Strategic Innovation Fund – Discovery Phase

DIVERSIFIED FLEXIBLE QUEUE MANAGEMENT

Quantifying and Analysing Network Congestion and Queue Management Report

JUNE 2023

CONFIDENTIAL

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Quantifying and Analysing Network Congestion and Queue Management Report

FINAL REPORT CONFIDENTIAL

PROJECT NO. 70090871

DATE: JUNE 2023

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QUALITY CONTROL

Issue/revision	Draft version	Final version
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Project number	70103129	70103129
Report number	70103129-001	70103129-001
File reference	70103129-001	70103129-001

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1 QUEUE MANAGEMENT

1.1 PROBLEM STATEMENT

Achieving net zero ambition relies on the integration of renewable energy sources and storage (RES) within the Great Britain power network. These RES are connected within the distribution network at specific locations that favour maximum generation, such as locations that are windy (for wind farms) or locations that are shade-free and southerly (for solar farm). Such requirements on location increases the loading at specific points within the distribution network. The connection requests for generation and storage traditionally consider the rated capacity of the generation units that typically results in significant restrictions on the generators operation or queues with long delays and expensive costs due to reinforcements.

It is known that the RES are unlikely to operate at their rated capacity at the same time. The actual capacity available is therefore higher than the headroom obtained through the conventional conservative approach. It can also be hypothesized that greater generation capacity can be incorporated within the distribution network if the diversity of the generation resources is varied, enabling effective utilisation of the headroom available.

The Diversified Flexible Queue Management project seeks to investigate the viability of data to drive network operation and adaptive management of distribution connections. It will assess the diversity of customer loads and the flexibility of their assets. It is aimed to identify actual existing and potential available capacity on the network, enabling faster connections for customers.

The project is divided into three work packages, and this report summarizes the task undertaken as part of work package 1 and 3. A brief description of work package 1 and 3 is presented in the next subsection.

1.2 WORK PACKAGE DESCRIPTION

In line with net zero aspiration and the subsequent evermore increasing RES connection requests on distribution networks, the estimation of real headroom availability becomes of utmost importance. Traditionally the available headroom at any given grid supply point (GSP) is calculated as the firm available capacity upstream minus the maximum expected power-flow through the GSP (load/generation), which we refer to as static headroom throughout this report. One major drawback of the static estimated headroom is its negligence of generation pattern diversity (e.g., wind and solar). Alternatively, a dynamic headroom can be estimated by utilising the existing historical data for each GSP and their corresponding generation composition.

1.2.1 WORK PACKAGE 1

Work package 1 focuses on analysing the GSPs within the distribution network operated by Northern Powergrid (NPg). There are two major tasks within the work package:

- The GSPs will be prioritised in order of the connection requests and will be analysed for their static and dynamic headroom availability. Grid supply point operational metering data will be utilised for this analysis.

- The second task involves the assessment of the generation capacity that can be incorporated within the distribution network by means of effective utilisation of the dynamic headroom enabled by diversification of generation mix at the GSP.

1.2.2 WORK PACKAGE 3

Work package 3 focuses on assessing and optimizing the utilization of capacity at GSPs, primarily involves evaluating the potential for increasing the installation of wind and solar generation and determining the optimal mix of these generation sources. The work package is divided into two main components:

- In this first part of the work package, we'll be looking closely at the hosting capacity at two GSPs. The goal is to understand how much more wind and solar generation can be added to these locations.

- The second part of the work package delves into the influence of storage and flexible demand, such as electrolysers, on the hosting capacity at GSP.

1.3 STRUCTURE OF THE REPORT

Remainder of this report is structured as follows:

The analysis of the GSPs is presented in Section 2. The shortlist of GSPs chosen for analysis are identified, followed by a brief description of the data made available for the analysis. A detailed assessment of Creyke Beck GSP, identifying its current static headroom and the actual headroom available is then presented. This is followed by presenting the summary of generation composition at all GSPs and the summary of the headroom analysis for all screened GSPs.

Section 3 presents the methodology for the evaluation of the flexibility enabled by considering the diversity of generation pattern of the generation technology and the variability in the composition of the generation technology itself. A detailed case study of Creyke Beck GSP has been presented, where the maximum generation capacity that can be realised with conventional approach and the proposed alternative are identified.

Section 4 presents a comprehensive analysis of hosting capacity at GSPs, focusing on the dynamic and static assessments of wind and solar generation. Additionally, it explores the potential benefits of incorporating storage and flexible demand to optimize distribution network operation. The findings aim to provide insights into achieving an efficient mix of generation sources.

Section 5 concludes the report.

2 GSP ANALYSIS FOR STATIC AND DYNAMIC HEADROOM

In this section an analysis of the GSPs is carried out to evaluate the static and dynamic headroom available. Forty GSPs have been analysed in order of their priority as presented within the table below:

Table 2-1 – Prioritised order of GSPs

Generation Type	Licence Area	Priority
Creyke Beck	YORKSHIRE	1
Norton 275/132kV	NORTHEAST	2
Keadby	YORKSHIRE	3
West Melton 3	YORKSHIRE	4
Ferrybridge B	YORKSHIRE	5
Skelton Grange	YORKSHIRE	6
Grimsby West	YORKSHIRE	7
Spennymoor 400/132kV	NORTHEAST	8
Saltend North	YORKSHIRE	8
West Melton/TM	YORKSHIRE	10
Blyth 'A' 66kV	NORTHEAST	11
Knaresborough 275/132kV	NORTHEAST	11
Osbaldwick 400/132kV	NORTHEAST	11
Thurcroft	YORKSHIRE	14
Drax	YORKSHIRE	15
Elland	YORKSHIRE	16
Hartmoor 275/66kV	NORTHEAST	17
Hawthorn Pit 275/66kV	NORTHEAST	17
Saltholme 275/132kV	NORTHEAST	19
Stella South & North 132kV (N)	NORTHEAST	19
Stella South & North 132kV (S)	NORTHEAST	19
Bradford West	YORKSHIRE	22
Camblesforth	YORKSHIRE	23
Ferrybridge A	YORKSHIRE	23
Lackenby 275/66kV	NORTHEAST	25
Tynemouth 275/132kV	NORTHEAST	25
Kirkstall B	YORKSHIRE	27

West Boldon 275/66kV	NORTHEAST	28
Fourstones 275/20kV	NORTHEAST	29
Poppleton 265/33kV	NORTHEAST	29
Offerton 275/132kV	NORTHEAST	31
Jordanthorpe	YORKSHIRE	31
Neepsend	YORKSHIRE	31
Pitsmoor	YORKSHIRE	31
Blyth 'B' 132kV	NORTHEAST	35
South Shields 275/33kV	NORTHEAST	35
Norton Lees	YORKSHIRE	35
Sheffield Ring	YORKSHIRE	35
Templeborough	YORKSHIRE	35
Wincobank	YORKSHIRE	35

The following section describes the data required for the analysis and any pre-processing that was required to undertake the analysis. The analysis of the Creyke Beck GSP is presented next, followed by summarising the generation composition at all GSPs. The section concludes with a summary of the headroom analysis for all the screened GSPs.

2.1 DATA FOR ANALYSIS

The data analysis carried out in this section is based on the following data received directly from NPg or retrieved from public websites.

Load and generation composition: load and generation composition for each GSP have been provided and were utilised to draw some insights into their impact on dynamic headroom estimation.

Firm capacity and contracted generation connection: Firm capacity at each GSP and the contracted future generation have been extracted from Heat Map data available on NPg website.

GSP timeseries data: Half hourly timeseries data has been provided for all GSPs and their downstream feeders in Yorkshire and Northeast region of the NPg network for the year 2022. The timeseries data was provided in json format for each month of the year. Upon a quick review of the data, it was identified that the time series data had missing values. A code was developed in python to:

- Extract data, clean and fill in missing values where appropriate for each GSP of interest
- Consolidate the variables of interest (e.g., active, and apparent power) for its downstream feeders for each month
- Append them all together and enable visualisation of total GSP variables for the whole year

Utilising the received data, the generation and load at each of the GSP is summarised followed by evaluation of the static and dynamic headroom. The static headroom (S_{Static}) is calculated as

$$S_{Static} = S_{Capacity} - S_{\max}$$

where, $S_{Capacity}$ is the firm capacity of the GSP and $S_{\max}$ is the worst case expected power flow through the GSP. When $S_{\max}$ is not monitored it can be calculated as:

$$S_{max} = Max\,\{(S_{Gen\_max} - S_{Load\_max})\,,(S_{Load\_max} - S_{Gen\_min})\}$$

where, S_{Gen_max} is the maximum installed generation capacity at the GSP, S_{Load_min} is the minimum load at the GSP, S_{Gen_min} is the minimum generation at the GSP and S_{Load_max} is the maximum load at the GSP.

When calculating the $S_{\max}$ the following assumptions were made:

- Minimum load at the GSP (S_{Load_min}) is considered as zero.
- Minimum generation at the GSP (S_{Gen_min}) is considered as zero.
- Maximum load (S_{Load_max}) was not provided for the GSPs but peak demands were, therefore, it was assumed that the peak total demand of the GSPs is when the generation is at its minimum. Furthermore, the demand factor of 0.65 was assumed to calculate the (S_{Load_max}) of the GSP.

The following sections will present the analysis of one GSP in detail as well as the summary of generation composition of all GSPs and time series analysis of all GSPs with available data.

2.2 SAMPLE GSP ANALYSIS: CREYKE BECK – YORKSHIRE AREA

A summary of installed generation by fuel type is summarised in Table 2-2. The total installed capacity of generation at Creyke Beck is 444.2 MW, with Wind generation dominating the mix at a percentage of 41.7% followed by Fossil Gas at 30.5%. The generation mix is visually represented in Figure 2-1.

Table 2-2 – Installed generation at Creyke Beck

Generation Type	Installed Capacity (MW)	Installed Capacity (%)
Biomass	34.3	7.7
Fossil Gas	135.6	30.5
Fossil Oil	0.0	0.0
Hydro (reservoir)	0.0	0.0
Hydro (run of river)	0.0	0.0
Other	1.4	0.3
Other – battery storage	52.5	11.8
Solar PV	23.2	5.2

Waste	12.1	2.7
Wind	185.1	41.7
(blank)	0.1	0.0
Total	444.2	100.0

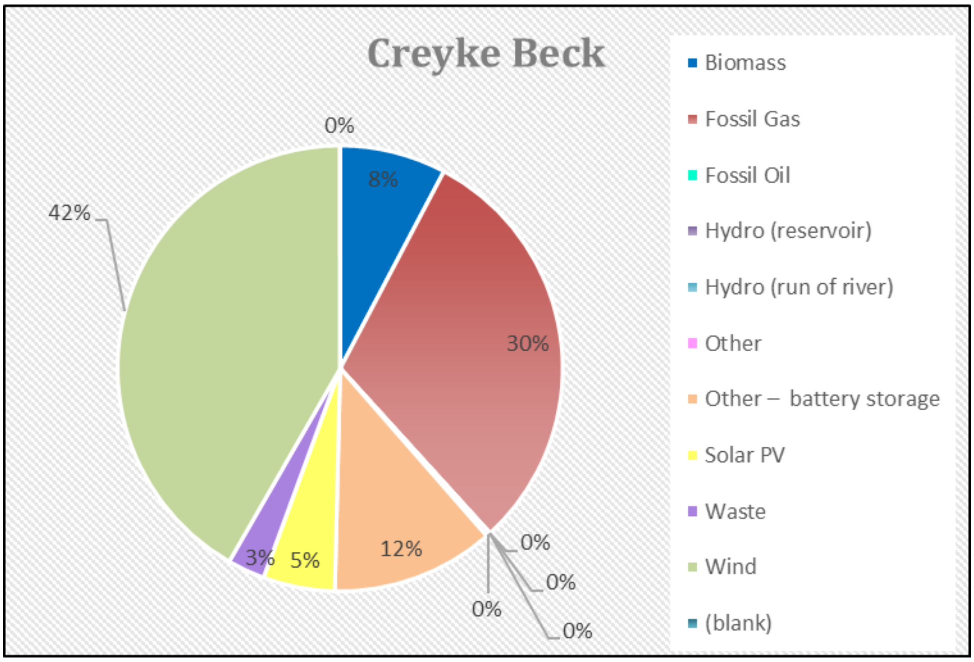

Figure 2-1 - Installed generation at Creyke Beck

The total demand connected at Creyke Beck stands at 369.67MVA, a breakdown of its composition with respect to energy consumption is presented in Table 2-3 and graphically visualised in Figure 2-2.

