could be established to deload Checkerhouse BSP, potentially in the vicinity of West Burton GSP.

Hawton BSP

GG CP

Despite extensive reinforcement in 2020, following demand growth to 2025 under Gone Green and Consumer Power the outage of either 132/33kV GT at Hawton BSP overloads the other.

A new BSP in the vicinity of Sibthorpe 33/11kV primary substation (in the south-west of the area supplied by Hawton BSP) could be established to deload Hawton BSP. Sibthorpe is close to both the TZ-route from Staythorpe to Melton Mowbray and Asfordby BSPs, and the HA-route from Staythorpe to Grantham South BSP.

TZ-route

GG CP

The TZ-route normally supplies Asfordby and Melton Mowbray BSPs from Staythorpe GSP. The first 350m of the TZ-route from Staythorpe are constructed with a higher rating and also supply the DE-route to Hawton BSP. Following demand and generation growth to 2025 under Gone Green and Consumer Power, the outage of either TZ-route circuit overloads the other.

Reducing the extent of transfers from Grendon GSP onto Staythorpe GSP via the TZ-route would reduce TZ-route overloads, but would increase the reinforcement requirement associated with the new GSP proposed to deload Grendon and Enderby GSPs (see Grendon GSP).

Unbanking the DE-route to Hawton BSP onto dedicated bays at Staythorpe GSP would alleviate overloads on the 350m shared section of the TZ-route.

Any remaining overloads could be alleviated by reconductoring the TZ-route with 300mm² AAAC (Upas) profiled for operation at 75°C.

Walpole GSP

South Holland and Spalding BSPs

GG

Spalding BSP has two 132/33kV GTs and South Holland BSP has one 132/33kV GT. The two BSPs are normally operated in parallel at 33kV. Following generation growth to 2025 under Gone Green, the SCO of two of these GTs overloads the remaining GT.

Establishing a second GT at South Holland BSP and breaking the 33kV parallel would alleviate the projected overloads. This reinforcement would also improve the flexibility of the Bourne 132kV network, deferring some demand-related line reinforcement.

West Burton GSP

No reinforcement requirements were identified in the 2025 scenarios.

Willington GSP

SGT capacity and Spondon 132kV network

GG CP SP NP

Despite extensive reinforcement in 2020, demand growth to 2025 results in overloads on:

1. The HY-route between Willington GSP and Spondon
2. The CL-route between Spondon and the tee for the CLT-route to Stanton BSP
3. The HM-route between the tee for the CLT-route to Stanton BSP and Loscoe
4. The HM-route between Loscoe and Staythorpe GSP

The projected overloads can be alleviated by establishing a fourth circuit from Willington GSP to Spondon and changing operational practices so that only Heanor BSP is transferred onto Staythorpe GSP for arranged SGT and circuit outages. These changes lead to SGT overloads at Willington GSP for the coincident arranged and fault outage of two SGTs, triggering the replacement of both 120MVA SGTs with 240MVA SGTs.

Under Gone Green and Consumer Power, it would also be necessary to overlay approximately 1km of 132kV cable from Willington GSP to the terminal tower of the HY-route.

Spondon BSP

GG CP

Spondon's GTs and 33kV board are in the Spondon B compound, approximately 400m from the 132kV board in the Spondon A compound. There are two 132kV transformer-feeder cables from Spondon A to the GTs at Spondon B. Following demand growth to 2025 under Gone Green and Consumer Power, an outage of either cable overloads the other.

The projected overloads could be alleviated by overlaying both 132kV cables with larger cables.

Stanton BSP

GG CP SP NP

Developments along the M1 corridor to 2025 between Derby and Nottingham further increase demand on Stanton BSP. Despite the replacement of both GTs with 60/90MVA units as proposed for Consumer Power and Gone Green in 2020, the arranged or fault outage of either GT overloads the other.

Under Slow Progression and No Progression, establishing a pair of 132/11kV 15/30MVA GTs at Stanton BSP or Toton BSP (the opposite side of the M1 from Stanton BSP) would alleviate the projected overload. Toton BSP has a 33/11kV primary substation on-site whose load could be transferred to the new GTs.

Under Gone Green and Consumer Power, it would be necessary to establish pairs of 132/11kV GTs at both Stanton and Toton. Alternatively, a new BSP could be established between Stanton and Toton and 132kV circuits extended from Stanton and Toton to the new BSP. This could have an additional benefit of enabling 132kV transfers between Willington and Ratcliffe GSPs.

2030

Studies were run for Slow Progression and No Progression 2030. Almost all reinforcements triggered by Gone Green and Consumer Power 2025 were also triggered by Slow Progression and No Progression 2030; notable exceptions are:

- SGT reinforcement was not triggered at Chesterfield GSP under Slow Progression or No Progression in 2030;
- GT reinforcement was not triggered at Hinckley, Rugby or Whitley BSPs under Slow Progression or No Progression in 2030;
- GT reinforcement was not triggered at Checkerhouse, South Holland or Willoughby BSPs under No Progression in 2030.

Studies were not run for Gone Green and Consumer Power 2030; it is expected that they would trigger extensive further reinforcement across the East Midlands.

Fault level results

Fault analysis was run for 2016 as a benchmark, and for 2020, 2025 and 2030 for all scenarios.

The results in Figure 42 show that the fault level on the 132kV network increasing over time under all scenarios. Gone Green and Consumer Power have the highest DG and demand growth and are showing the highest increase in fault . Under Gone Green 2030 the fault level sees an average increase of 28.9% over the 2016 fault level.

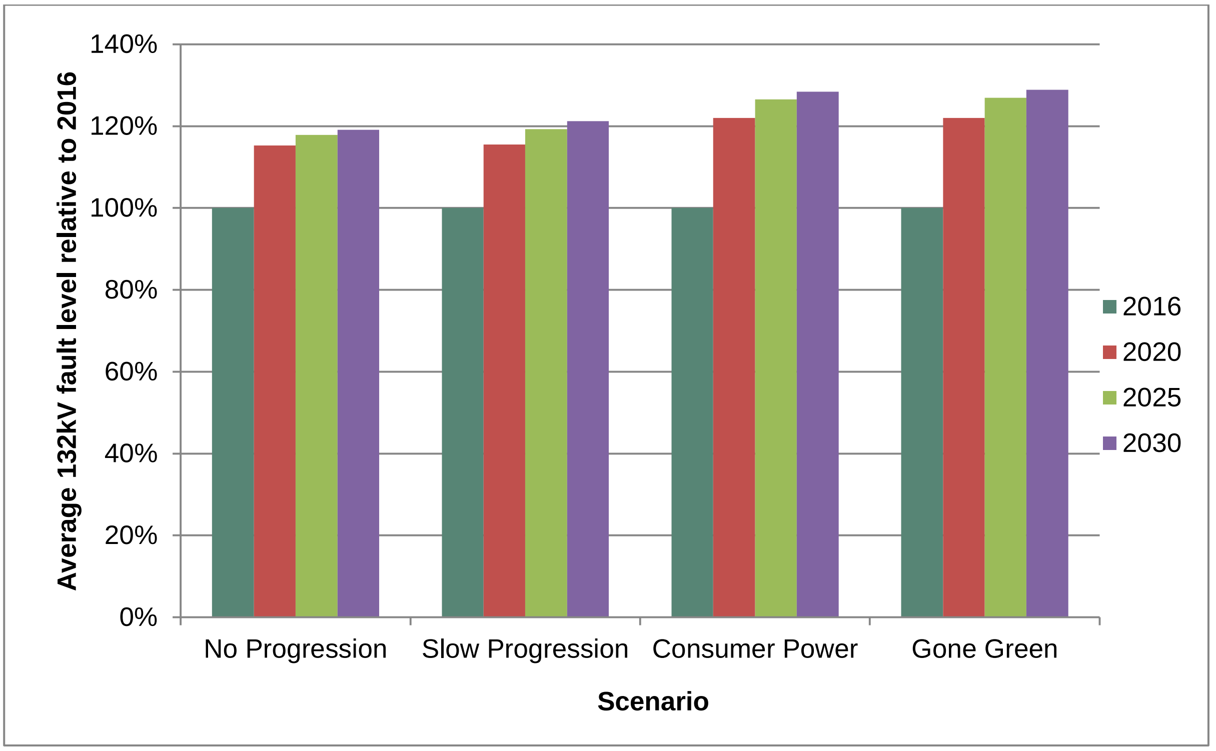

Figure 42: Average 132kV fault level under each scenario, relative to 2016

These results reflect fault level changes due to the growth of demand and DG only; it does not take into account changes in transmission infeed. Transmission infeed is expected to change significantly as the UK's generation mix changes and more reliance is placed on HVDC interconnectors. Transmission infeed forecasts for each scenario would be required from National Grid for a complete assessment.

Some network areas will see a higher increase in fault level than others. This will be dependent on the increase in demand and generation, but is heavily dominated by any new SGTs, or busbar running arrangement changes. The increase in local fault level due to DG will vary depending on the generation technology. Areas with high growth in synchronous connected plant will see a higher increase in fault level compared with areas with high growth in inverter connected technologies, due to their higher fault infeed.

Grendon 132kV – new running arrangements

An example of a significant increase in fault level is at Grendon Reserve 2 busbar, this is shown in Figure 43. The main increase in steady-state three-phase fault level is between 2016 and 2020 under all scenarios. This is due to Grendon getting replanted in our 2020 model to run the busbars at the GSP solid and significant new generation connections. The growth from 2020 to 2030 under all scenarios is much lower and is dominated by the connection of 33kV demand and generation. This highlights the dominating impact the NGET infeed has on 132kV fault level.

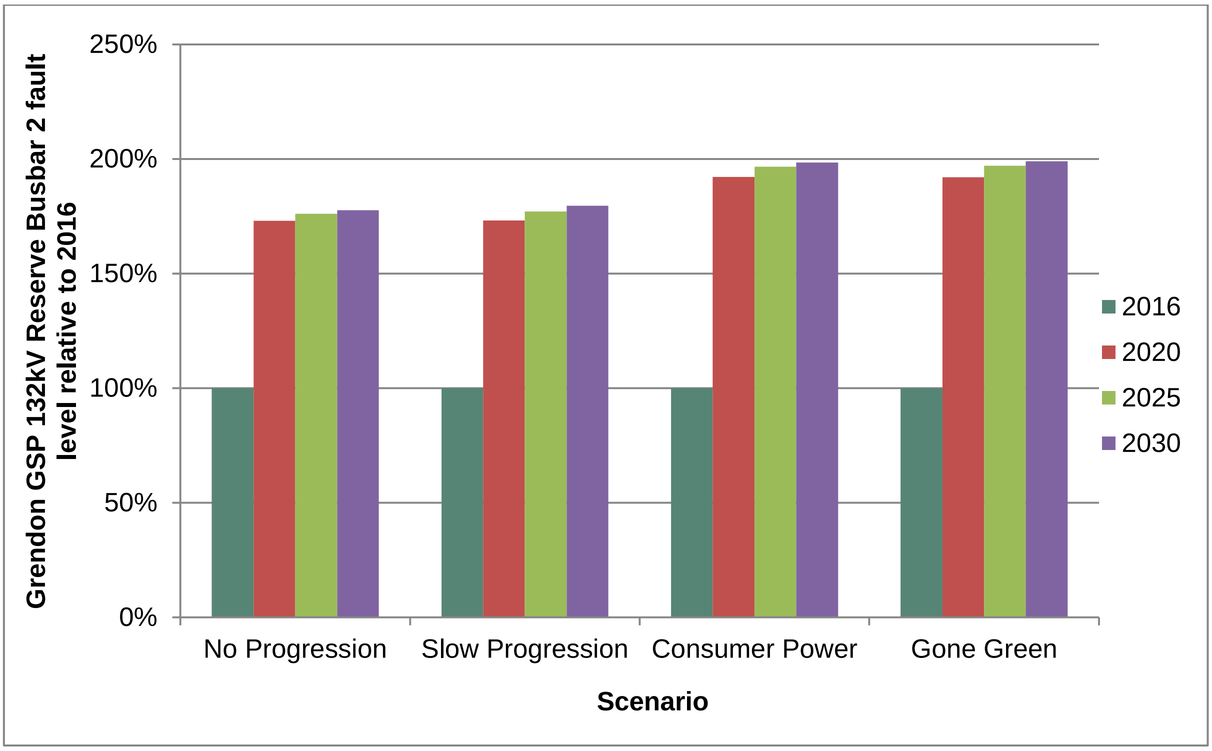

Figure 43: Grendon GSP 132kV Reserve Busbar 2 fault level under each scenario, relative to 2016

Coventry 132kV – unchanged running arrangements

An example where normal network running arrangement changes were not required is at Coventry GSP. The increase in fault level shown in Figure 44 is due to growth in distribution connected demand and generation. This highlights how the increase from predominately 33kV connected generation has less of an impact on the 132kV GSP fault level than the NGET infeed. The highest fault level increase is seen in Gone Green 2030 and is showing an 8% increase compared with the 2016 fault level. This is assuming a static NG infeed, which is not representative. Transmission infeed forecasts for each scenario would be required from National Grid for a complete assessment.