Table 2-3 - Demand energy consumption combination of Creyke Beck

Load Type	Yearly energy consumption (GWh)	Yearly energy consumption (%)
Domestic (GWh)	750.35	37.3
EV - cars & vans (GWh)	10.01	0.5
EV - other transport (GWh)	1.16	0.1
HPs - Domestic (GWh)	7.62	0.4
HPs - I&C (GWh)	12.24	0.6
I&C (GWh)	1231.2	61.2
Total Baseline Demand Consumption (GWh)	1981.56	98.5
Total demand (GWh)	2012.59	100.0

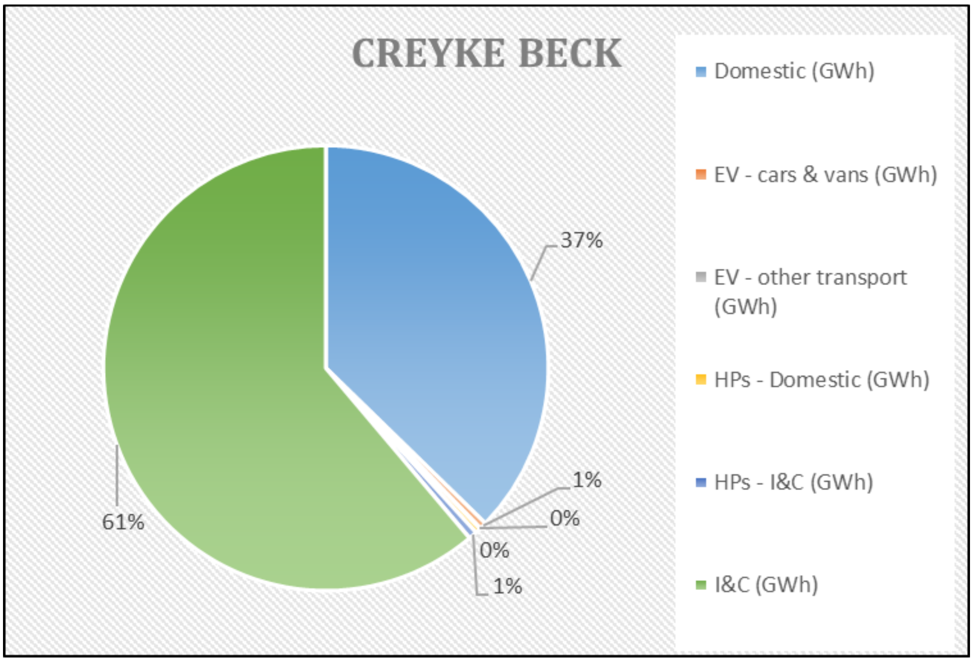

Figure 2-2 – Demand energy consumption combination of Creyke Beck

There are four transformers at Creyke Beck. The aggregated active and apparent power at the GSP is presented in Figure 2-3 and Figure 2-4. As can be observed from the figures, the data from October to December is either missing or erroneous. Data until September is considered for further analysis.

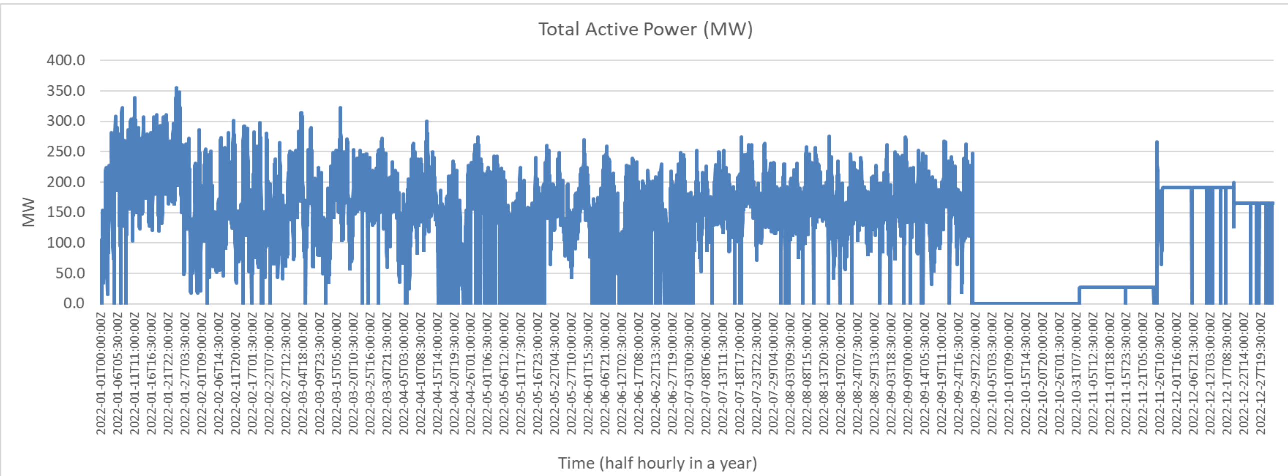

Figure 2-3 - Total Active Power at Creyke Beck

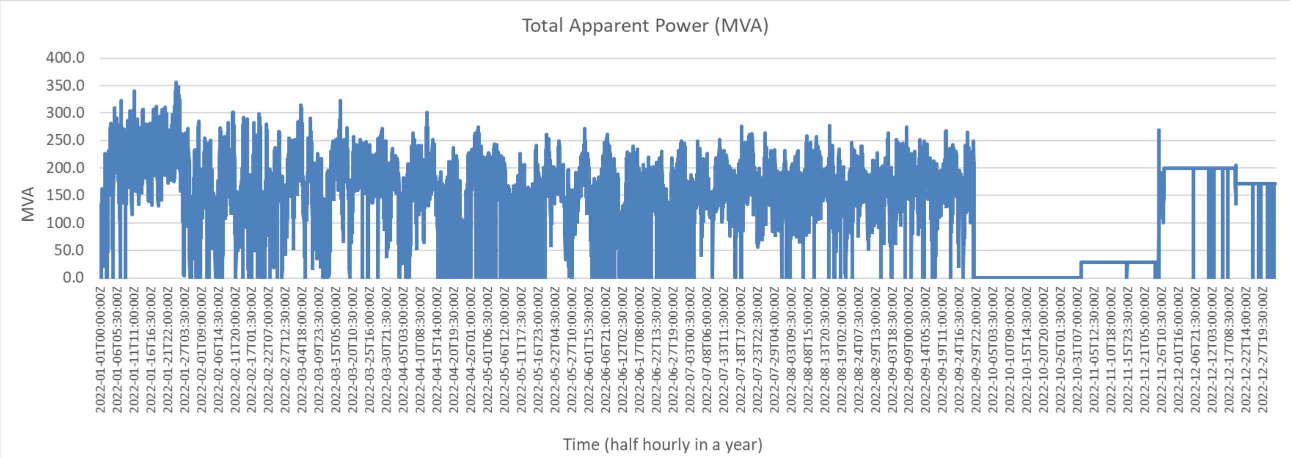

Figure 2-4 – Total Apparent Power at Creyke Beck

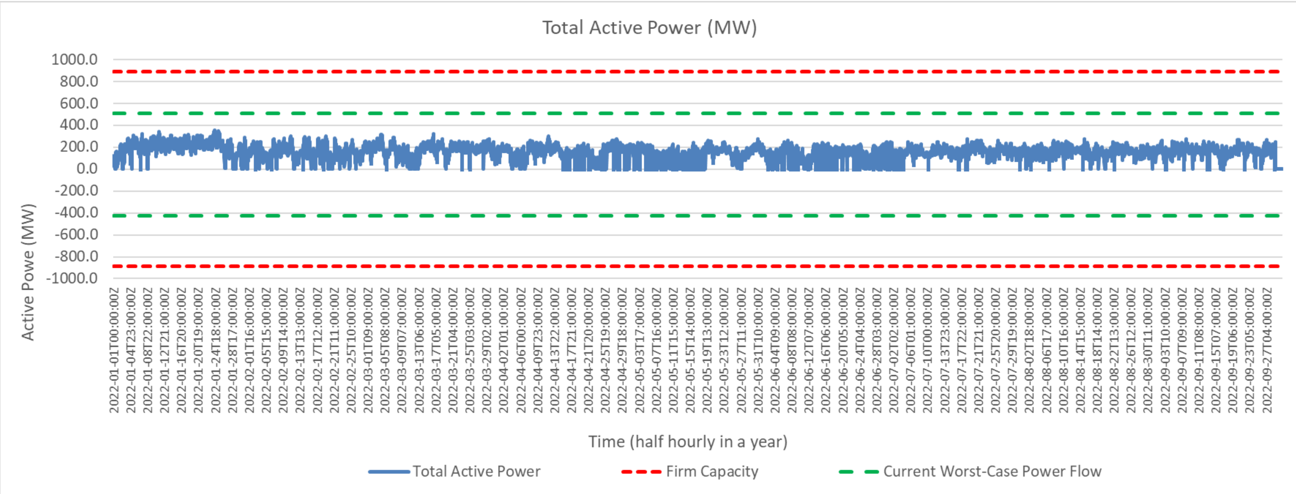

Figure 2-5 – Static headroom at Creyke Beck

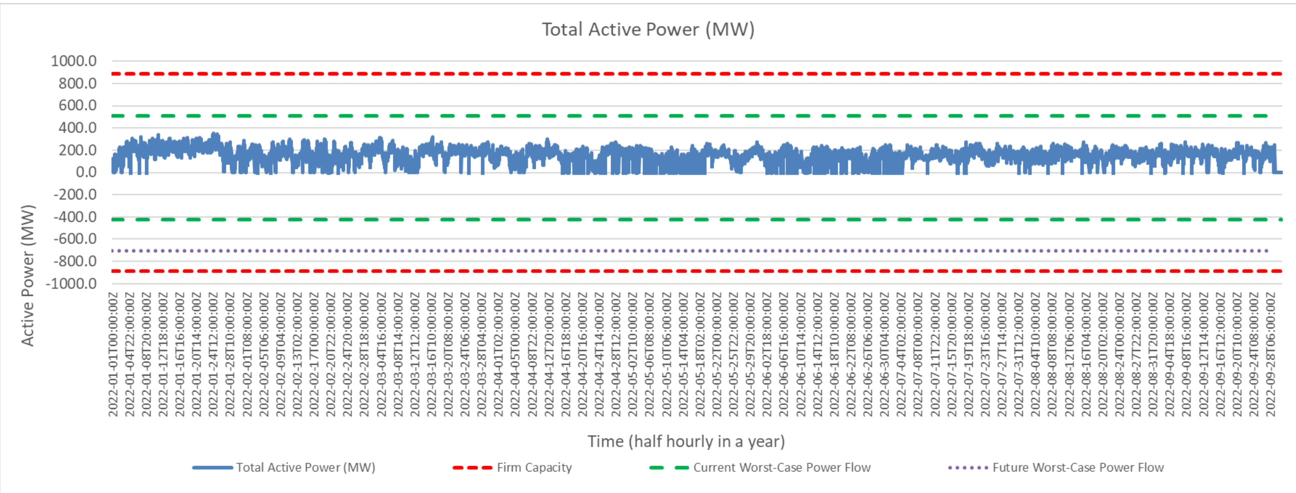

Figure 2-6 – Future static headroom at Creyke Beck

The static headroom is visually presented in Figure 2-5, and is the difference between the firm capacity (red line) and the worst-casr power flow at the GSP (green line). As can be observed from the figure, the worst-case power flow is never reached throughout the nine months considered. This evidences greater available headroom than expected. The dynamic headroom is therefore the difference between the firm capacity and the measured power flow at the GSP (blue line).

Figure 2-6 presents the static headroom with the inclusion of the generation capacity that has been contracted but not yet connected to the GSP. This demonstrates a drastic reduction in available static headroom at the GSP.

2.3 GENERATION COMPOSITION OF GSPS

In this section, an analysis of all GSPs is carried out in terms of their current generation composition, i.e., generation type, as presented in Figure 2-7. As can be observed, there is generation at each of the analysed GSPs, with 16 GSPs having over 100 MVA penetration of distributed generation. Fossil gas or wind dominates the generation composition at most GSPs with biomass dominating the mix at Blyth 132kV GSP. There is wind and solar generation at 34 GSPs and battery energy storage available at 9 GSPs.

The future contracted generation of all GSPs is extracted and added to the analysis, presented in Figure 2-8. It should be noted that information on type of generation for the future contracted generation was not made available to be included within the analysis.

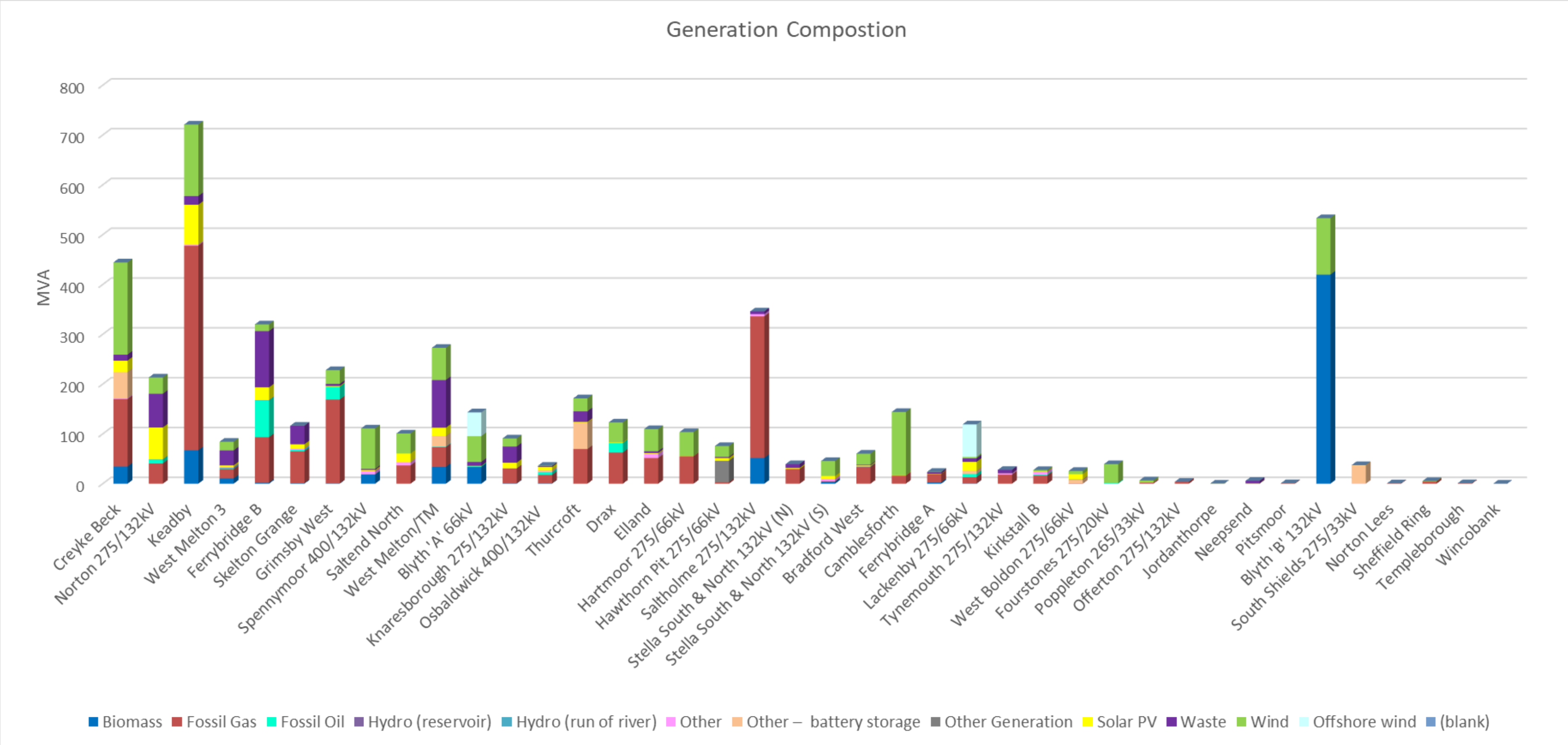

Figure 2-7 – Generation compostion for 40 GSPs

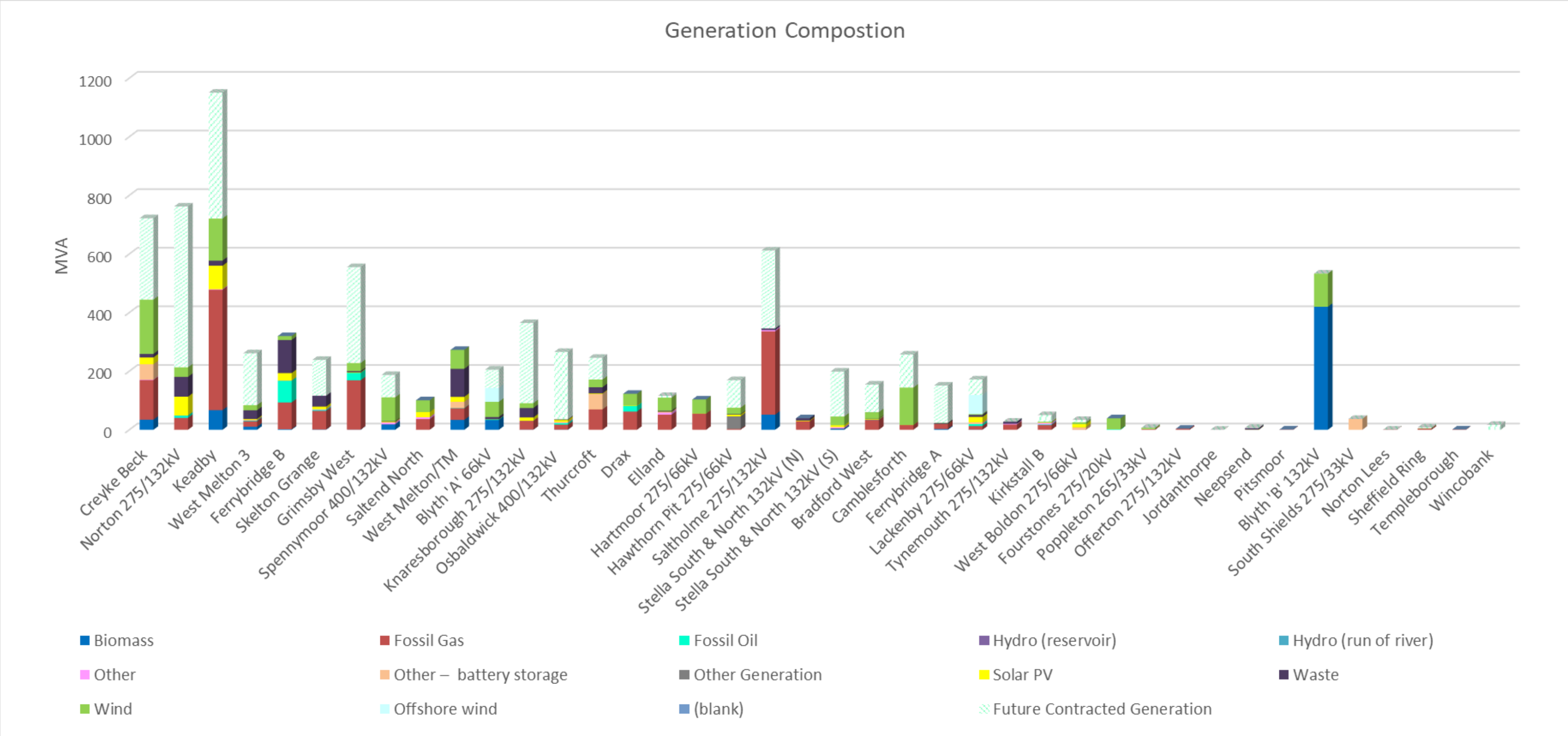

Figure 2-8 – Generation compostion for 40 GSPs (40) with the future contracted generation

2.4 STATIC AND DYNAMIC HEADROOM OF SCREENED GSPS

Adopting the analysis presented in section 2.2, 40 GSPs have been screened to extract the static and dynamic headroom. The monitored peak demand and the worst-case power flow expected at the GSP are presented in Figure 2-9. Some observations summarised below:

- Out of 40 GSPs analysed, 4 GSPs (Ferrybridge B, Drax, Stella South & North 132kV (N) and Stella South & North 132kV (S)) had no available time series data for active and apparent power, therefore they were excluded from the analysis of time series data (although their generation composition can be found in Section 2.3).

- For seven of the GSPs (West Melton 3, Spennymoor 400/132kV, Blyth ‘A’ 66kV, West Boldon 275/66kV, Jordanthorpe, South Shields 275/33kV and Templeborough), the monitored peak power flow was bigger than the worst-case power flow. The worst-case power flow is calculated as explained in 2.1. This indicates one of the following: (i) The power flow data at the GSP is incorrect or (ii) the peak demand data at the GSP is incorrect.

- Four of the GSPs (Blyth ‘A’ 66kV, Blyth ‘B’ 132kV, South Shields and Fourtstones 275/20 kV), the monitored peak demand is higher than the firm capacity at the GSP.

- Four of the GSPs (Saltend, Fourstones 275/20 kV, Blyth ‘B’ 132kV and Hartmoor), the worst-case power flow is higher than the firm capacity at the GSP.

Figure 2-10 presents the future worst-case power flow including the generation contracted at the GSPs. Some observations below:

- Ten GSPs (Keadby, Grimsby West, Saltend, Knaresborough, Thurcroft, Hartmoor 275/66 kV, Saltholme, Camblesforth, Fourstones and Blyth ‘B’ 132kV) will have their worst-case power flow exceeding the firm capacity at the GSP when the contracted generation is included.

This can be further evidenced from Figure 2-11, where the headroom for each of the GSPs is analysed.

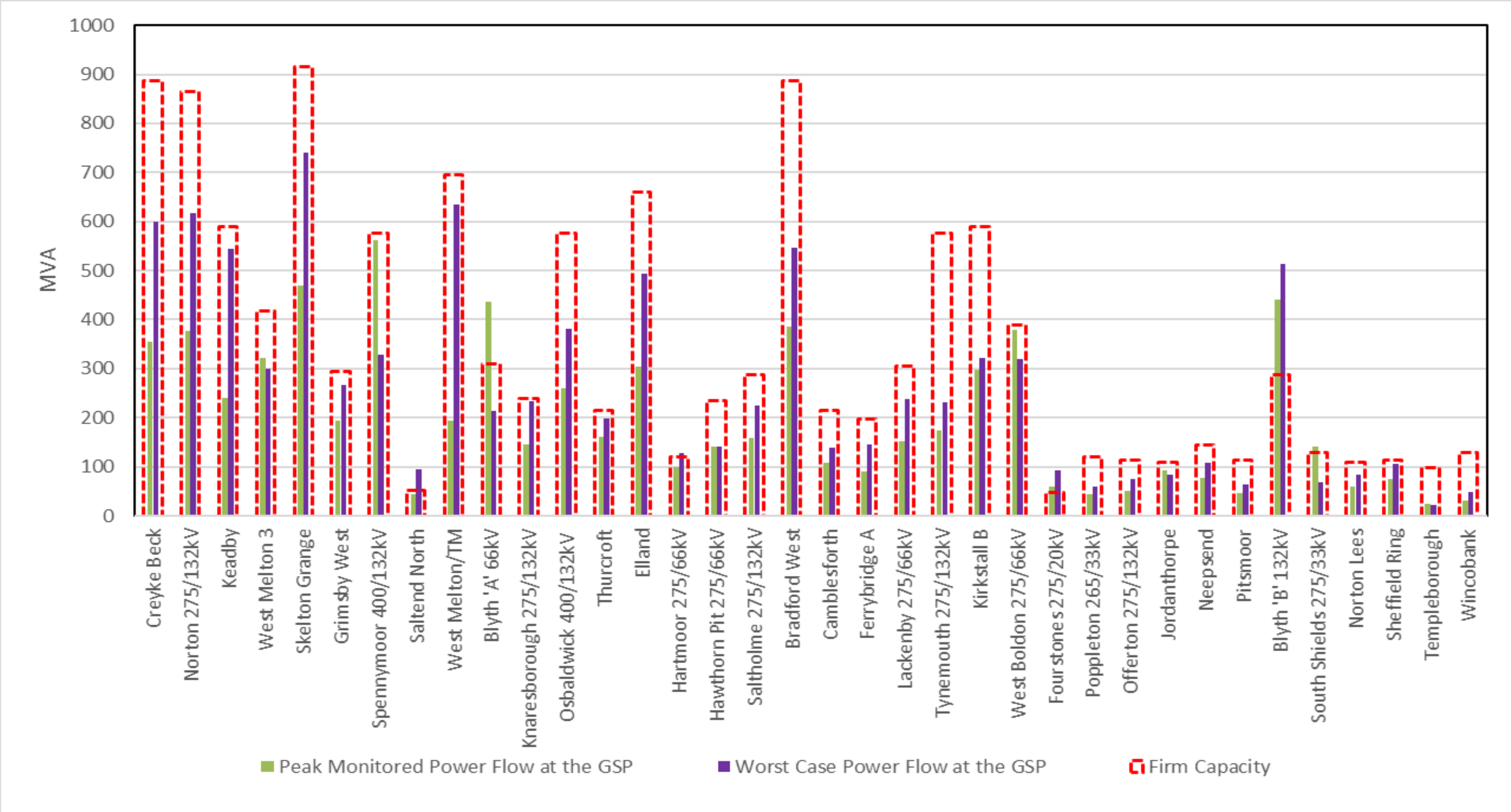

Figure 2-9 – Peak powerflow of the 36 GSPs using monitored and calculated values versus firm capacity