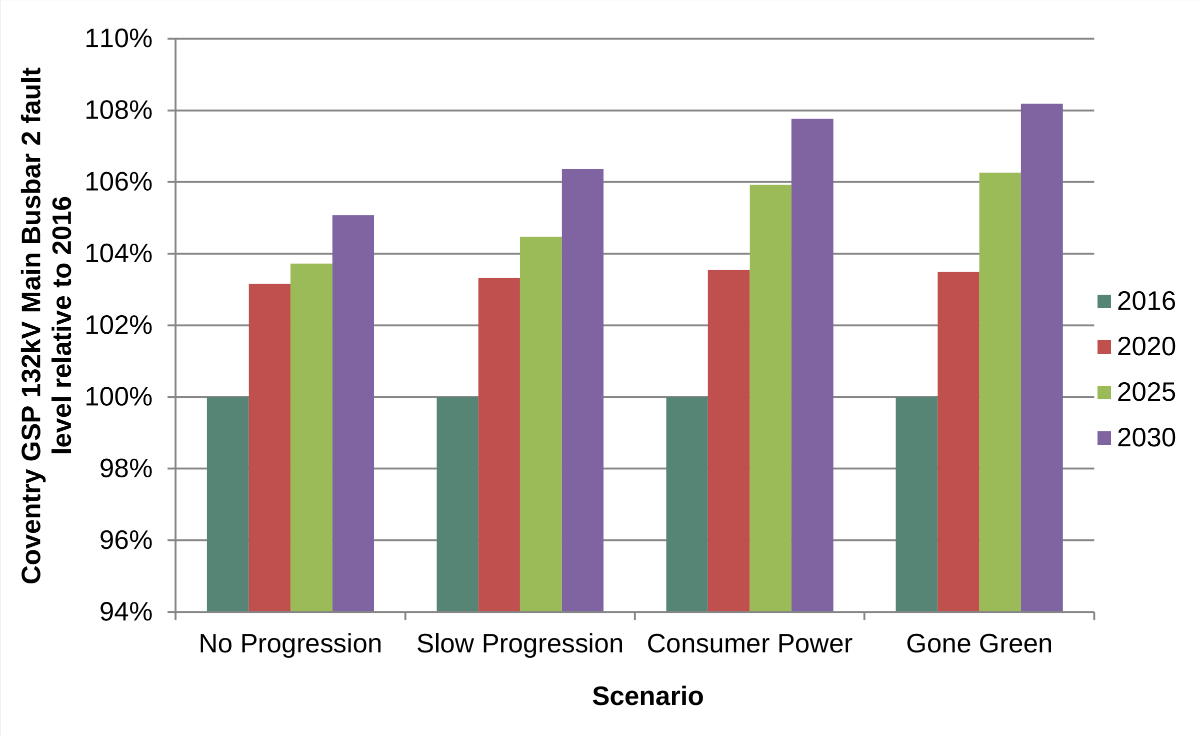

Figure 44: Coventry GSP 132kV Main Busbar 2 fault level under each scenario, relative to 2016

Leicester North 132kV – new generation

Whilst the most noteworthy fault level increases are due to GSP running arrangement changes or new SGTs, there are a number key locations on the 132kV network that are seeing significant growth due to distribution connected demand and generation growth. Figure 45 shows the 132kV bar three-phase fault level at Leicester North BSP (GT1 side). This graph shows there is a relatively low increase in fault level under No Progression and Slow Progression out to 2030. Consumer Power and Gone Green see a significant increase in fault level from 2016 to 2020 at Leicester North due to large generation connections in the area.

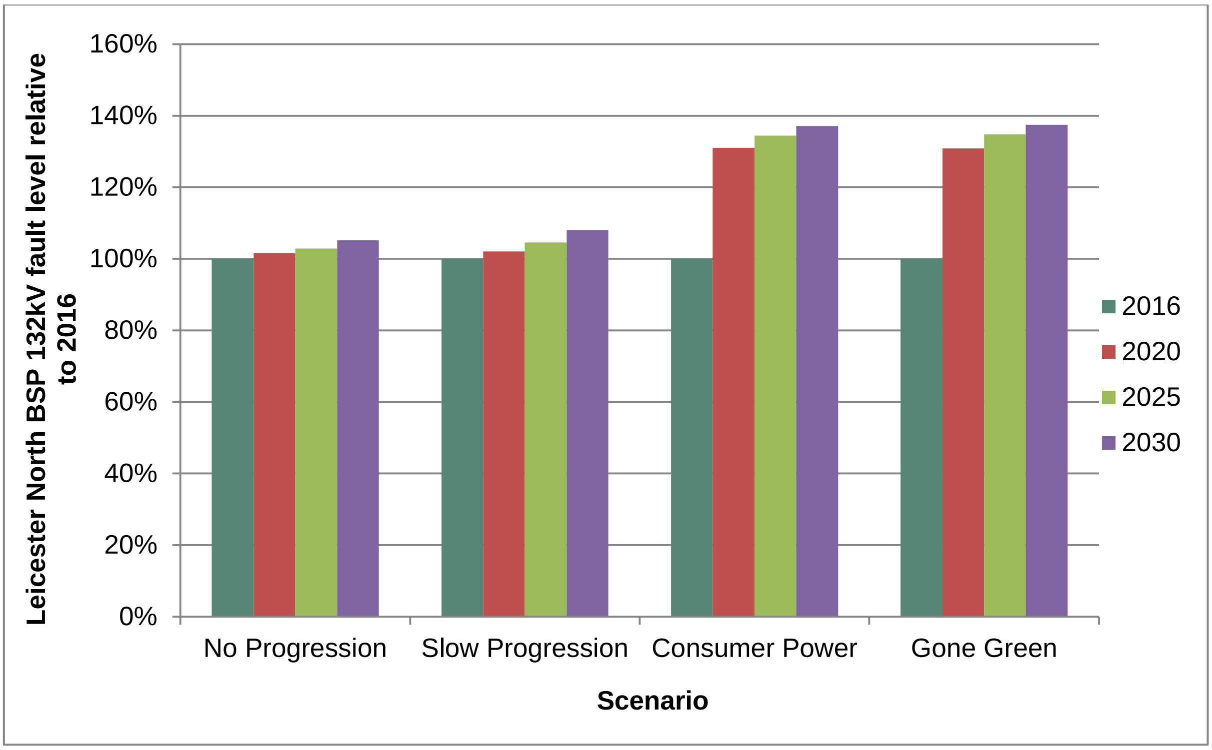

Figure 45: Leicester North BSP 132kV (GT1 side) fault level under each scenario, relative to 2016

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

Network Security

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

Underlying assumptions

Our networks shall, as a minimum:

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

Active Network Management

One method of deferring reinforcement is Active Network Management. In the RIIO-ED1 business plan for 2015-2023, WPD committed to improve network performance, provide excellent customer service and connect more renewable generation to the network. ANM was introduced as a method of enabling generator connections without the requirement for costly and time-delaying EHV and 132kV network reinforcement.

With the potential transition from a DNO to more of a Distribution System Operator (DSO), the use of ANM will become more important to accommodate any more DG connections. In addition, the DSO Strategy and Transition Plan recently published by WPD states that ANM will be fully available across the entire network by 2021. The existing generation ANM connection options will be expanded in 2017 to include demand connections, storage operators and those using a lower level of system capacity.

Currently there are four active network management areas in the East Midlands:

- Skegness BSP

- Corby area 132kV networks
- Northampton area 132kV networks
- Horncastle area 33kV networks

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

1. The customer acceptability of generator output curtailment for those connecting in the area (currently a trade-off for the lower cost of initial connection or faster connection time); and
2. The technical capabilities of the ANM scheme and the network it is managing.

Technical capabilities of ANM

Network complexity

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

Network monitoring and control

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

Operating timeframe and network transient ratings

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

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

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

1. Switchgear
2. Transformers
3. Overhead lines
4. Cables

5. Protection schemes

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

Where network behaviour would result in voltages or flows that exceed the 3 minute ratings of equipment, ANM will not be capable of managing the constraint by post-event curtailment. Instead pre-event curtailment or conventional reinforcement will be required. Pre-event curtailment of generator output is likely to reduce the energy output of generators much more than post-event curtailment. All of the active planned ANM systems used by WPD utilise pre-event curtailment. This is because there is a limited knowledge base on the short term overload capabilities of distribution network equipment.

Case Study: Corby ANM Zone

The strategic studies demonstrate a good example of where the balance between conventional reinforcement and DG output curtailment must be managed. The Corby ANM system is in operation to manage flows on the four circuits between Grendon GSP and Corby BSP and the surrounding BSPs which operate in reverse power during periods of high contribution from distributed generation. There are planned reinforcement works in this area to increase the thermal rating of the four circuits between Grendon GSP and Corby BSP. The ANM system curtails generation in the area using a Last in First out (LIFO) principle to ensure that the circuit flows do not exceed the thermal rating.

Figure 46, Figure 47 and Figure 48 show the half hourly flows on one of the circuits between Grendon GSP and Corby BSP for a summer representative day for a Gone Green scenario in 2020. The graphs show the circuit loading for an intact network, also for the most onerous first circuit outage and second circuit outage.

In Figure 46, the modelled network includes all 2020 planned reinforcement but does not include any ANM system for the Corby area. For a first circuit outage, the modelled circuit is overloaded for 11 of the 48 half hourly periods.