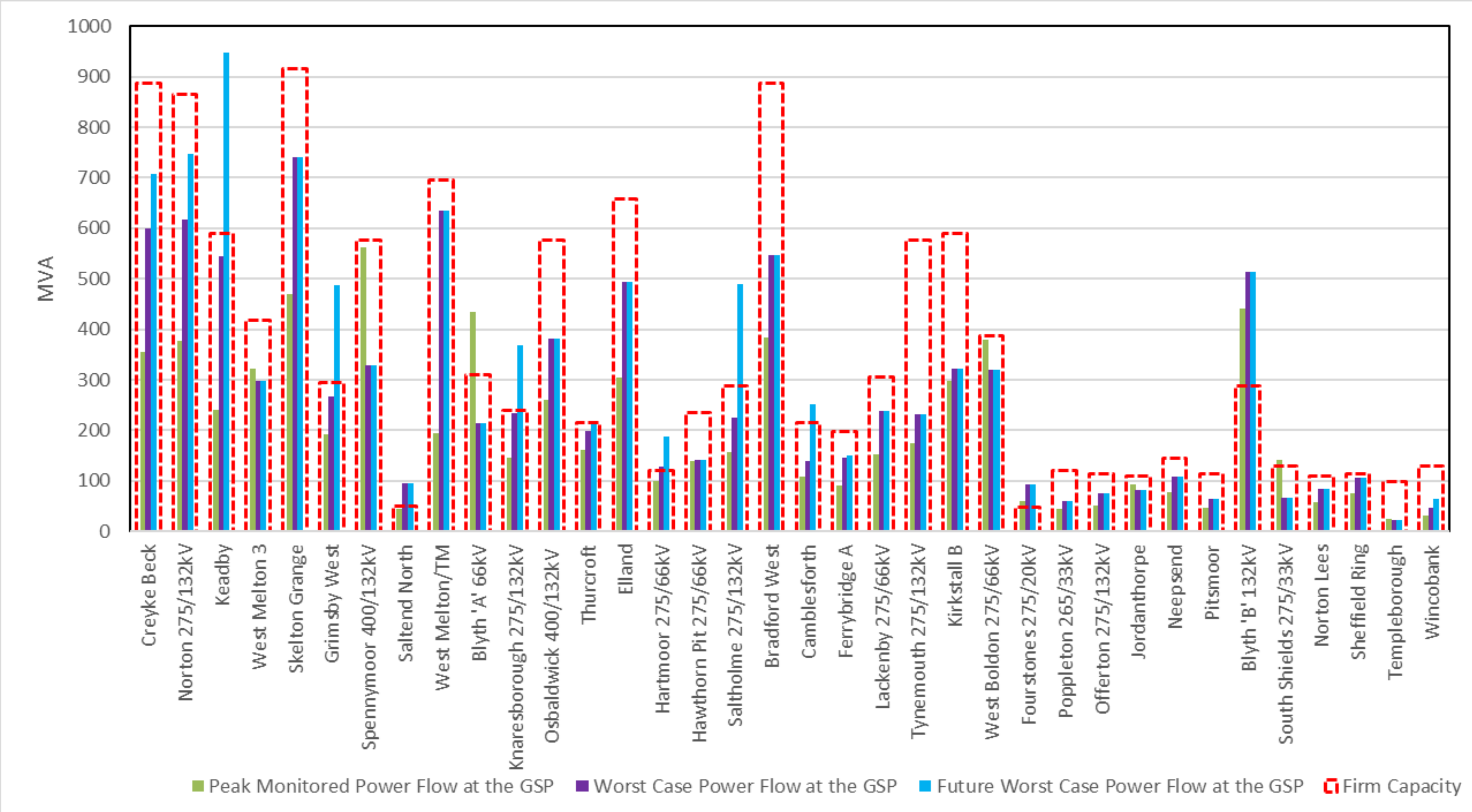

Figure 2-10 – Peak powerflow of the 36 GSPs using monitored and calculated values (both current and future) versus firm capacity

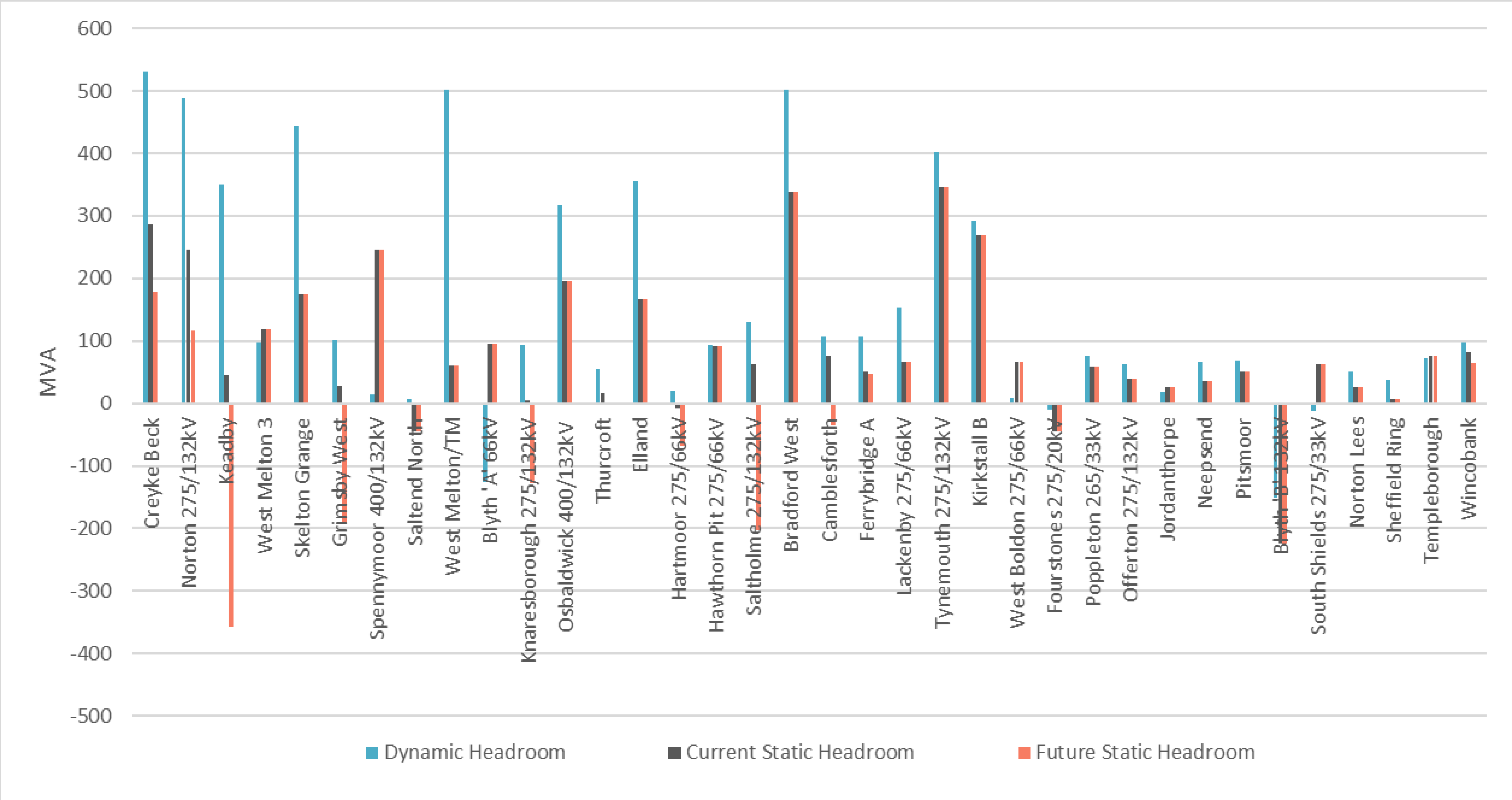

Figure 2-11 – Dynamic headroom, current static headroom and future static headroom – 36 GSPs

Table 2-4 summarises the timeseries data availability and suitability for next stage analysis.

Table 2-4 – GSP data availability/quality summary

GSP name	Licence Area	Priority	Note
Creyke Beck	YORKSHIRE	1	Included
Norton 275/132kV	NORTHEAST	2	Included
Keadby	YORKSHIRE	3	Included (Future Worst-Case Power Flow exceeds Firm Capacity)
West Melton 3	YORKSHIRE	4	Included (Monitored Peak Power Flow greater than Worst Case Power Flow)
Ferrybridge B	YORKSHIRE	5	No active or apparent power time series data
Skelton Grange	YORKSHIRE	6	Included
Grimsby West	YORKSHIRE	7	Included (Future Worst-Case Power Flow exceeds Firm Capacity)
Spennymoor 400/132kV	NORTHEAST	8	Included (Monitored Peak Power Flow greater than Worst Case Power Flow)
Saltend North	YORKSHIRE	8	Included (Current Worst-Case Power Flow and Future Worst-Case Power Flow exceeds Firm Capacity)
West Melton/TM	YORKSHIRE	10	Included
Blyth 'A' 66kV	NORTHEAST	11	Included (Monitored Peak Power Flow greater than Worst Case Power Flow and exceeds Firm Capacity)
Knaresborough 275/132kV	NORTHEAST	11	Included (Future Worst-Case Power Flow exceeds Firm Capacity)
Osbaldwick 400/132kV	NORTHEAST	11	Included
Thurcroft	YORKSHIRE	14	Included
Drax	YORKSHIRE	15	No active or apparent power for transformer time series data
Elland	YORKSHIRE	16	Included
Hartmoor 275/66kV	NORTHEAST	17	Included

			(Current Worst-Case Power Flow and Future Worst-Case Power Flow exceeds Firm Capacity)
Hawthorn Pit 275/66kV	NORTHEAST	17	Included
Saltholme 275/132kV	NORTHEAST	19	Included (Future Worst-Case Power Flow exceeds Firm Capacity)
Stella South & North 132kV (N)	NORTHEAST	19	No active or apparent power for transformer time series data
Stella South & North 132kV (S)	NORTHEAST	19	No reliable active or apparent power (Only 0.915 value for few time steps for both S and P)
Bradford West	YORKSHIRE	22	Included
Camblesforth	YORKSHIRE	23	Included (Future Worst-Case Power Flow exceeds Firm Capacity)
Ferrybridge A	YORKSHIRE	23	Included
Lackenby 275/66kV	NORTHEAST	25	Included
Tynemouth 275/132kV	NORTHEAST	25	Included
Kirkstall B	YORKSHIRE	27	Included
West Boldon 275/66kV	NORTHEAST	28	Included (Monitored Peak Power Flow greater than Worst Case Power Flow)
Fourstones 275/20kV	NORTHEAST	29	Included (Current Worst-Case Power Flow and Future Worst-Case Power Flow exceeds Firm Capacity, Monitored Peak Power Flow exceeds Firm Capacity)
Poppleton 265/33kV	NORTHEAST	29	Included
Offerton 275/132kV	NORTHEAST	31	Included
Jordanthorpe	YORKSHIRE	31	Included (Monitored Peak Power Flow greater than Worst Case Power Flow)
Neepsend	YORKSHIRE	31	Included
Pitsmoor	YORKSHIRE	31	Included
Blyth 'B' 132kV	NORTHEAST	35	Included

			(Current Worst-Case Power Flow and Future Worst-Case Power Flow exceeds Firm Capacity, Monitored Peak Power Flow exceeds Firm Capacity)
South Shields 275/33kV	NORTHEAST	35	Included (Monitored Peak Power Flow greater than Worst Case Power Flow)
Norton Lees	YORKSHIRE	35	Included
Sheffield Ring	YORKSHIRE	35	Included
Templeborough	YORKSHIRE	35	Included (Monitored Peak Power Flow greater than Worst Case Power Flow)
Wincobank	YORKSHIRE	35	Included

Based on the summary presented in the table above, the following conclusions have been reached:

- Ferrybridge B, Drax, Stella North and Stella South will not be taken forward for analysis due to lack of data for the GSPs.
- Blyth 'A' 66kV, Fourstones and Blyth 'B' 132kV are unsuitable for further analysis as the current peak demand is higher than the firm capacity at the GSP, indicating erroneous data.
- The GSPs that constitute a problem with the incorporation of contracted generation will be shortlisted for further analysis. These GSPs include Keadby, Grimsby West, Saltend North, Knaresborough 275/132kV, Thurcroft, Hartmoor 275/66kV, Saltholme 275/132kV, and Camblesforth.

3 EVALUATING FLEXIBILITY ENABLED THROUGH DIVERSIFICATION OF GENERATION RESOURCES

More generation is expected to be connected at each of the GSPs identified. The objective is to understand if the dynamic headroom at the GSPs can be better utilised by means of diversifying the generation sources at the GSPs. As has been described earlier, only the net power flow at the GSP is available as time series data. While the type and ratings of generators are available for each GSP, the time series data is unavailable. This makes it difficult to analyse the flexibility enabled through incorporation of diversified generation. The methodology to evaluate the flexibility enabled through diversification of generation resources was developed and is explained in the following subsection:

3.1 METHODOLOGY

The methodology disaggregates the total power flow at the GSP into base demand and generation profiles. To enable this, publicly available data for solar irradiation and wind speed profiles at the geographic locations is relied upon. This enables the extraction of a base power flow profile that is the combination of the power consumption of the loads connected at the GSP and the power generated from conventional sources of generation such as fossil oil, fossil gas and waste.

The following assumptions are made for disaggregating the load and generation profiles:

- While the solar farms and wind farms connecting to the GSP can be geographically distant from the GSP, the solar irradiation and wind speed profiles are chosen for the geographic location of the GSP only.

- The data available for solar irradiation and wind speed is for 2019, collected at an interval of one hour. The time series data for power flow at GSPs available form NPg open data platform is half hourly. To enable analysis, only data points for every hour have been extracted from the available data.

- The conventional generation (fossil, biomass, waste) are non-curtailable, generating at their full capacity.