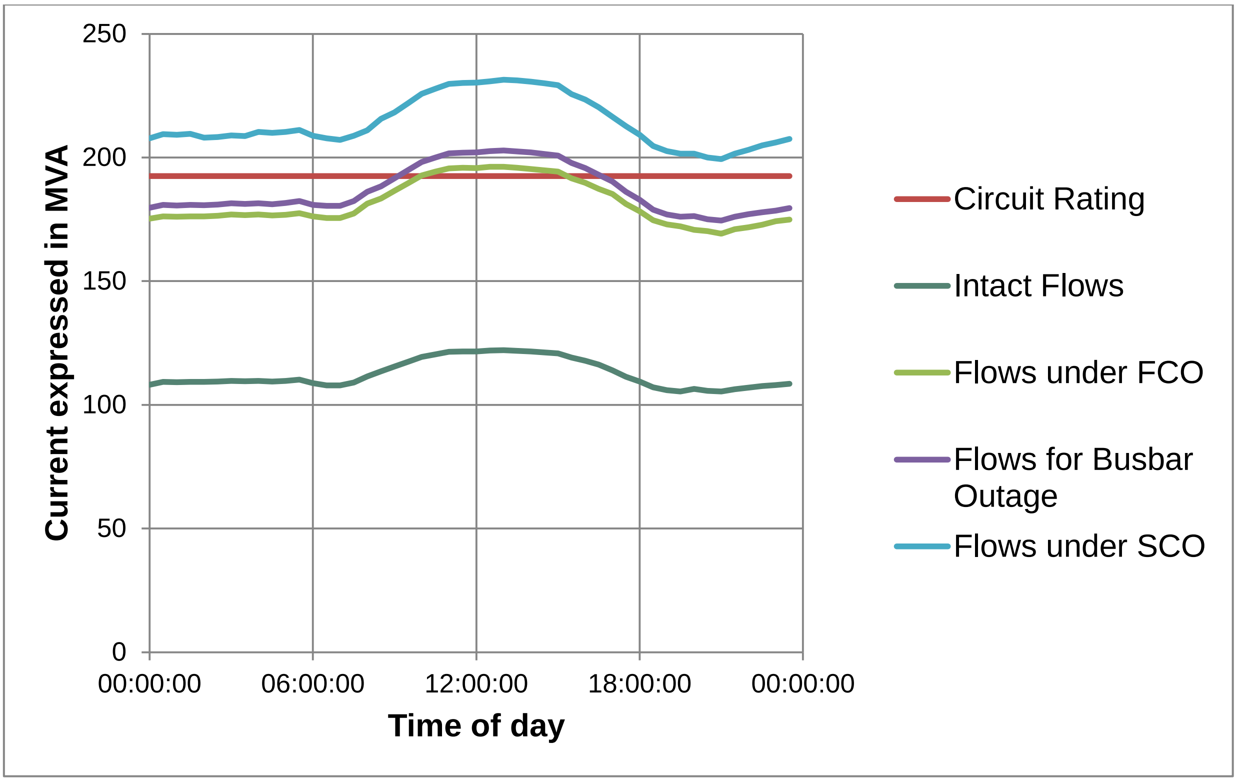

Figure 46 Summer Peak Generation day flow through Grendon-Kettering-Corby circuit during intact network conditions and the most onerous outage combinations, Gone Green 2020

Figure 47 shows a graph for the same circuit including the Corby ANM system modelled. It shows that with the ANM system is in operation, the circuit is not overloaded for the most onerous first circuit outage; however the circuit is overloaded for a second circuit outage.

As the ANM system utilises pre-event curtailment, for an intact network the generators are curtailed to a level as if the network was under a first circuit outage. This is to simulate the most onerous first circuit outage as the next system event. Similarly for a network under a first circuit outage, the generators are curtailed to a level as if the network was under a second circuit outage. The generator curtailment graph in Figure 47 shows the total amount of MW curtailed by the ANM system for each half hour under intact network conditions and for a first circuit outage.

In this scenario, it was noted in the results that the ANM system is not capable of alleviating system overloads for a second circuit outage. The ANM system becomes exhausted at the peak generation as no further generation can be curtailed, yet the circuit is still subject to overloads. In addition, there is significant generator curtailment for intact network conditions of approximately 60MW in total. It was noted that there is a poor load share between the four circuits from Grendon GSP to Corby BSP. Reinforcement was proposed to replant the switchgear at Grendon GSP such that the 132kV busbars could be run solid to improve this load share. It may be possible to defer this reinforcement if all new generation in the area is ANM-controlled.

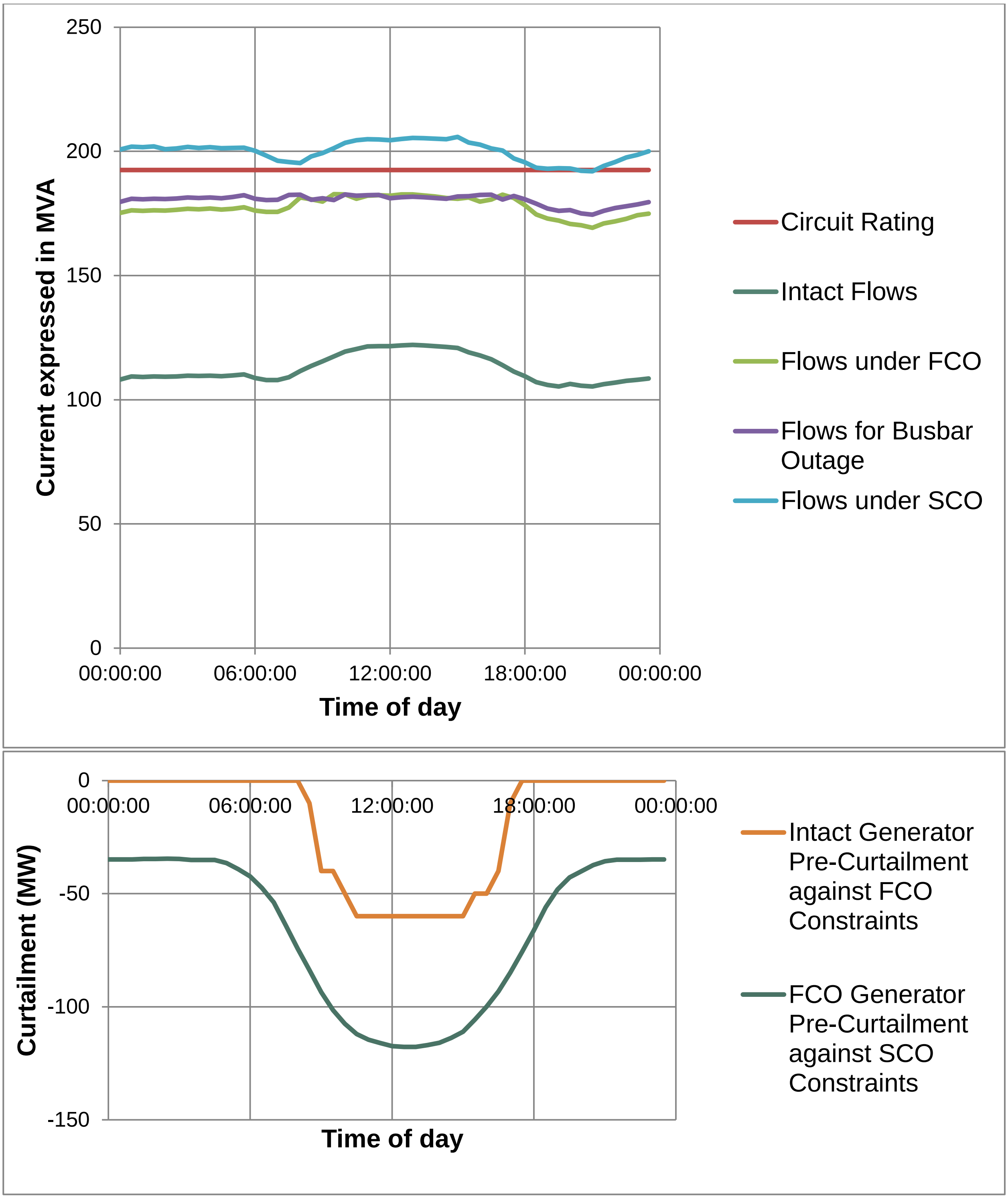

Figure 47 Summer Peak Generation day flow through Grendon-Kettering-Corby circuit during intact network conditions and the most onerous outage combinations with Corby ANM System installed, Gone Green 2020

Figure 48 shows a graph for the same circuit including the Corby ANM system modelled and Grendon GSP 132kV switchgear replanted such that Grendon could run solid at 132kV. It shows that with the ANM system is in operation, the circuit is remains within the thermal rating for all outage combinations. The load share on the Grendon

GSP-Corby BSP circuits in this case is more equal, and the ANM system does not have to curtail any generation for intact network conditions for a pre-curtailment of an FCO. However, the ANM system does curtail generation in anticipation of a second circuit outage when the network is under a first circuit outage.

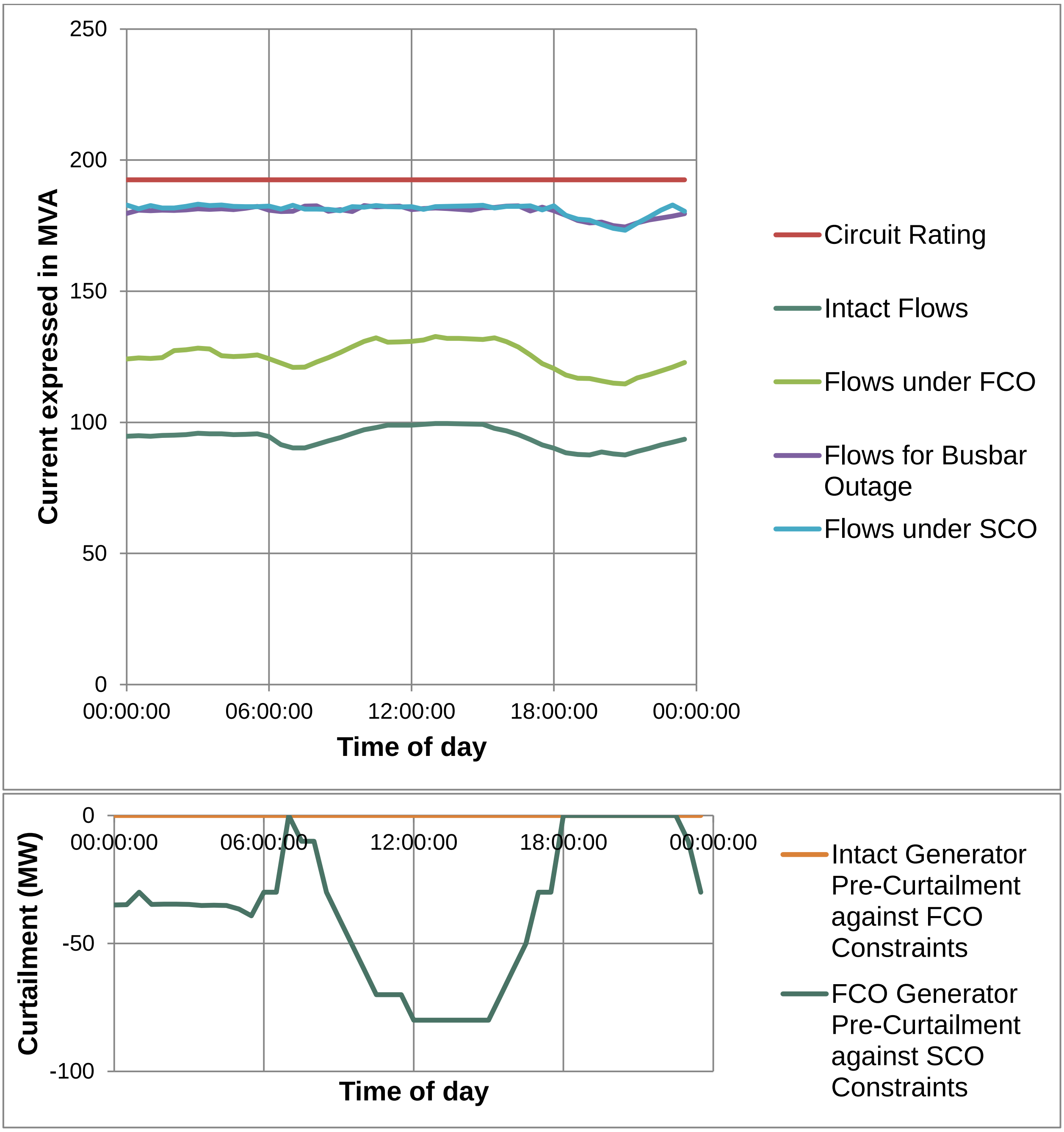

Figure 48 Summer Peak Generation day flow through Grendon-Kettering-Corby circuit during intact network conditions and the most onerous outage combinations with Corby ANM System installed and Grendon GSP replanted to run solid at 132kV, Gone Green 2020

It is interesting to note that under intact network conditions in 2020, the generators in the ANM zone are curtailed. With the current commercial arrangements for ANM, there will be a limit to the level of curtailment customers will accept, and this may deter future connections in this region. If this inhibits connections to the network, conventional reinforcement must be employed to release more capacity for further connection of generation in the area. The modelled program shows the benefit of installing an ANM system in the Corby region to manage circuit flows for periods of high summer generation. It does however show that whilst ANM and similar arrangements can be utilised to manage flows, traditional reinforcement is still necessary to help facilitate further generation connections in constrained areas.