Once the disaggregated base profile and generation (solar and wind) profiles are extracted, the evaluation of the headroom with increasing amount of generation connecting to GSP is evaluated. The assumptions for the analysis are presented below:

- While the analysis is presented for an increasing amount of generation connecting to the GSP, the load at the GSP is assumed to remain the same.

- The increase in generation is assumed to be a mix of solar and wind only, at this stage no other generation type has been evaluated.

First, the amount of generation at the GSP is increased to obtain the limit of generation capacity with respect to the conventional conservative approach and the limit of generation capacity considering the actual power flow at the GSP. The conservative approach considers the rated generation capacity as the maximum power output feasible from the generation units simultaneously. For this analysis, the composition of the incremented generation is assumed to be same as current composition of wind and solar at the GSP. For example, for a given GSP, if the current distribution of solar and wind energy follows a ratio of 4:1, any increment in generation will abide by this ratio; thus, a 100 MW increase in generation will be a sum of 80 MW wind and 20 MW solar.

Once the limit of penetration of additional generation has been obtained, composition of the generation is varied by making scaled adjustments to the generation profiles. This enables the analysis of the impact of the technology on the dynamic headroom. The objective is to understand the potential of a technology type to unlock further increase of generation capacity at the GSP.

3.2 FLEXIBILITY EVALUATION - CREYKE BECK

This section presents the results of the methodology applied to Creyke Beck. First the power flow at the GSP is disaggregated, followed by the evaluation of the headroom with increasing generation.

3.2.1 DISAGGREGATING POWER FLOW AT GSP

The first step of the methodology is to disaggregate the power flow profile at the GSP to obtain the power flow at the GSP without the solar and wind generation. Using the solar irradiation and wind speed data at the geographical location of Creyke Beck, the solar and wind power profiles for the installed capacity of solar and wind generation were obtained. The 24-hour wind and solar power profile at Creyke Beck is presented in Figure 3-1 and Figure 3-2 while the yearly wind and solar power profile is presented in Figure 3-3 and Figure 3-4. The combined solar and wind profile for 24-hours and a year are presented in Figure 3-5 and Figure 3-6.