It should be noted that a limitation of the ANM program is that the generation is curtailed off in 10MW sections. This is a feature of the ANM program which will be improved in future studies to show a higher level of granularity.

8 – Next Steps

Low regret reinforcement schemes

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

1. Berkswell GSP SGT capacity and associated transfer capacity to Coventry GSP;
2. Alfreton BSP GT capacity;
3. Coventry GSP SGT capacity under busbar fault conditions;
4. Rugby 132kV ring;
5. Enderby GSP SGT capacity and associated transfer capacity to Grendon GSP;
6. Leicester 132kV rings;
7. Grendon GSP SGT capacity and associated fault level constraints;
8. Northampton group 132kV circuits;
9. Staythorpe GSP SGT capacity and associated fault level constraints;
10. Hawton BSP GT and transformer-feeder capacity;
11. Checkerhouse BSP GT capacity;
12. Bourne 132kV network circuit capacity and associated transfer facilities to Staythorpe GSP;
13. Willington GSP SGT capacity/Spondon 132kV network capacity and associated transfer facilities to Staythorpe GSP; and
14. Stanton BSP GT capacity.

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

- A fourth SGT at Berkswell GSP;
- A third SGT at Bicker Fen GSP;
- The reconfiguration of Annesley BSP during asset replacement of GTs and 132kV switchgear;
- The reconfiguration of Clipstone BSP for a third 132/33kV GT;
- Establishing new supplies into the area between the M1 and M40 described in the East Claydon GSP 2025 results;
- Establishing a new GSP to deload Grendon and Enderby GSPs;
- Establishing a fourth 132kV circuit into the Northampton group during any asset replacement or reinforcement activities;
- Unbanking the 132kV circuits to Hawton BSP during the expansion of Staythorpe C 132kV bar; and

- Establishing a fourth 132kV circuit from Willington GSP to Spondon.

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

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

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 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 UKPN to assess WPD and UKPN's interdependent 132kV networks supplied from Walpole GSP.

As our understanding of the behaviour of battery storage develops, it should be incorporated into future studies. Similarly, any data on the charging behaviour of large populations of fast-charging, high-capacity EVs with a broad range of users should be used to refine the EV charging profiles used in these studies. WPD has recently undertaken a consultation on "Energy Storage Growth Scenarios and Operating Modes" to assist in future network modelling. The results from this consultation will be used to develop operating modes that will be integrated into future strategic studies.

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

1. More detailed fault level analysis including switchgear stressing,
2. Protection,
3. Dynamics,
4. Power quality.

9 – Definitions and references

References

External documents

G74

Engineering Recommendation G74 (*Procedure to Meet the Requirements on IEC 909 for the Calculation of Short-Circuit Currents in Three-Phase AC Power Systems*) is used to calculate fault levels for the determination of switchgear stressing.

P2

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

P18

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

P27

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

Electricity Act 1989 as amended

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

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

Future Energy Scenarios (FES) 2015, 2016

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

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

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

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

Report published by Regen SW to forecast the future changes in demand and generation in the East Midlands WPD licence area. Available from our website at: https://www.westernpower.co.uk/About-us/Our-Business/Our-network/Strategic-network-investment/East-Midlands.aspx

ENA Active Network Management Good Practice Guide

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

Insight Report Electric Vehicles

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

Western Power Distribution documents

1. ST:SD8A/2 (*Relating to Revision of Overhead Line Ratings*), used in conjunction with ER P27 to determine the ratings applicable to overhead lines;
2. ST:SD8C/1 (*Relating to 132kV, 66kV and 33kV Medium Power Transformer Ratings*), 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. East Midlands Subtransmission network single line diagram; available from our website at: https://www.westernpower.co.uk/About-us/Our-Business/Our-network/Strategic-network-investment/East-Midlands.aspx
5. East Midlands Subtransmission network geographic map; available from our website at: https://www.westernpower.co.uk/About-us/Our-Business/Our-network/Strategic-network-investment/East-Midlands.aspx

General definitions, initialisms and acronyms

Table of Units

Term	Definition
kV	Kilo-volt, a unit of Voltage (x10^3)
LV	This refers to voltages up to, but not including, 1kV
HV	Voltages over 1kV up to, but not including, 22kV
EHV	Voltages over 20kV up to, but not including, 132kV
kW	Kilo-watt, a unit of Power (x10^3)
MW	Mega-watt, a unit of Active Power (x10^6)
GW	Giga-watt, a unit of Active Power (x10^9)
MVA	Mega-volt-ampere, a unit of Apparent Power (x10^6)
MVAr	Mega-volt-ampere (reactive), a unit of Reactive Power (x10^6)
MWh	Mega-watt-hour, a unit of energy (x10^6). Equivalent to a constant 1MW of Active Power delivered for an hour
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

General Glossary

Term	Acronym/ initialism	Definition
Active Network Management	ANM	The ENA Active Network Management Good Practice Guide summarises ANM as: *Using flexible network customers autonomously and in real-time to increase the utilisation of network assets without breaching operational limits, thereby reducing the need for reinforcement, speeding up connections and reducing costs.*
Automatic Voltage Control	AVC	Automatic adjustment of transformer tap position required for transformers on the Primary Distribution and Subtransmission networks to maintain system voltage within limits as the demand changes.
Department for Business, Energy & Industrial Strategy	BEIS	The governmental department responsible for energy and climate change policy. Formed as a merger between the Department for Business, Innovation & Skills (BIS) and the Department for Energy & Climate Change (DECC)
Distribution Network Operator	DNO	A DNO is a holder of an electricity distribution licence.
Distribution System Operator	DSO	A role which may be established in the future whereby the DNO undertakes some of the roles of the System Operator at a regional level to balance supply and demand.
Electricity Supply Area	ESA	Each ESA represents a block of demand and generation as visible from the Subtransmission network. Each is one of:

		• The geographical area supplied by a Bulk Supply Point (or group or part thereof) providing supplies at a voltage below 66kV; • The geographical area supplied by a Primary Substation supplied at 66kV (or group or part thereof); • A customer directly supplied at 132kV or 66kV (or by a dedicated BSP or 66kV Primary Substation); or
Energy Networks Association	ENA	Taken from the ENA website: *…Represent the 'wire and pipes' transmission and distribution DNOs for gas and electricity…Influence regulation and the wider representation in UK, Ireland and the rest of Europe…*
Engineering Recommendation	ER	National standard engineering document published by the ENA
First Circuit Outage	FCO	P2/6 defines a First Circuit Outage as: *…a fault or an arranged Circuit outage…* Also referred to as N-1 in some contexts.
Office for Gas and Electricity Markets	Ofgem	Ofgem is responsible for regulating the gas and electricity markets in the UK to ensure customers' needs are protected.
National Grid	NGET	Transmission Network Operator in England and Wales
National Innovation Allowance	NIA	Funding scheme for innovation projects introduced as part of RIIO-ED1. For the RIIO-ED1 period, WPD requested the minimum 0.5% of total regulated income.
Remedial Action Scheme	RAS	Add-on module supplied by Siemens for PSS/E power system analysis software that enabled simulation of Corrective Action, control room actions in reaction to specific network conditions
Second Circuit Outage	SCO	P2/6 defines a Second Circuit Outage as: *…a fault following an arranged Circuit outage.* Also referred to as N-1-1 or N-2 in some contexts.
Sequential Control	SQC	Method of managing the network without the need for manual intervention from a Control Engineer.
Statement of Works	SoW	The process under which DNOs request that National Grid assesses the potential impact of the connection of DG upon the National Electricity Transmission System.
Time Of Use tariff	TOUT	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.*

Distribution Network Topology Glossary

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

Distribution Network Equipment Glossary

Term	Acronym/ initialism	Definition
All Aluminium Alloy Conductor	AAAC	Family of overhead line conductors, each of which is composed of strands of an aluminium alloy which combines mechanical strength with electrical conductivity. 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.
Aluminium Conductor, Steel	ACSR	Family of overhead line conductors, each of which combines steel strands for mechanical strength

Reinforced		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.
Cross Linked Poly-Ethylene	XLPE	Commonly used name for type of underground cable, which uses cross linked poly-ethylene insulation. They can be different sizes and are used extensively on the distribution network.
Copper	Cu	–
Distribution Transformer	–	A transformer that steps voltage down from 11kV or 6.6kV to LV
Grid Transformer	GT	A transformer that steps voltage down from 132kV to 66kV, 33kV or 11kV.
Primary Transformer	–	A transformer that steps voltage down from 66 or 33kV to 11kV or 6.6kV
Super Grid Transformer	SGT	A transformer that steps voltage down from 400kV or 275kV to 132kV, 66kV or 33kV

Future Technologies Glossary

Term	Acronym/ initialism	Definition
Anaerobic Digestion	AD	Generation process that utilises energy from waste products such to produce biogas for gas generator sets.
Combined Heat and Power	CHP	Method of utilising the excess heat energy as part of the electricity generation process to produce heat for local customers
Demand Side Response	DSR	Ofgem led tariffs and schemes which incentivise customers to change their electricity usage habits
Distributed Generation	DG	Generation connected to a distribution network. Sometimes known as Embedded Generation.
Electric Vehicle	EV	A vehicle which uses electric motors as its method of propulsion
Heat Pump	HP (Also ASHP)	Extracts heat from surroundings which can then be used to produce hot water or space heating. Heat Pumps can be in different forms, Air Source Heat Pumps absorb heat from the outside air.
Photovoltaic	PV	Type of Distributed Generation which uses solar irradiance to generate electricity.
Short Term Operating Reserve	STOR	National Grid reserve contract to respond to periods of peak demand using fast response generator sets.

Seasons

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

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

Transformer ratings

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

Cooling methods

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

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

Rating categories

Term	Acronym	Definition
Continuous Maximum Rating	CMR	The allowable sustained loading of a transformer for given cooling conditions that leads to a yearly average winding hot-spot temperature of 98°C (and so unity ageing) under the following ambient temperature conditions: • 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}	$Cyclic_{Winter\ ONAN}$	$Cyclic_{Winter\ Final}$
15/30	OFAF	15	30	19.5	39
20/40	OFAF	20	40	26	52
22.5/45	OFAF	22.5	45	29	58
30/60	OFAF	30	60	39	78
37.5/75	OFAF	37.5	75	48.5	97
37.5/90	OFAF	37.5	90	48.75	117
40/60	ONAF	40	60	52	78
45/90	OFAF	45	90	58.5	117
60/90	ONAF	60	90	78	117
60/120	OFAF	60	120	78	156

132/25kV traction supply transformers

Nameplate rating [MVA]	**Final Forced cooling method**	CMR_{ONAN}	CMR_{Final}	$Cyclic_{Winter\ Final}$
18	ONAN	18	18	18
18/26.5	OFAF	18	26.5	26.5

Notes:

1. *No spring or autumn ratings are tabulated in ST:SD8C/1, so Summer ratings were applied to the Spring/Autumn studies.*
2. *No ONAN Cyclic ratings are tabulated for transformers fitted with forced cooling in ST:SD8C/1, so a notional ONAN Cyclic rating was approximated where required by:*

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

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

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

Appendix

Program Summary

WPD East 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 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, N-1 and N-1-1 contingency analysis was run to assess the state of the network.

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

- An appropriate network model;
- The underlying demand capacity on each BSP;
- The forecast capacity of each DG and new demand on each BSP;
- Half-hourly profiles for each type of demand and DG; and
- The appropriate ratings of network component; and
- Existing corrective actions such as: intertripping, curtailment and automated reconfiguration.

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

- MVA flow on all branches of interest for all network conditions detailed in ‘Contingency Analysis’ below; 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
- MW/MVAr flows at the interface between WPD and National Grid for the intact network; and
- Any studies where the program was unable to calculate valid results (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, N-1 and N-1-1 study for any available task and writes the processed results to the database. To further improve runtime efficiency, the python multiprocessing module was utilised which allowed up to 6 parallel processes to run on each computer: significantly increasing CPU utilisation.

Corrective Action

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

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

The simplified processes followed by the analysis program is summarised in Figure 49.

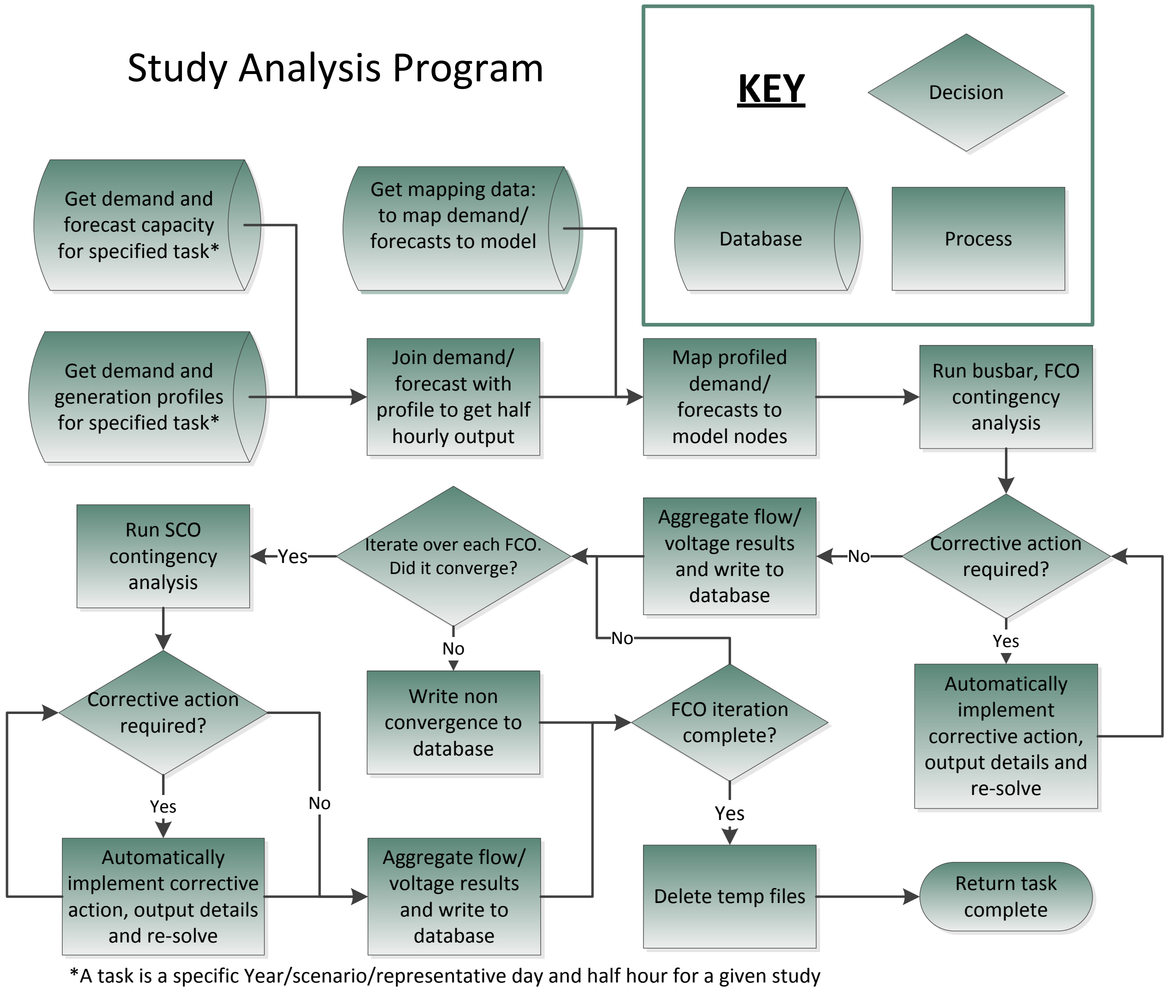

Figure 49: Simplified summary of analysis for a full N-1-1 analysis

Contingency Analysis

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

Circuit breakers were included in the network model in order to determine the protective zones bounded by circuit breakers which are de-energised under fault conditions. The following conditions were modelled:

1. The intact (normal running) network – 'BASE';

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

The contingency of each protective zone that includes at least one 132kV 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 limitation of the contingency analysis is the assumption that planned outages would always apply to the same zones as faults, rather than using isolators, links or jumpers to allow part of the zone to be brought back into service for the bulk of the duration of the outage.
2. A minor limitation of the program was that in a very small minority of studied conditions PSS/E were unable to converge (approximately 30 contingencies out of 9.6 million per study). 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.
3. 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 East Midlands model is an equivalent generator connected to the 400kV or 275KV side of the SGT transformers for each GSP. With no GSPs run in parallel on the 132kV this simplified equivalent is usually sufficient to represent distribution network behaviour. The limitation is where the equivalent of the GSP is oversimplified meaning the model is not representing the correct load share on the SGTs. This is not a major issue where the 132kV bars are run solid on the 132kV, but where the bars are run normally split it is causing incorrect model flows on the 132kV.
4. No model of battery storage behaviour was available, so their impact was excluded from the studies. WPD currently have a consultation on "Energy Storage Growth Scenarios and Operating Modes" to assist in future network modelling. The results from this consultation will be used to develop operating modes that will be integrated into future strategic studies.
5. 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

6. Only load-flow assessing steady-state voltage and power flows and high-level fault level studies have been carried out. No power quality, protection or stability studies have been carried out.
7. The East Midlands network has a significant number of loose couples. All loose couples between BSPs were removed from the model prior to running the analysis. This was done to increase model convergence success and reduce the complexities of modelling 33kV reconfiguration, which was beyond the scope of this project. This was shown to have a minor impact on 132kV flows, but was negligible compared with the non-convergences issue that arose if they were not removed.
8. The fault level analysis undertaken as part of this project used the PSS/E inbuilt ASCC analysis so does not meet Engineering Recommendation (ER) G74 – "Procedure to Meet the Requirements on IEC 909 for the Calculation of Short-Circuit Currents in Three-Phase AC Power Systems". This was due to the complexity in running a G74 analysis and the aim of this project was to get a fault level trend rather than absolute fault level.
9. The fault infeeds used a static NG 2016 winter peak fault infeed, due to no other available data. Infeeds from distribution connected demand and generation were based on generic assumptions per technology type; these were derived from the best available information. All BSP connected demand and generation is modelling on the LV bar of the BSP with the 33kV network de-energised, which will have an impact on the fault level and X/R ratio.

Industrial and Commercial Demand Profiles

The figures below show the typical half hourly MW profile of the 15 different industrial and commercial demand categories used in the project. Each is shown for a typical size of development in the category.

Factory and Warehouse

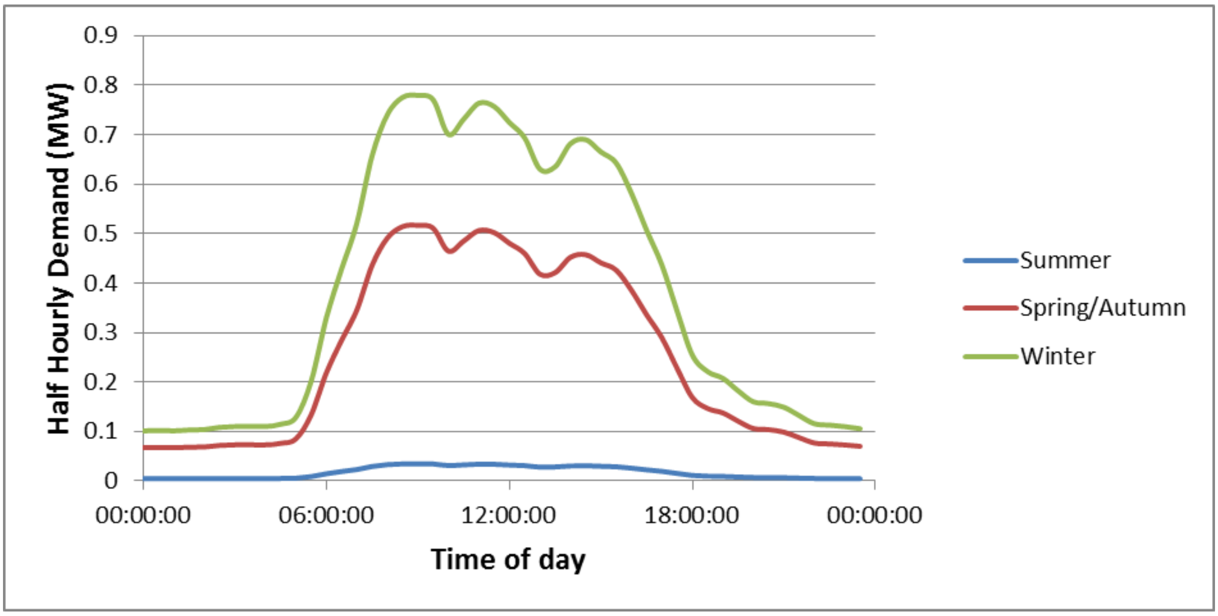

Figure 50: A typical half hourly profile used in the studies in the 'Factory and Warehouse' category of a typical size of 2000m^2, showing seasonal variation