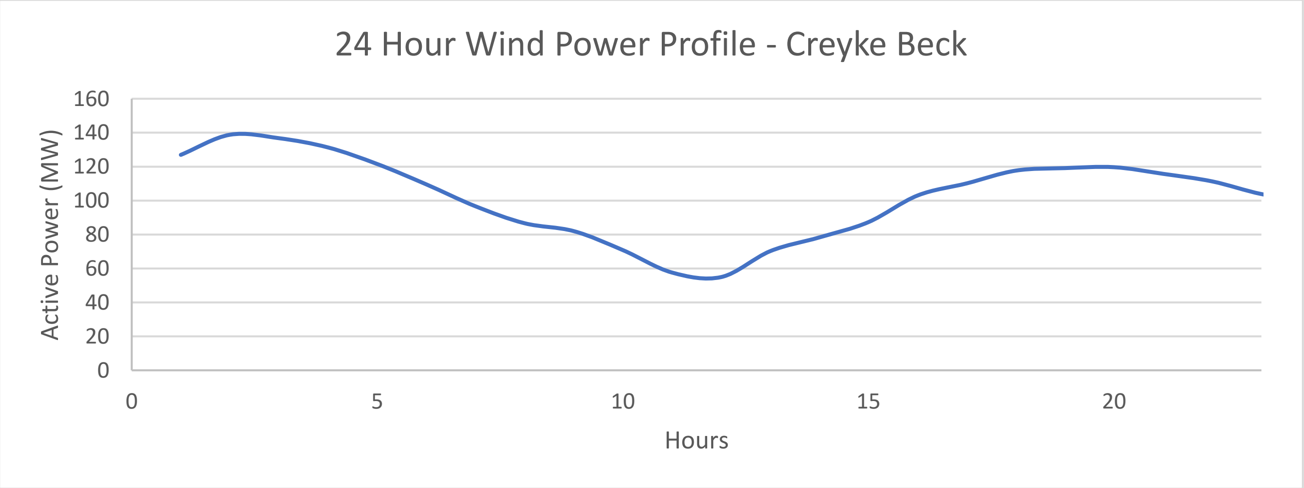

Figure 3-1 – 24 Hour Wind Power Profile - Creyke Beck

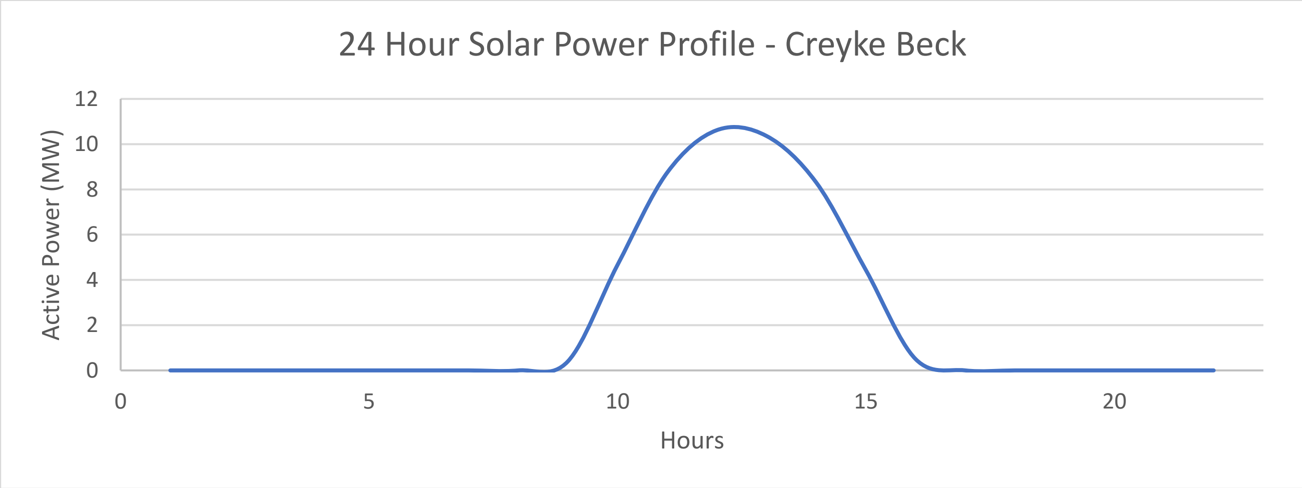

Figure 3-2 – 24 Hour Solar Power Profile - Creyke Beck

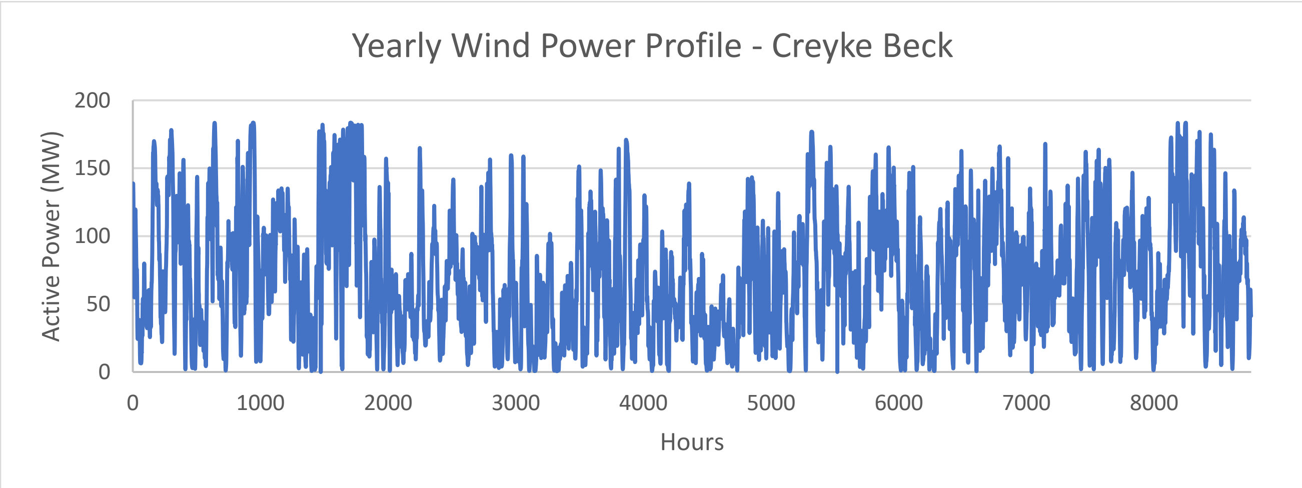

Figure 3-3 – Yearly Wind Power Profile - Creyke Beck

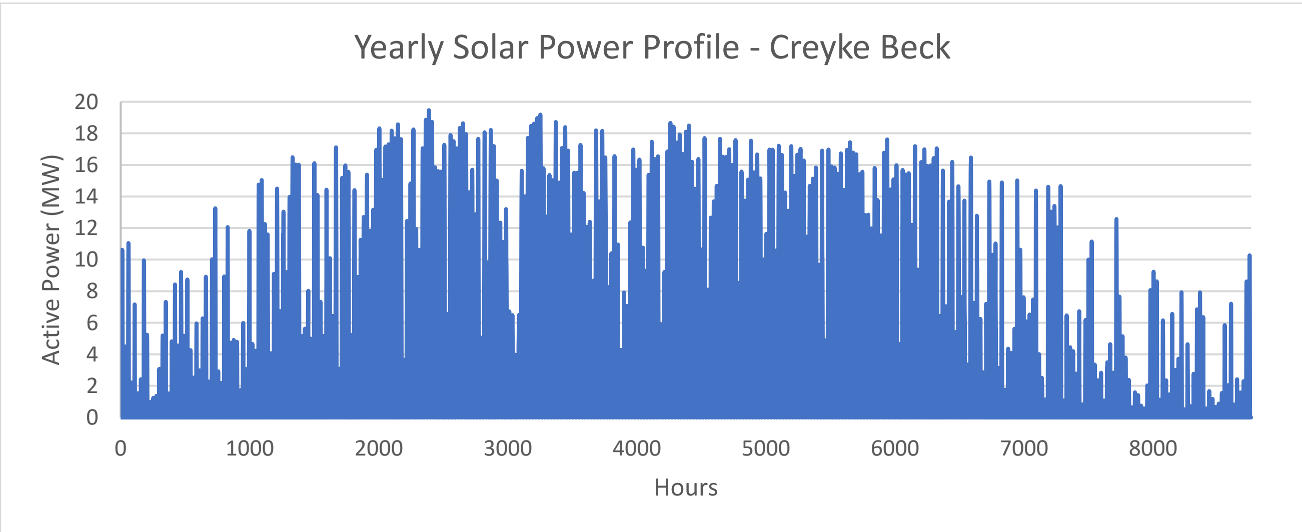

Figure 3-4 – Yearly Solar Power Profile - Creyke Beck

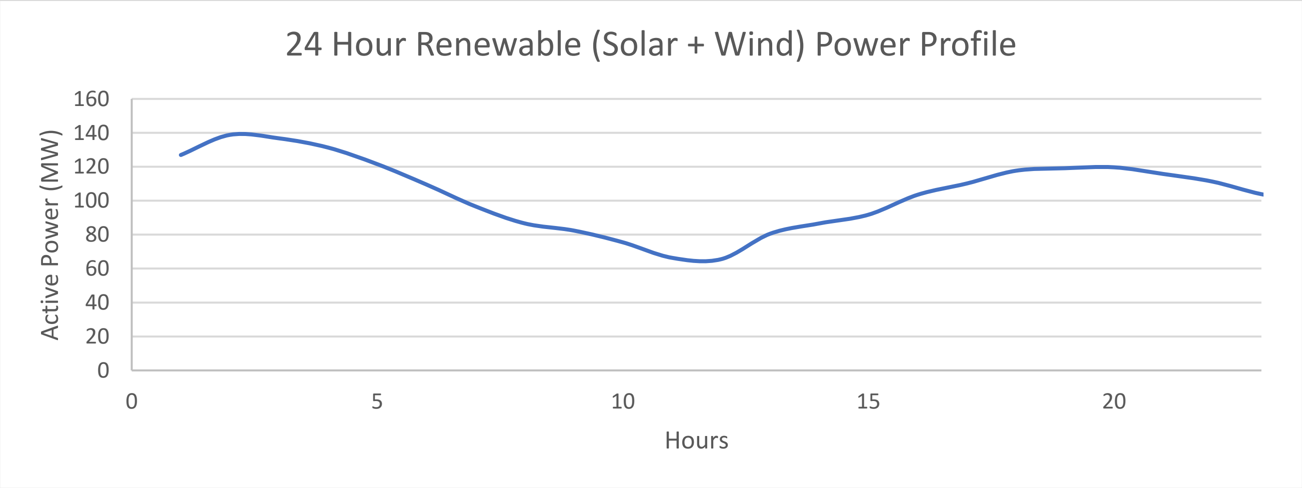

Figure 3-5 – 24 Hour Combined Solar and Wind Power Profile

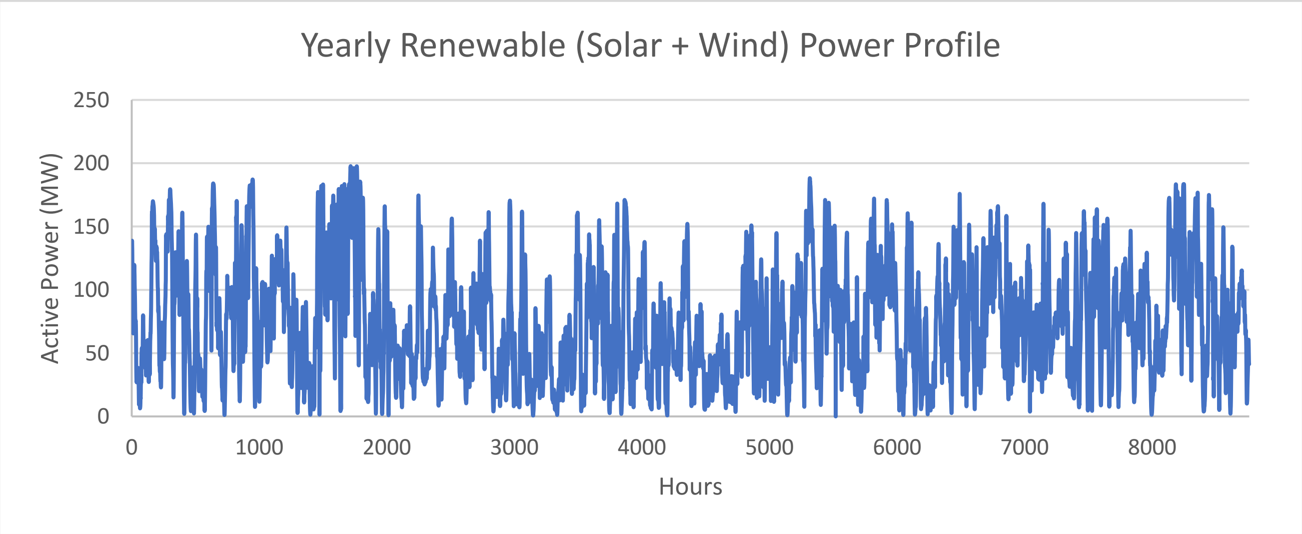

Figure 3-6 – Yearly Combined Solar and Wind Power Profile

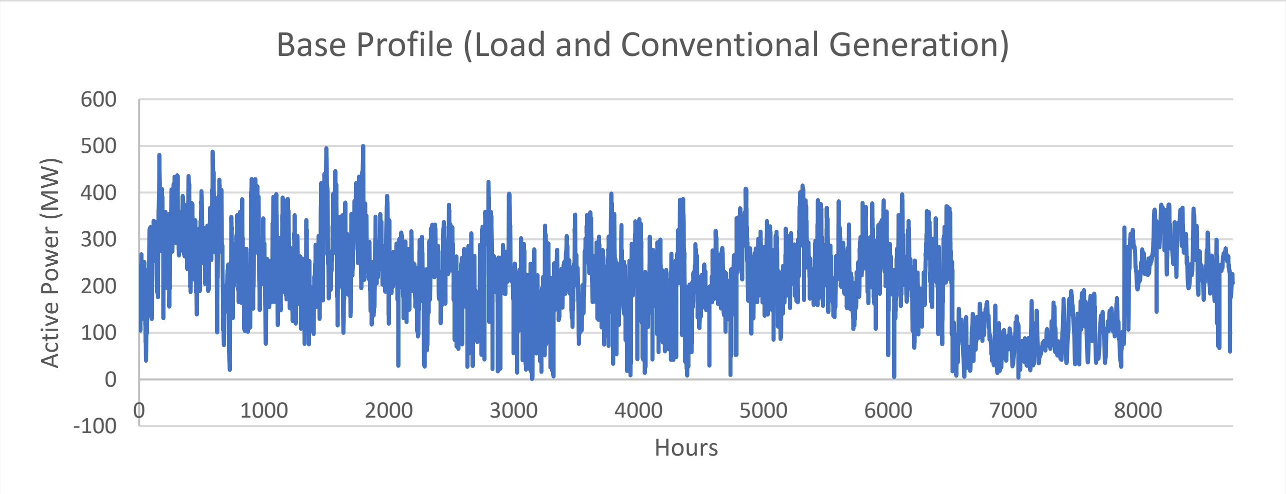

Figure 3-7 – Yearly Base Profile - Creyke Beck

Subtracting the solar and wind generation profile from the power flow at GSP, the base profile at the GSP with loads and conventional generation sources can be obtained, as shown in Figure 3-7.

3.2.2 EVALUATING FLEXIBILITY WITH VARYING GENERATION COMPOSITION

This section presents two Case Studies to evaluate the flexibility enables through utilisation of dynamic headroom at Creyke Beck GSP in alignment with the methodology presented in Section 3.1.

3.2.2.1 Case Study 1: Increasing Generation in Present Day Ratio (~89% Wind and ~11% Solar)

The results for increasing the generation capacity (250 MW, 500 MW and 1000 MW) at Creyke Beck are presented in Figure 3-8, Figure 3-9 and Figure 3-10 respectively. The current power flow refers to the power flow at the GSP in 2022 with present-day connected generation capacity. The projected power flow refers to the expected power flow at the GSP with increased generation capacity connected at the GSP. The firm capacity at the GSP is indicated as positive and negative values, representing limitation in power flow in both directions. The conventional limit of generation increase calculated as the worst case maximum expected power flow is also identified within the figures.

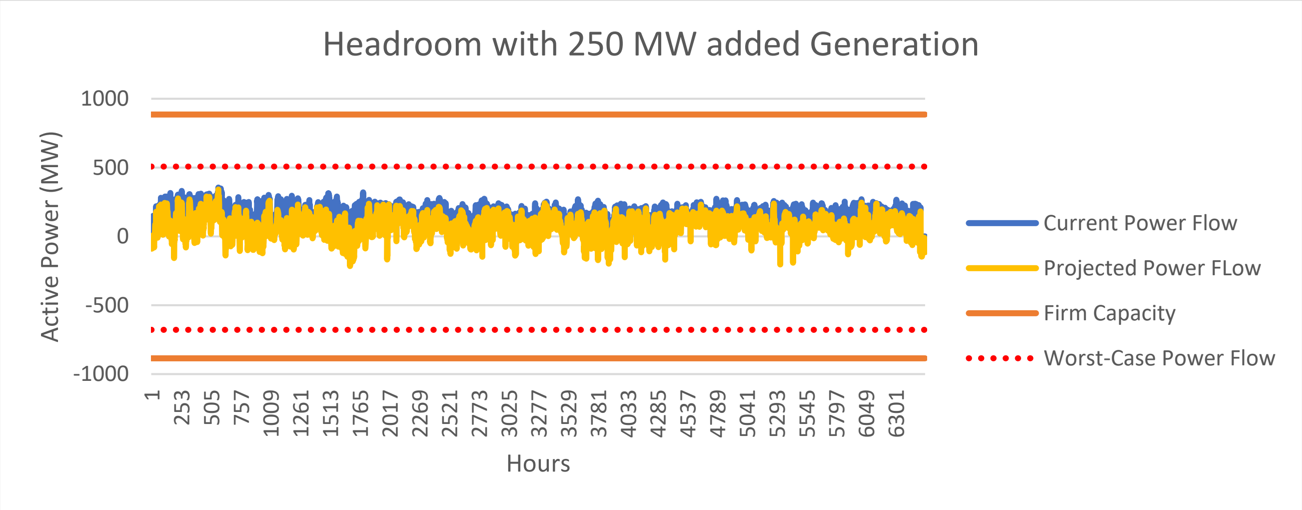

Figure 3-8 – Headroom with 250 MW added Generation (~89% Wind and ~11% Solar)

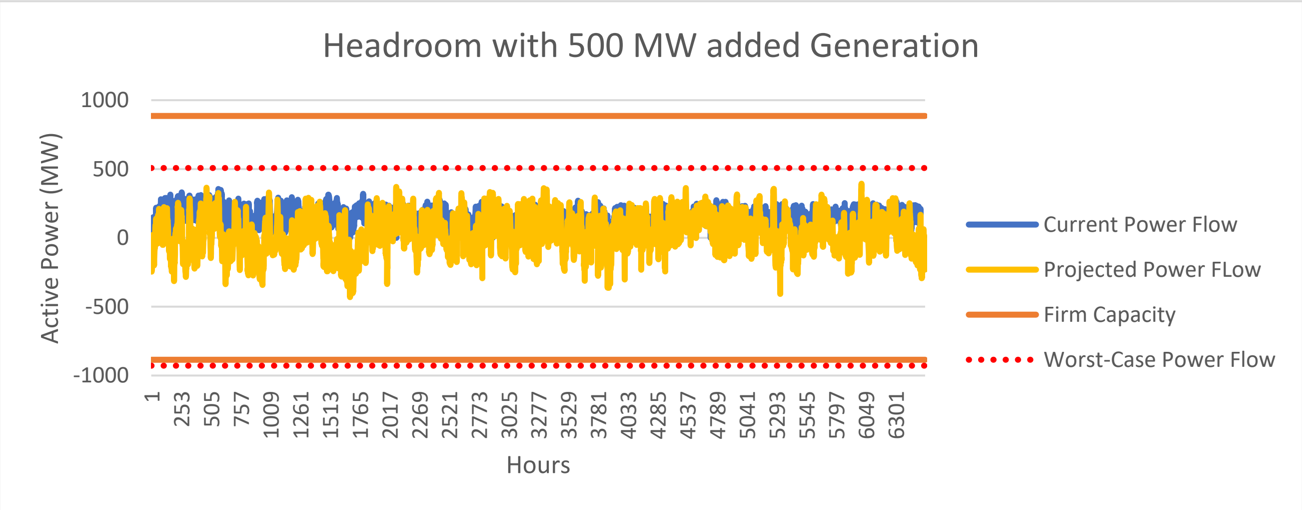

Figure 3-9 – Headroom with 500 MW added Generation (~89% Wind and ~11% Solar)

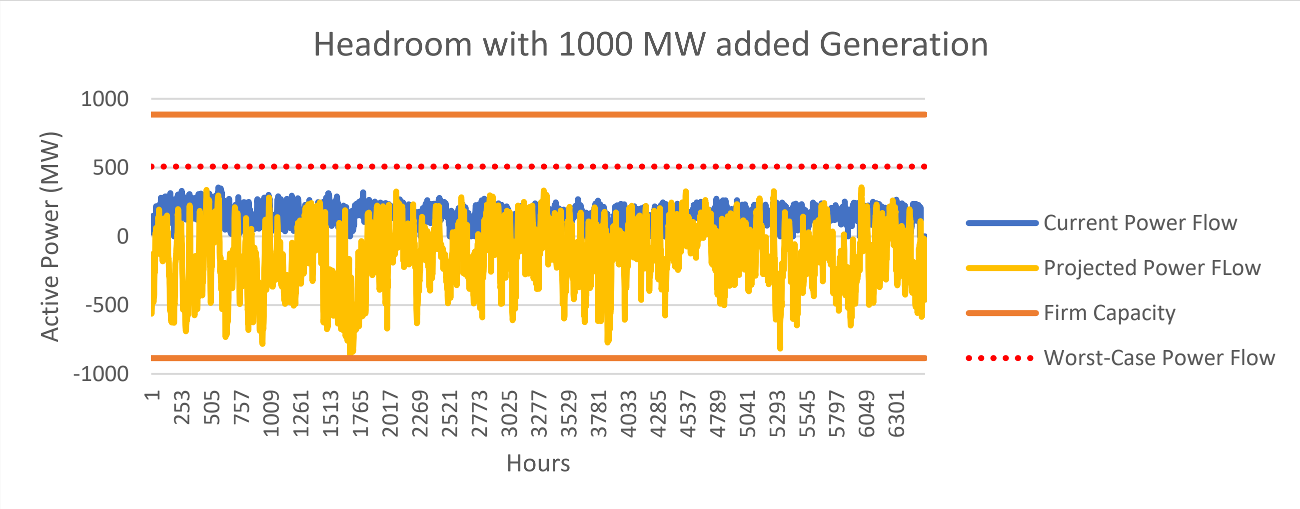

Figure 3-10 – Headroom with 1000 MW added Generation (~89% Wind and ~11% Solar)

As can be observed from Figure 3-9, with an increase of 500 MW in generation capacity at Creyke Beck, the expected maximum (worst case) power flow exceeds the firm capacity at the GSP. However, as can be observed, the measured power flow is well within the firm capacity of the GSP. With an additional 500 MW, i.e., a total increase of 1000 MW of generation capacity at Creyke Beck, the power flow at the GSP reaches the firm capacity only once within the entire year, as can be seen in Figure 3-10.

3.2.2.2 Case Study 2: Varying Generation Composition for Dynamic Headroom Evaluation

In this set of studies, the increment in generation is divided in different proportions to as they currently are present at the GSP. The composition ratio of wind to solar at Creyke beck is approximately 9:1, however varied ratios are trialled to understand the impact of their composition.