Government

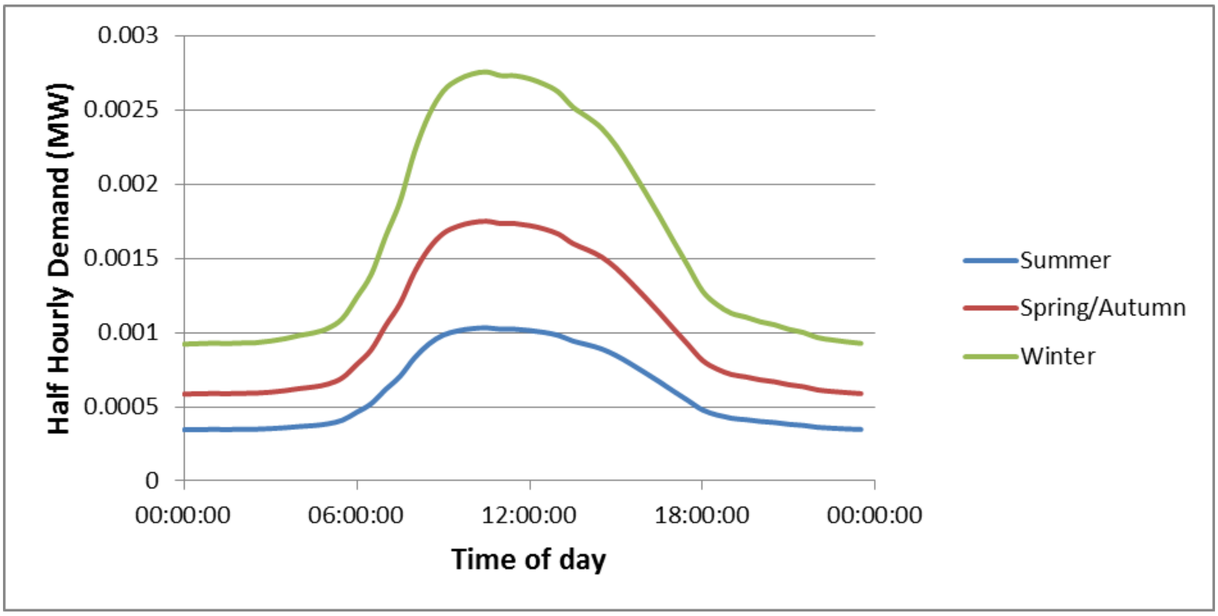

Figure 51: A typical half hourly profile used in the studies in the 'Government' category of a typical size of 250m^2, showing seasonal variation

Hospital

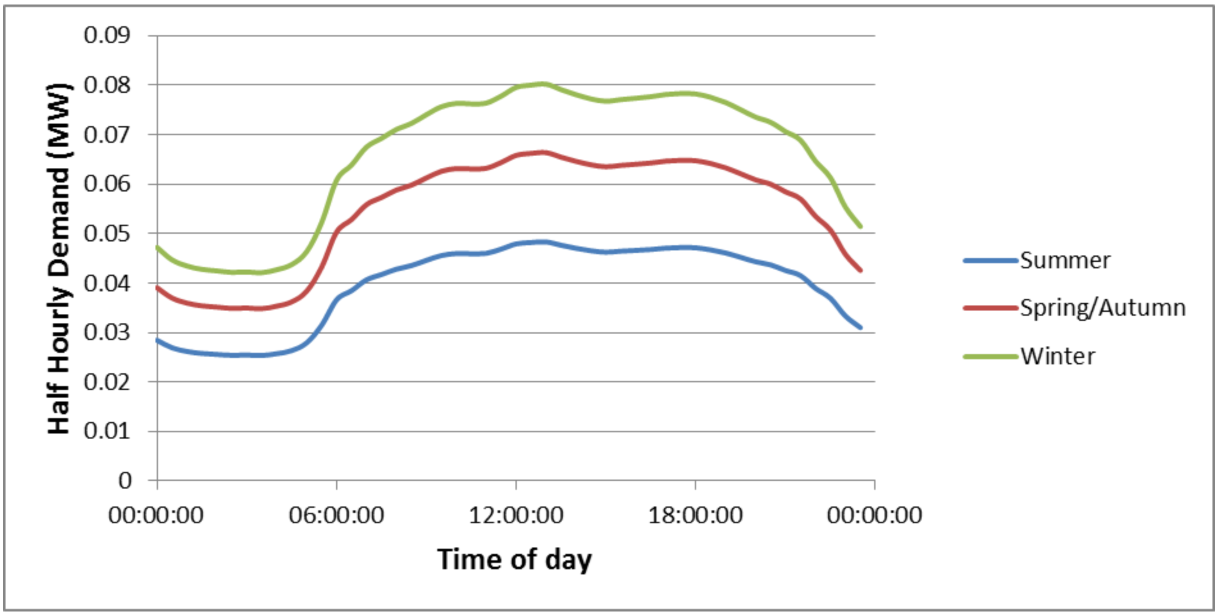

Figure 52: A typical half hourly profile used in the studies in the 'Hospital' category of a typical size of 2500m^2, showing seasonal variation

Hotel

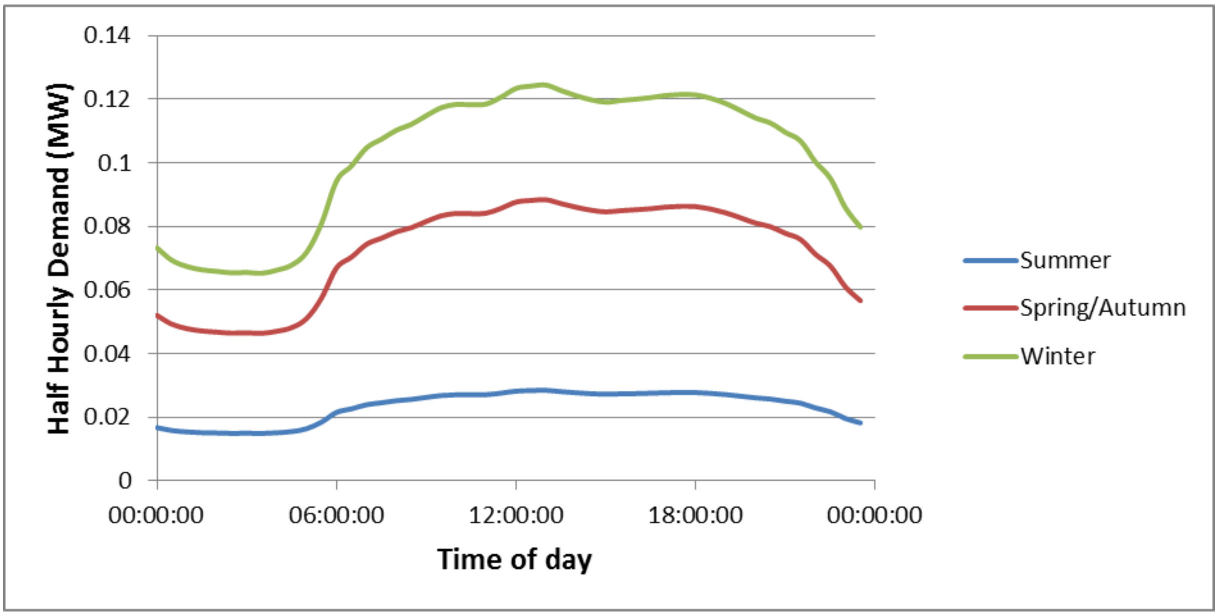

Figure 53: A typical half hourly profile used in the studies in the 'Hotel' category of a typical size of 1000m^2, showing seasonal variation

Hypermarket

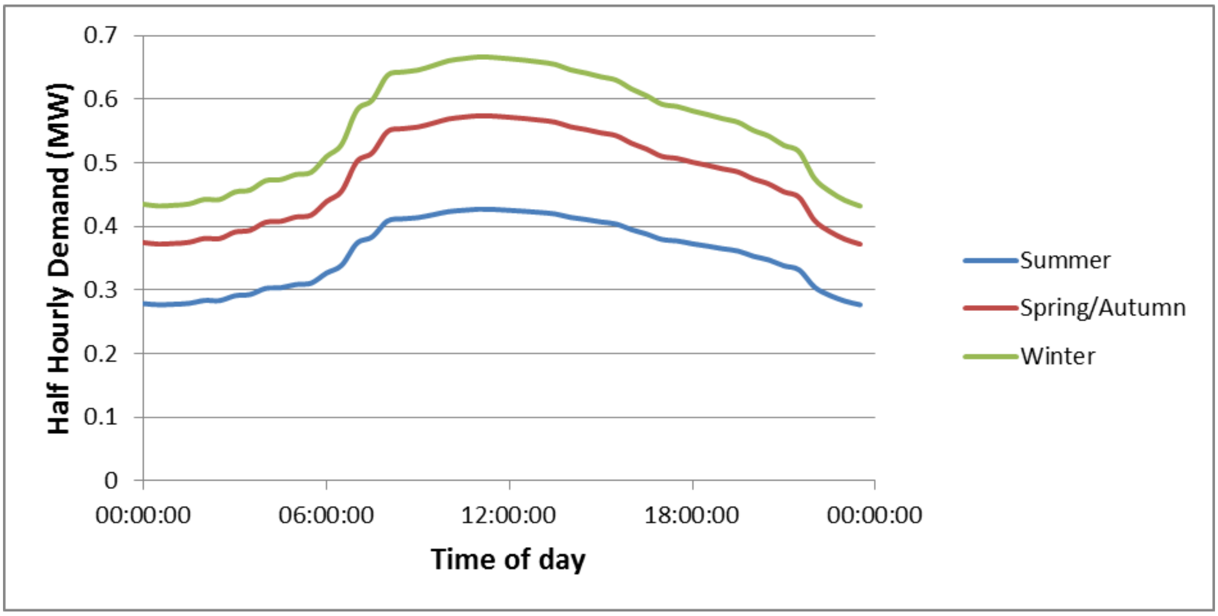

Figure 54: A typical half hourly profile used in the studies in the 'Hypermarket' category of a typical size of 1750m^2, showing seasonal variation

Medical

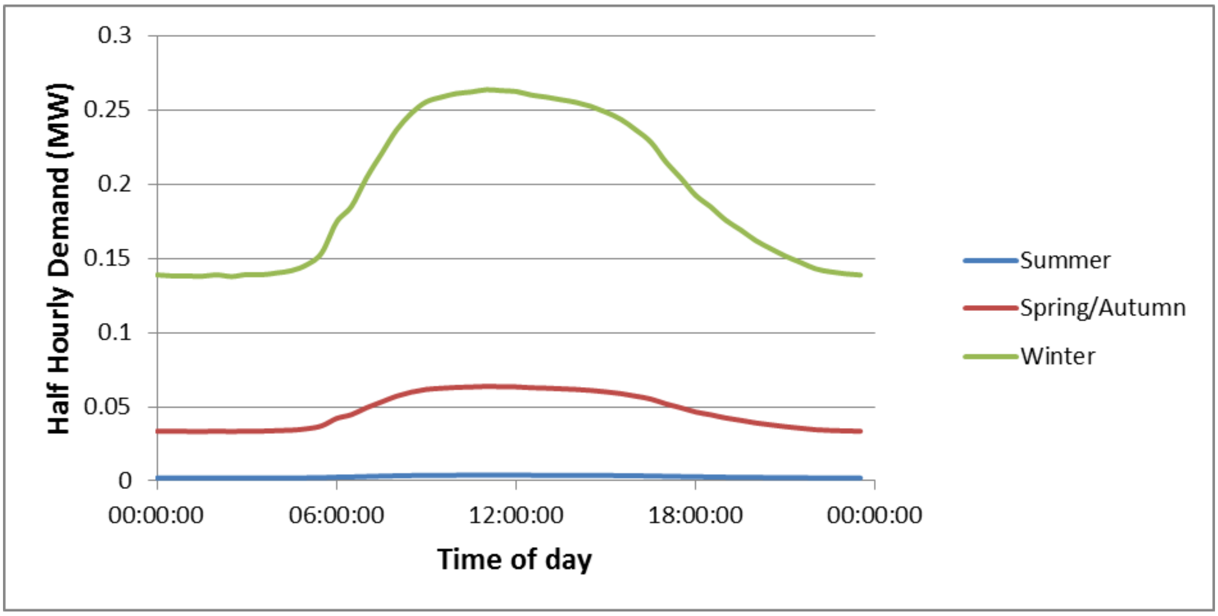

Figure 55: A typical half hourly profile used in the studies in the 'Medical' category of a typical size of 350m^2, showing seasonal variation

WESTERN POWER DISTRIBUTION
Serving the Midlands, South West and Wales

Office

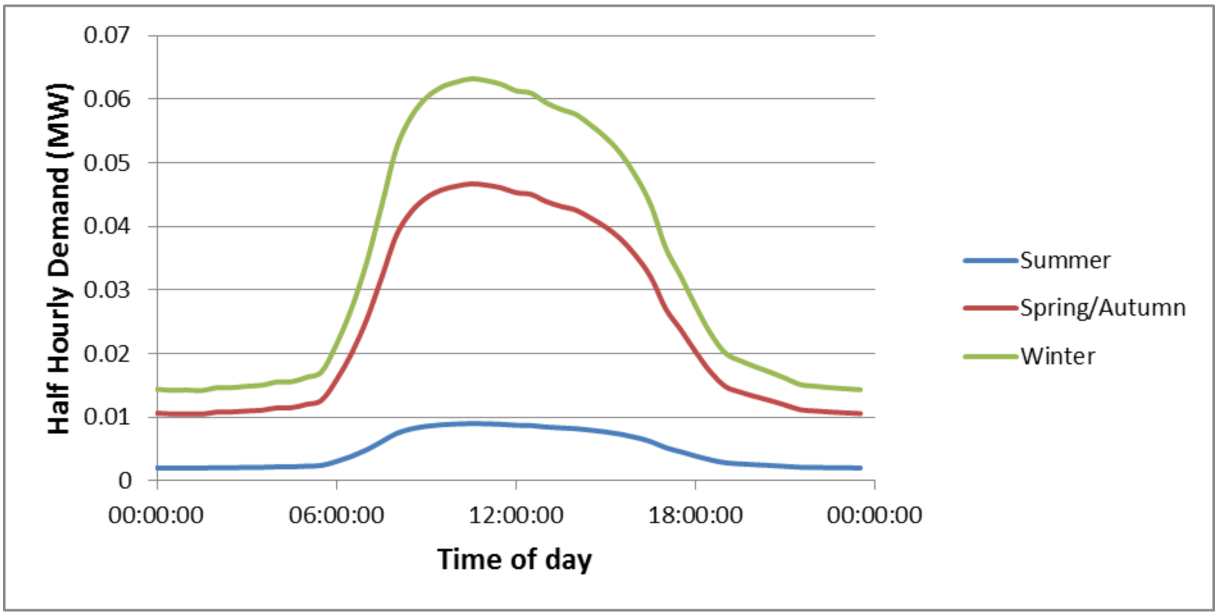

Figure 56: A typical half hourly profile used in the studies in the 'Office' category of a typical size of 500m^2, showing seasonal variation

Other

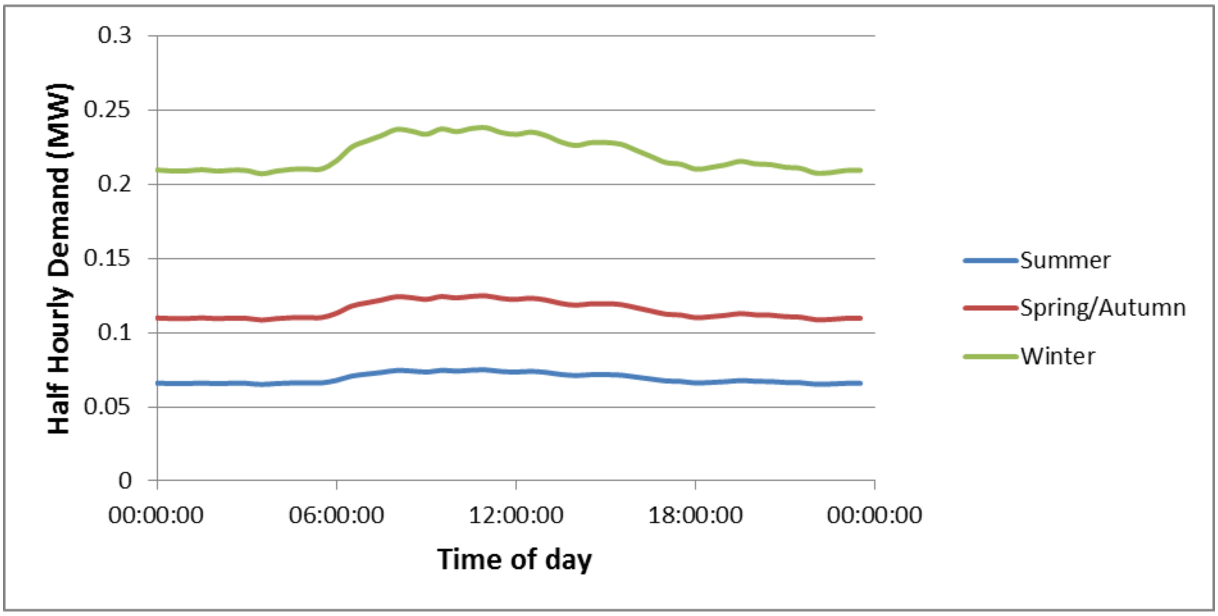

Figure 57: A typical half hourly profile used in the studies in the 'Other' category of a typical size of 1000m^2, showing seasonal variation

Police

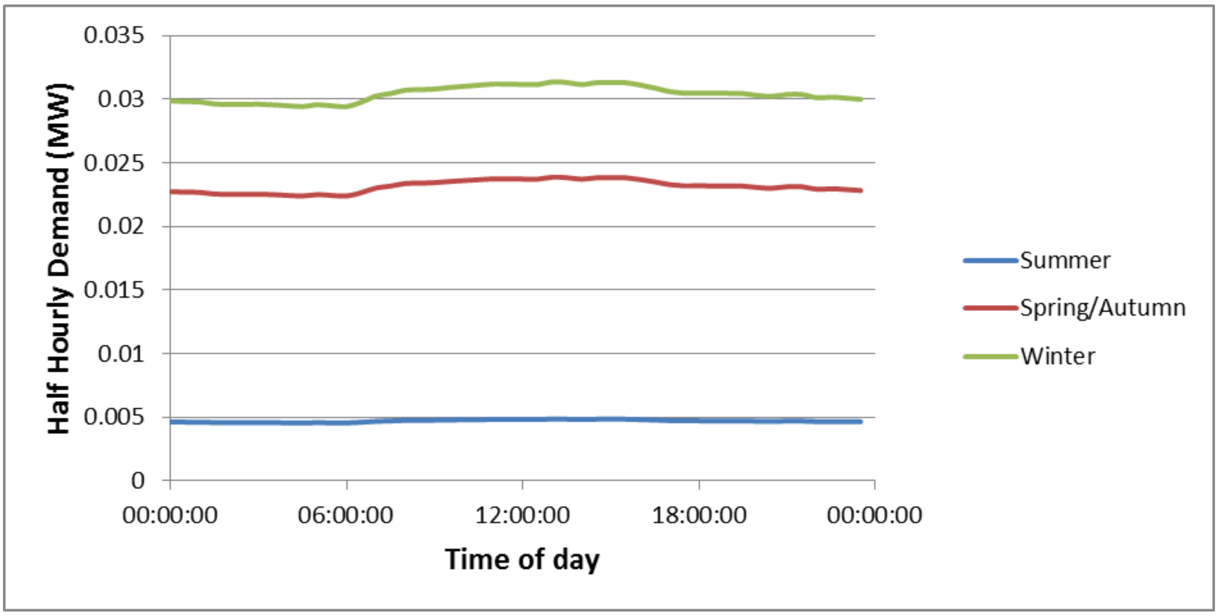

Figure 58: A typical half hourly profile used in the studies in the 'Police' category of a typical size of 250m^2, showing seasonal variation

Restaurant

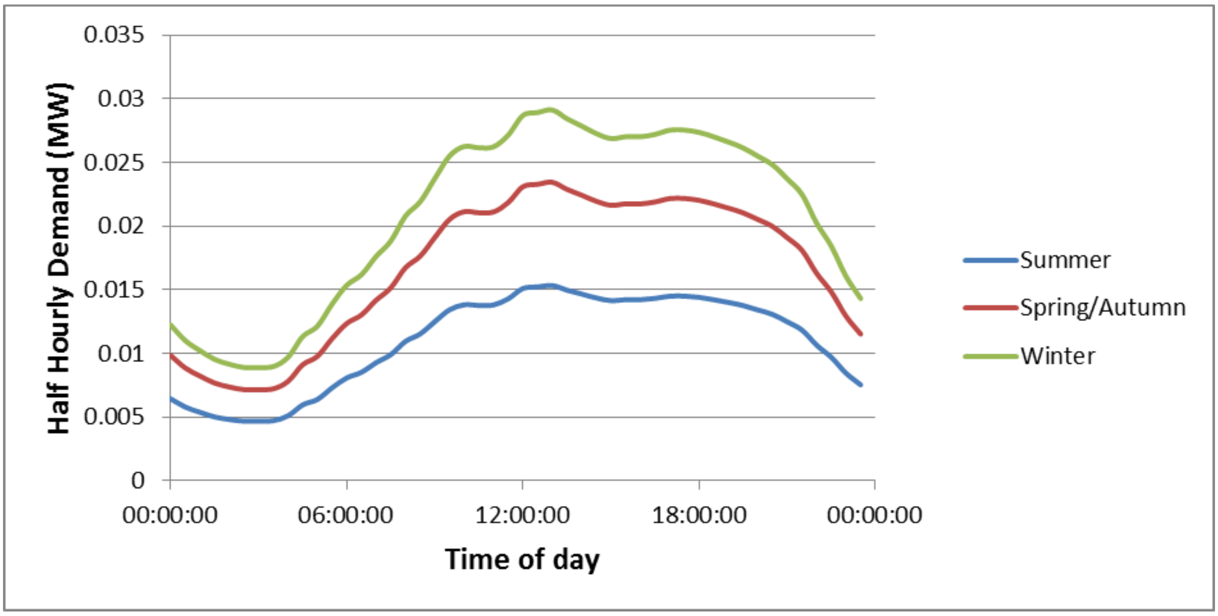

Figure 59: A typical half hourly profile used in the studies in the 'Restaurant' category of a typical size of 100m^2, showing seasonal variation