Figure 3-11 presents the results of power flow at the GSP for 1000 MW of additional generation capacity in the ratio of 1:1 (50% wind and 50% solar). As can be observed, with 1000 MW of additional

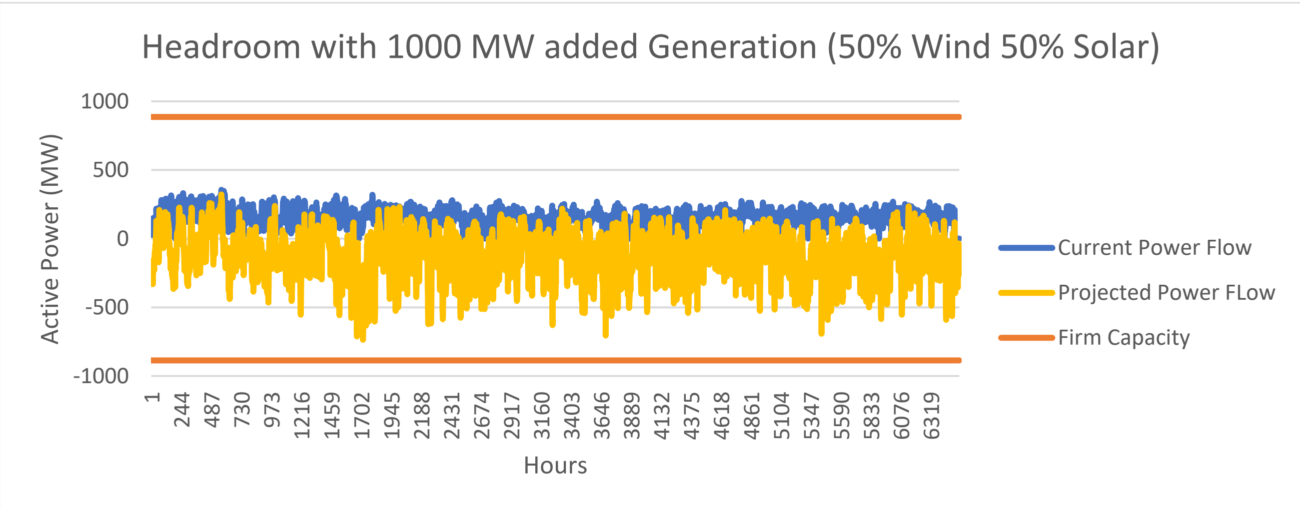

Figure 3-11 – Headroom with 1000 MW added Generation (50% Wind 50 % Solar)

generation, the power flow at the GSP does not breach the firm capacity limit. It is worth to mention that the same additional generation in ratio of present-day composition reached the firm capacity as in Figure 3-10.

Additional analysis with 1200 MW increase in generation capacity in ratio of 1:1 (50% wind and 50% solar) and 2:3 (40% wind and 60% solar) is undertaken with results presented in Figure 3-12 and Figure 3-13. As can be observed, a generation capacity of 1200 MW in ratio of 1:1 can be safely added to the GSP with the power flow only reaching the firm capacity once through the year. By means of adding the generation in a ratio of 2:3, the firm capacity is still reached once through the year, however, additional headroom is realised at other times of the year.

The analysis presented further demonstrates that by varying the composition of the generation at the GSP, the headroom at the GSP can be more effectively and efficiently utilised to enable higher penetration of connected generation capacity.

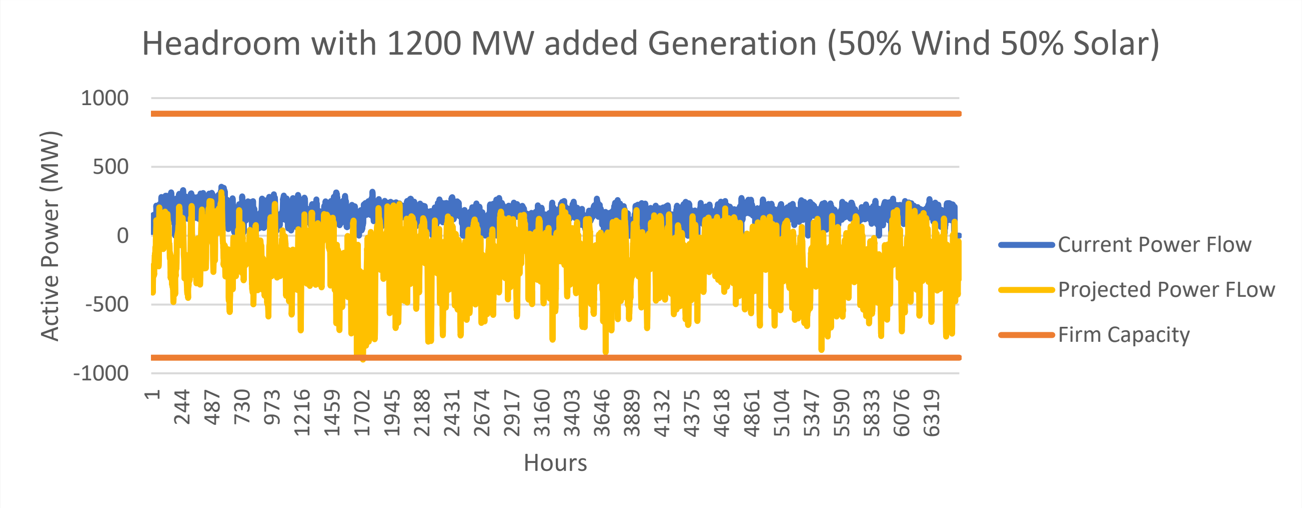

Figure 3-12 – Headroom with 1200 MW added Generation (50% Wind 50% Solar)

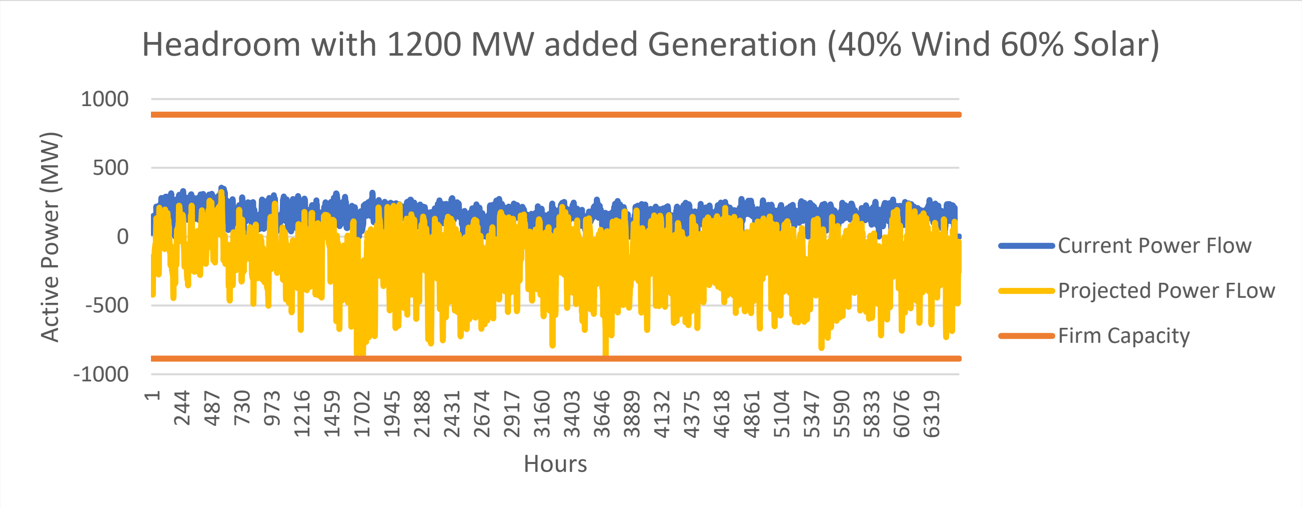

Figure 3-13 – Headroom with 1200 MW added Generation (40% Wind 60% Solar)

3.3 SUMMARY OF FLEXIBILITY ANALYSIS

The summary of the analysis is presented in Table 3-1, presenting where the firm capacity has been breached, when static headroom exceeds the firm capacity and the percentage increase in generation penetration enabled by dynamic headroom rather than static headroom.

Table 3-1 - Flexibility Enabled through Generation Composition Variation

Additional Generation (MW)	Wind Penetration (%)	Solar Penetration (%)	Firm Capacity Breached	Static Headroom Exceeds Firm Capacity	Increased Penetration (%)
250	90	10	No	No	-
500	90	10	No	Yes	11
1000	90	10	No	Yes	122
1000	50	50	No	Yes	122
1200	50	50	No	Yes	166
1200	40	60	No	Yes	166

From the analysis undertaken, it is clear that the amount of generation that can be hosted without breaching the firm capacity is significantly higher than when considering static headroom, up to 166% higher than static headroom. It is also evident that the generation composition plays a role in utilising the dynamic headroom effectively, additional 200 MW can be incorporated at the GSP when the composition of the generation is changed from 9:1 to 1:1.

4 OPTIMISATION OPPORTUNITIES

This section summarises the methodology, results and analysis pertaining to Work Package 3 looking at opportunities for the use of optimisation for determining the appropriate mix of generation to ensure effective utilization of headroom at GSP.

4.1 DYNAMIC AND STATIC HOSTING CAPACITY ASSESSMENT WITH VARIED WIND AND SOLAR PENETRATION – 2 GSPS

In order to assess the maximum possible increase in installed wind and solar generation, various ratios between them have been considered for two GSPs (Creyke Beck and Norton). In order to better visualise the results, the installed wind and solar generation have been plotted on x and y axis respectively ((**Error! Reference source not found.** and Figure 4-2).

The ratios between wind and solar penetration can be expressed using the degrees as shown in the following formula:

$$deg_{S,W} = \tan^{-1}\left(\frac{S_S}{S_W}\right)$$

where, S_S and S_W are the increased solar and wind capacity at the GSP in MVA.

10 different degrees each separated by 10° between 0° and 90° have been analysed for both GSPs. These 10 degrees, correspond to 10 different ratios between increased wind and solar generation capacity.

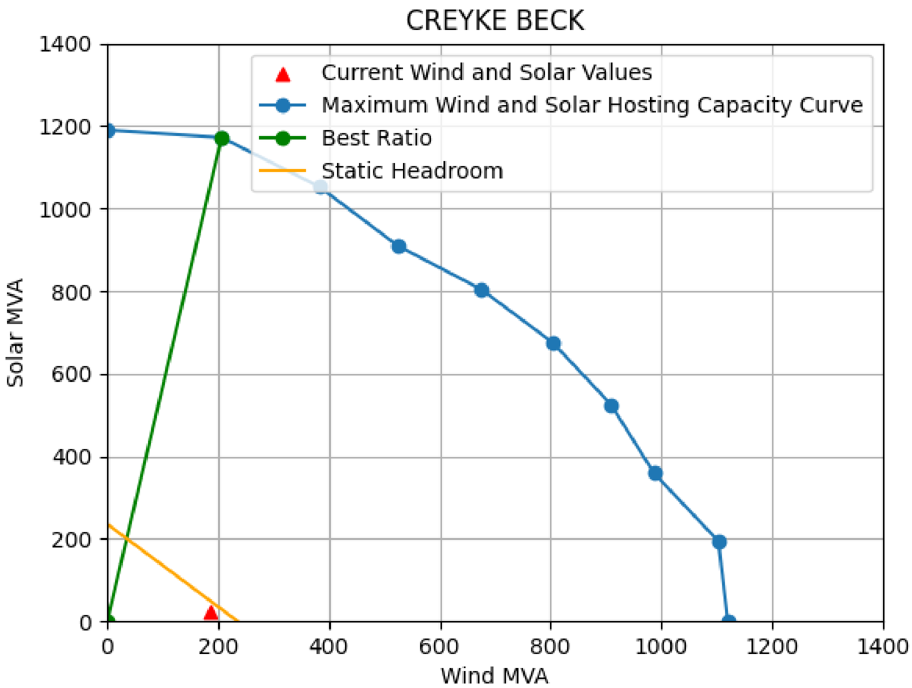

Figure 4-1 – Maximum Hosting Capacity Assessment considering Static and Dynamic Headrooms for varied ratio between Wind and Solar Generation penetration – Creyke Beck

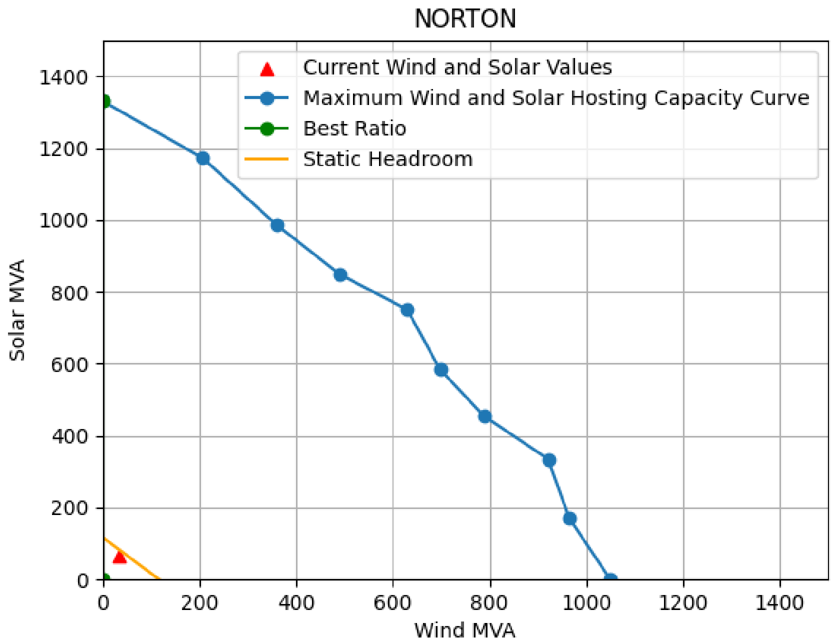

Figure 4-2 – Maximum Hosting Capacity Assessment considering Static and Dynamic Headrooms for varied ratio between Wind and Solar Generation penetration – Norton

For each ratio/degree the generation was increased until the representative time series data of the particular GSP violated its associated firm capacity at least once throughout the year. The value of the maximum increased generation for all ratios for the particular GSP (in this case Creyke Beck and Norton) have been plotted as the blue graph in **Error! Reference source not found.** and Figure 4-2. This line represents the maximum wind and solar hosting capacity of the GSP based on dynamic headroom assessment.

In order to draw a comparison between dynamic and static headroom assessment impact on maximum wind and solar hosting capacity evaluation, a yellow graph representing the maximum hosting capacity of wind and solar generation based on static headroom is added to **Error! Reference source not found.** and Figure 4-2. The area between the yellow and the blue graphs show the extra hosting capacity unlocked for solar and wind generation in case dynamic headroom assessment gets implemented.

The current installed solar and wind generation at the GSPs are shown by the red rectangle in **Error! Reference source not found.** and Figure 4-2. As it can be seen in **Error! Reference source not found.** and Figure 4-2, the current installed solar and wind generation (red rectangle) is located alarmingly close to the yellow graph. Meaning, if we were to continue using static headroom assessment there is almost no extra hosting capacity available for solar and wind at either of the two GSPs. Leading to unnecessary delayed and costly connection process due to inaccurate/under-estimated real hosting capacity available.

Furthermore, as it can be seen in **Error! Reference source not found.** and Figure 4-2, the distance between the points on the blue graph and the point (0,0) is varied for different ratios/degrees between solar and wind generation. Also, these distances represent the maximum hosting capacity for solar and wind using dynamic headroom assessment. Therefore, this serves as indication for possibility of unlocking even more hosting capacity by incorporating an optimisation algorithm that takes into account the ratios between these two technologies. The best ratio/degree (meaning longest distance from point (0,0)) is shown as the green line in both graphs. The impact of ratios between wind and solar generation on the maximum hosting capacity is rooted in inherently different daily diversity of each technology in different locations.

4.2 UNLOCKED HOSTING CAPACITY ASSESSMENT USING STORAGE/FLEXIBLE DEMAND FOR VARIED WIND AND SOLAR PENETRATION – 2 GSPS

This section summarises the results and analysis carried out for impact assessment of having storage or flexible demand (e.g., electrolysers) on hosting capacity of two GSPs Creyke Beck and Norton.

The analysis was carried out considering various ratios between solar and wind generation. The ratios between wind and solar penetration were expressed using the degrees as discussed in section 4.1.

For each ratio/degree the generation was increased from their baseline maximum hosting capacity identified in section 4.1 until the representative time series data of the GSP violated either of the following values throughout the year at least once:

$$S_{firm\_cap} + S_{storage}$$

$$-S_{firm\_cap} - S_{storage}$$

where, S_{firm_cap} is the firm capacity of the GSP in MVA and $S_{storage}$ is the storage size in MVA.

300MVA of storage/flexible demand was considered for each of the GSPs throughout the year and the amount of daily energy excursions from firm capacity throughout the year was calculated for the maximum generation increase (increased hosting capacity for solar and wind).

Th result of this analysis is shown in Figure 4-3 and Figure 4-4 for Creyke Beck and Norton GSP respectively. X axis shows the ratios/degrees between Solar and Wind generation. The scattered box plots are encapsulating the statistic results for the daily energy excursions throughout the year for each ratio/degree and their values can be read using the left Y axis. The maximum increase in the hosting capacity with the inclusion of the storage is shown by the purple star points for each ratio/degree and their values can be read using the right Y axis.

The higher the scatter box plot the higher energy requirement for that storage size, and the higher the star point the larger unlocked hosting capacity using that storage size.

As storage/flexible demand MWh size/requirement, extra hosting capacity (MW), storage/flexible demand MW size/requirement all can be translated to costs, this analysis is a proof of concept for leveraging generation technology diversity and storage/flexible demand (e.g., electrolysers) to reach a more optimal operation of distribution network GSPs.

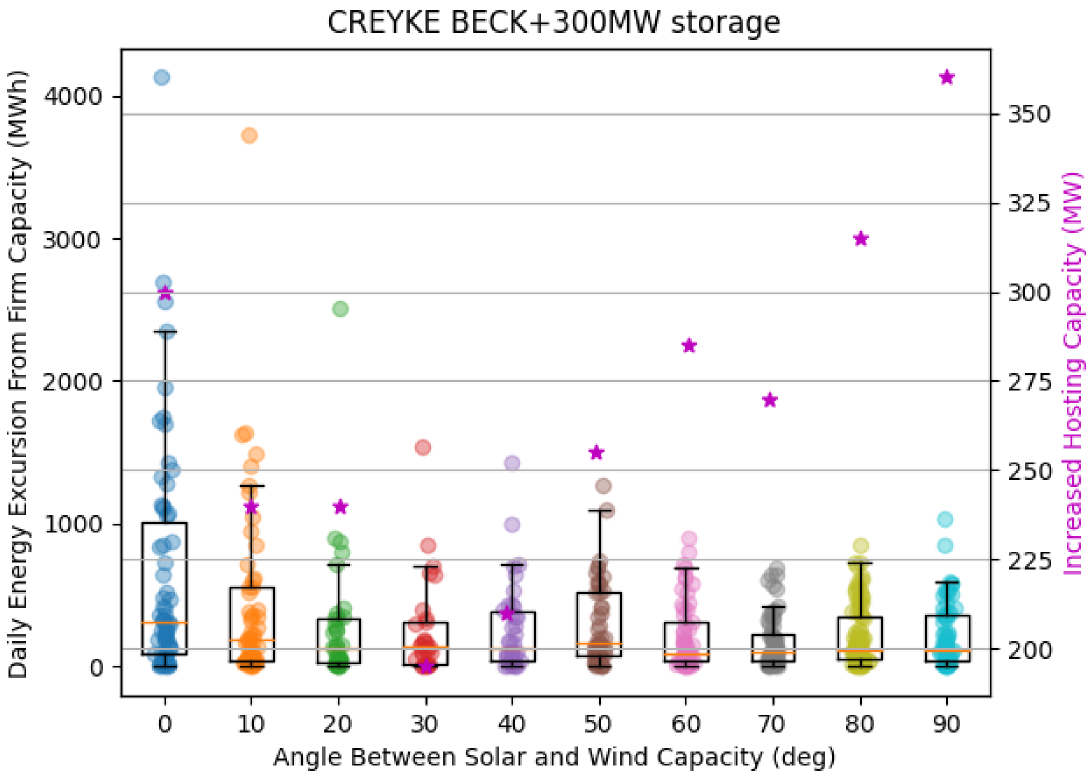

Figure 4-3 – Left Axis: Daily energy excursion above Firm Capacity assessed throughout the year and for varied ratio between Wind and Solar Generation penetration (scatter box plots). Right Axis: Increased Hosting Capacity Unlocked via installation of 300MW storage for varied ratio between Wind and Solar Generation penetration (star points) – Creyke Beck

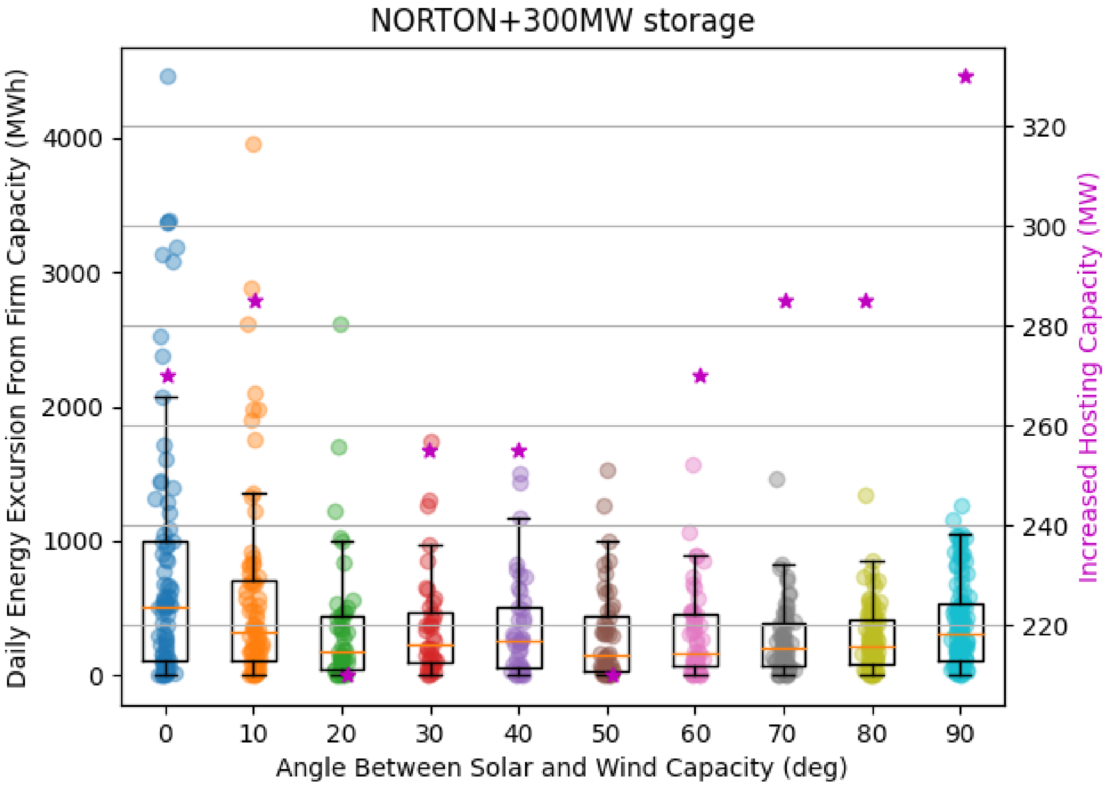

Figure 4-4 – Left Axis: Daily energy excursion above Firm Capacity assessed throughout the year and for varied ratio between Wind and Solar Generation penetration (scatter box plots). Right Axis: Increased Hosting Capacity Unlocked via installation of 300MW storage for varied ratio between Wind and Solar Generation penetration (star points)– Norton

5 CONCLUSIONS

The Distribution Network Operators (DNO) are receiving an increasing number of connection requests at their grid supply points (GSP). While the GSPs of the DNOs may not have any constraints at the distribution level, there may be import and export limitations at the GSP imposed by the transmission system operator. The conventional approach to evaluating the available headroom at the GSPs is very conservative and experience/observations from historical data has suggested the same. The conservative approach of headroom evaluation significantly limits or delays the new connections at the GSP as the GSP waits for reinforcements to realise greater firm capacity, and therefore greater headroom.

This report analyses the headroom available at various GSPs within the distribution network of Northern Powergrid (NPg). The analysis utilises publicly available GSP operational metering time series data available through NPg website. The maximum expected worst case power flow (conservative approach to identify headroom) is determined with respect to current connected generation and the contracted but not yet connected generation.

A methodology to ascertain the maximum generation capacity utilising the dynamic headroom at the GSPs is proposed. The methodology relies upon the actual power flow at the GSP rather than on the worst case expected power flow to determine the limit of penetration of new generation capacity. Furthermore, the methodology evaluates the impact of the composition of the generation technology on the limit of generation capacity at the GSP.

A detailed analysis of Cryeke Beck GSP is presented where the results substantiate the two hypotheses set forth.

- The capacity of generation at GSP can be increased if dynamic headroom is considered rather than static headroom calculated using worst case maximum power flow at the GSP.

- The variation of composition of generation technology can help maximise the dynamic headroom, enabling more generation capacity to be interconnected at the GSP.

The report further explored optimization opportunities to determine the ideal mix of generation for maximizing the utilization of headroom at GSPs. The outcomes support the feasibility of employing optimization algorithms to enhance capacity. Additionally, the potential to unlock hosting capacity using storage or flexible demand is analysed, offering a glimpse of how these technologies could optimize GSP operation by considering energy diversity and cost factors.

It should be mentioned that the analysis presented is preliminary and specific to the GSP under consideration. However, the analysis presented serves as a proof-of-concept that will be taken forward for evaluation in the next phase of the project. Furthermore, the methodology is generic and can be applied to any GSP within the Great Britain power network.