Retail

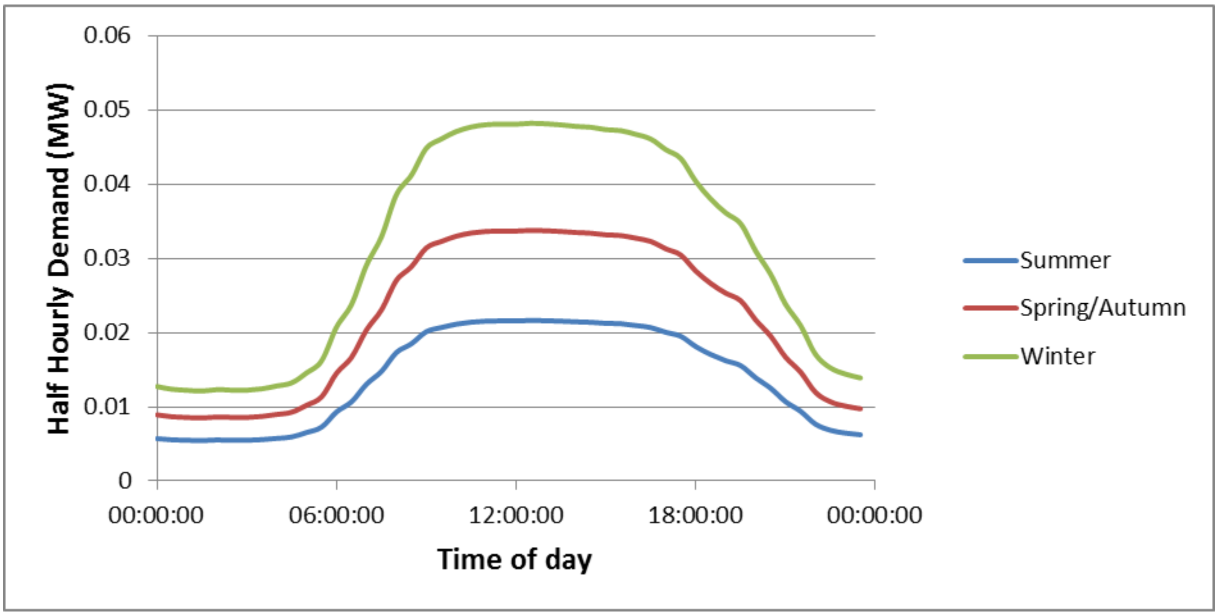

Figure 60: A typical half hourly profile used in the studies in the 'Retail' category of a typical size of 1250m^2, showing seasonal variation

School & College

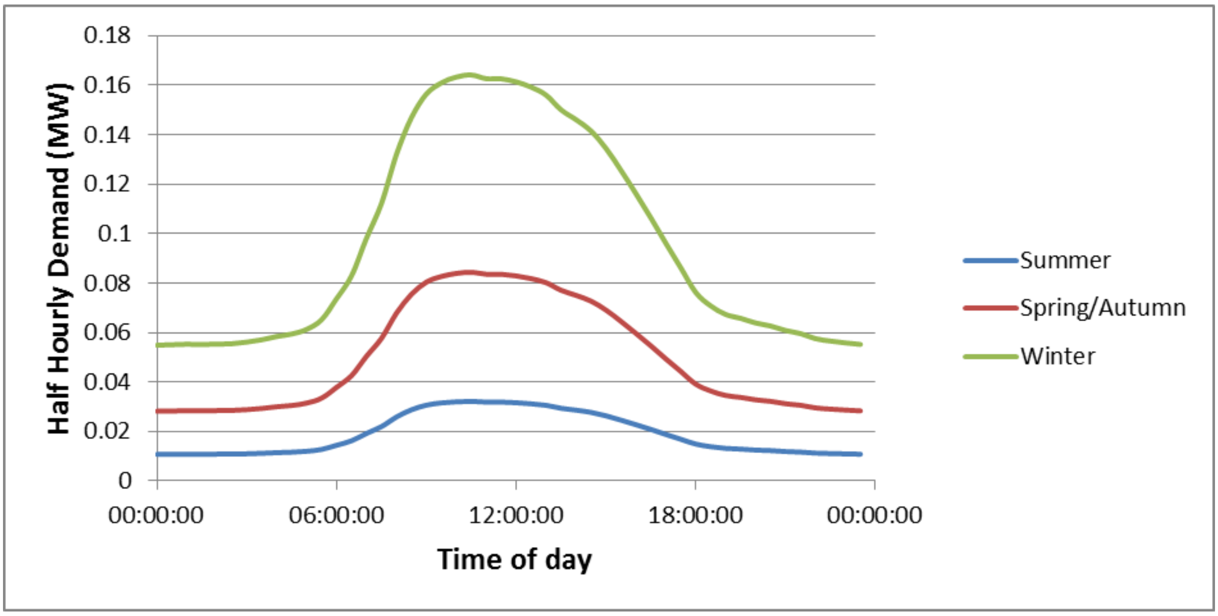

Figure 61: A typical half hourly profile used in the studies in the 'School and College' category of a typical size of 3000m^2, showing seasonal variation

Shop

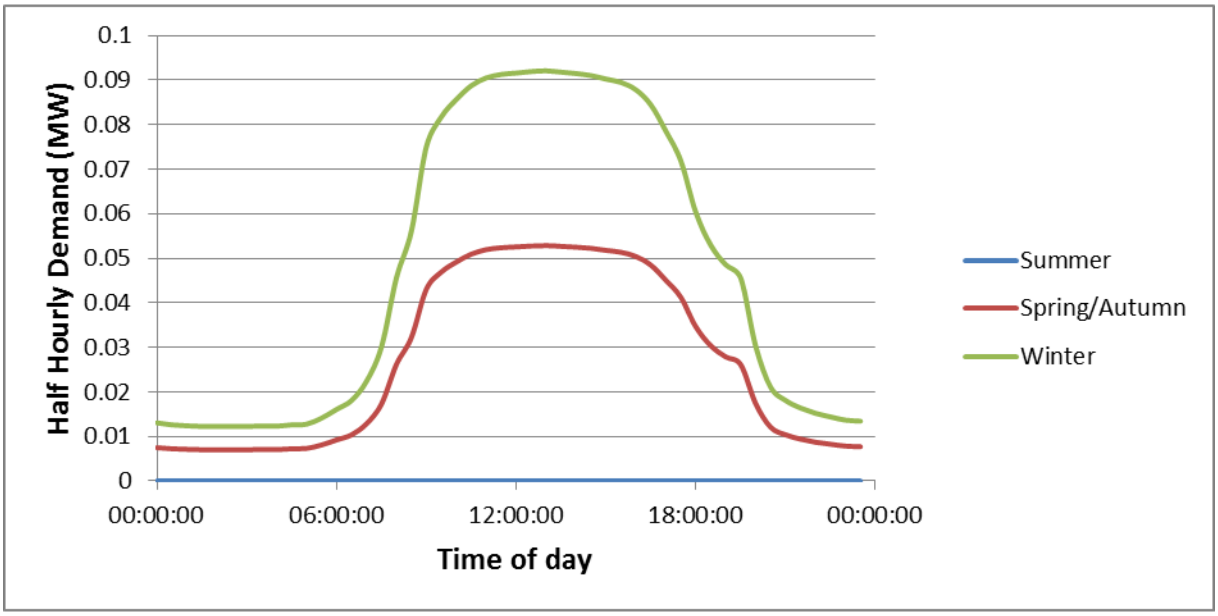

Figure 62: A typical half hourly profile used in the studies in the 'Shop' category of a typical size of 250m^2, showing seasonal variation

Sport & leisure

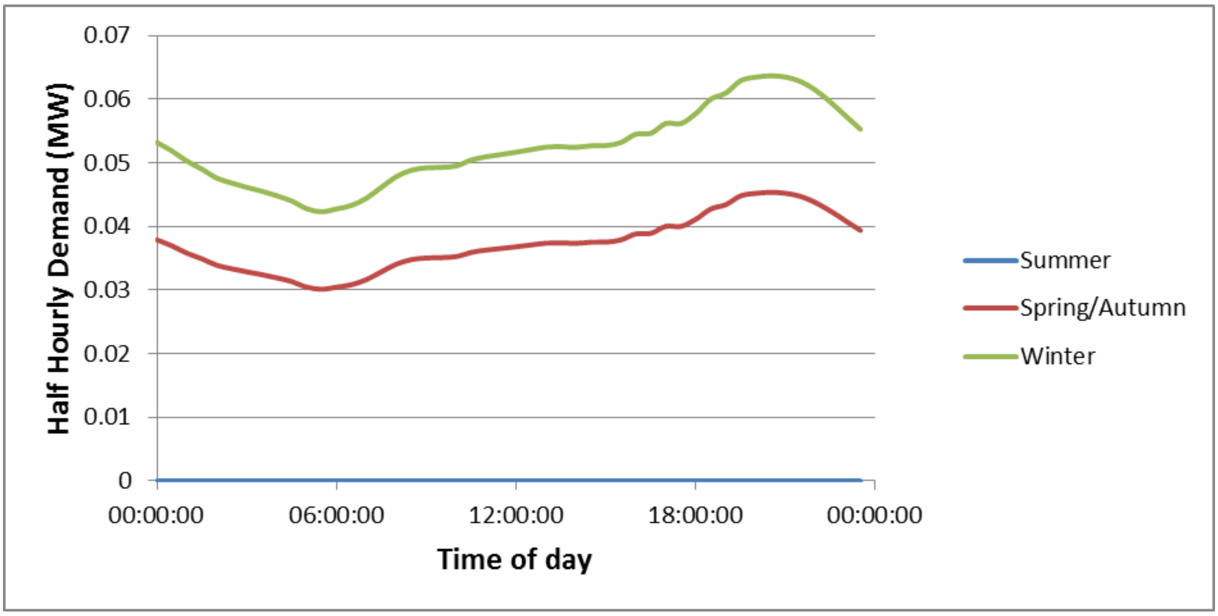

Figure 63: A typical half hourly profile used in the studies in the 'Sport and Leisure' category of a typical size of 1750m^2, showing seasonal variation

University

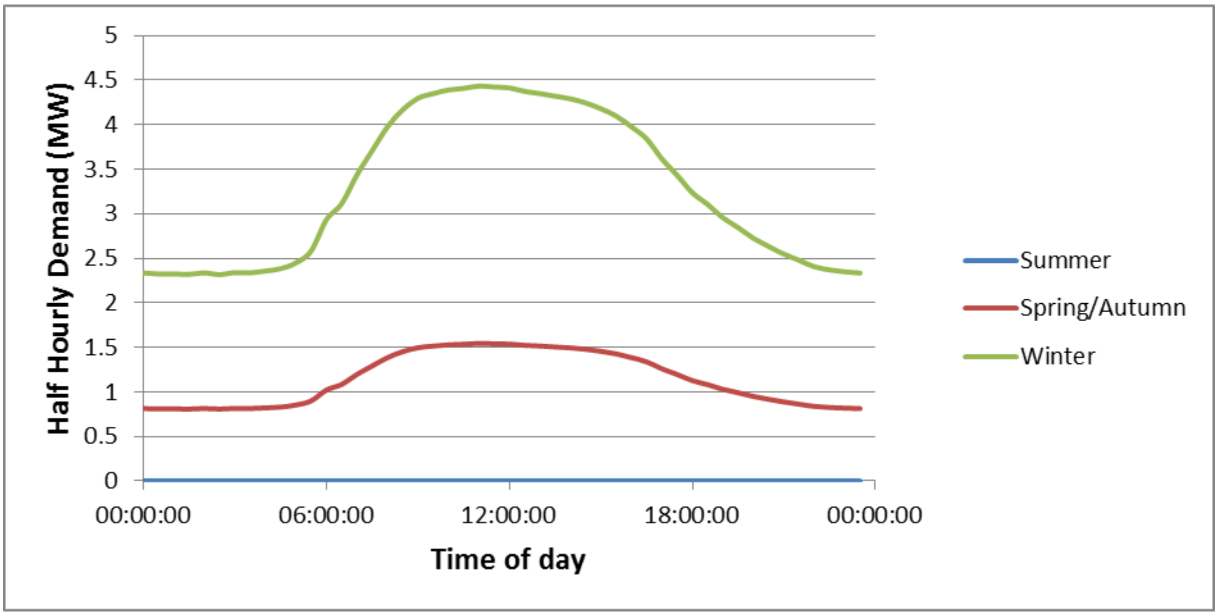

Figure 64: A typical half hourly profile used in the studies in the 'University' category of a typical size of 10000m^2, showing seasonal variation