March 2022

Year-round Thermal Probabilistic Assessment

nationalgridESO

Contents

Chapter 1

Introduction

The Great Britain National Electricity System (NETS) is seeing higher penetration of intermittent low carbon energy resources.

Therefore, to help us assess the capability of the NETS to adequately transfer power to demand centres, we're developing a tool (the POwer Uncertainty Year-round Analyser – POUYA) to evaluate the impact of intermittent low carbon resources on the NETS – through a detailed year-round probabilistic modelling and statistical analysis of network flows.

With our developing POUYA tool, we can capture the power transfer limitations on the GB NETS that not only occur during the winter but also those that occur across the year, driven by the seasonality characteristics of low carbon energy resources as well as network outages for construction/maintenance

This takes us a step closer toward performing a year-round probabilistic analysis – capturing the range of system limitations that might occur on the NETS, then quantifying the magnitude and likelihood of events on the NETS, and finally resulting in more informed network investment and operational planning decisions, with clear cost and risk measures accounted for.

We have decided to have a separate publication for our 2021/22 probabilistic analysis.

Here we focus on our POUYA proof of concept work – highlighting the developments completed, the results of our validation tests and to showcase the statistical analyses that we can undertake. We have decided to have a separate publication for our 2021/22 probabilistic analysis. Here we focus on our POUYA proof of concept work – highlighting the developments completed, the results of our validation tests and to showcase the statistical analyses that we can undertake.

The report focuses on the year-round thermal probabilistic analysis development, but we also provide updates on our innovation projects related to voltage and stability year-round assessment work.

For our POUYA year-round thermal modelling and analysis, we've built on our previous published work and, in this publication. we will demonstrate the new capabilities from our tool development over the last year. For example, we've tested and validated our thermal tool's results against our standard winter peak analysis tools on selected boundaries B2, B6, B7a, B8 and SC3. We've then further scaled our work to complete full year-round analyses on three boundaries - B4, B6 and SC3 - to run our automated data analytics to deal with the high volume of data produced from our year-round simulations

We've engaged with the three TOs throughout to show the different types of network needs we can identify, thereby giving a more holistic understanding of network requirements. This way we can use POUYA results to provide additional information to the assumptions behind the deterministic boundary capability analysis used in the *NOA*.

Key Messages

Our key messages build on those earlier published in the ETYS and are summarised below

Key Message 1

We've completed our POUYA validation exercises both against our traditional winter peak SQSS planning standard tool and the ability of our POUYA tool to generate credible year-round generation and demand backgrounds using historical data.

Results from this validation have produced close alignment both with the *ETYS* winter peak results calculated from the traditional winter peak SQSS planning standard tool as well as with the historical data used to generate the year-round generation and background scenarios

Key Message 2

We've selected three boundaries representing the three key regions of the Scottish Highlands, the Anglo-Scottish border and the South of England where constraints are likely to be seen, according to the *ETYS* 2021 publication.

We've used POUYA to conduct a year-round analysis to understand the NETS requirements throughout the year on these three regions in addition to the winter peak analysis made in the *ETYS*

Key Message 3

From our analysis we've captured power transfer limitations that not only occur during the winter but also those that occur across the year. In the Scottish regions we've noticed, additional wind output driven constraints occurring in the autumn season.

In the South of England, we've noticed the year-round impact of interconnectors on power transfer limitations. However, these results consider an intact network and further development is underway to complete this analysis considering year-round network outages to draw better network planning insights

Key Message 4

By the fourth quarter of 2022/23 we expect to have improved our thermal probabilistic modelling accounting for network outages. This will then be developed, tested, and implemented to completely account for the year-round background conditions that we need to consider in assessing the year-round the capability of the NETS.

Chapter 2

Year-round Thermal Assessment Methodology

The POUYA engine uses historical profiles as inputs to a Monte-Carlo method that samples those inputs and uses the technical operational logic of generation and demand to produce realistic outputs of wind farms, solar panels, hydro units, generation units' availability and demand dispatches

We use these dispatches to estimate the likely power flow on individual transmission circuits or a group of circuits. A group of circuits are also known as a boundary. The NIA project on probabilistic stability analysis is looking into improvements on our probabilistic modelling approach with more sophisticated statistical analysis.

When Monte-Carlo is used to sample likely background generation and demand conditions, it produces hourly snapshots of generation and demand for each sample year. We then use Economic Dispatch (ED) to find out the probable dispatches of energy resources assuming an ideal electricity market. The results, which are hourly generation and demand snapshots, are evaluated by power system analysis based on DC power flow for a set of credible contingencies. We have improved our DC load flow engine by modelling and adding grid losses to the model.

Pre- and post-faults actions are applied, when applicable, to relieve congestion and increase the transfer capability. The results from the power flow analysis lets us understand the impact on the GB NETS. Our probabilistic approach can be summarised by two key elements – the Monte Carlo sampling economic dispatch and the DC power flow network assessor element. Further details on the overall probabilistic approach are given in next session.

Comparing POUYA with our traditional deterministic approach

Developing our probabilistic approach has involved reconsidering our deterministic process to identify the steps in the process that we could enhance and incrementally evolve toward a full probabilistic analysis process. We've summarised this in the two figures that follow. Figure 1 for the probabilistic process and Figure 2 for the deterministic process.

In Figure 1, the green highlights show the steps in our analysis where we have improved on our deterministic process, as allow us to generated multiple year-round generation and demand scenario data. We then use this data to generate several network flows which we can then statistically analyse to determine likelihood of constraints on a boundary.

Figure 1: probabilistic analysis process

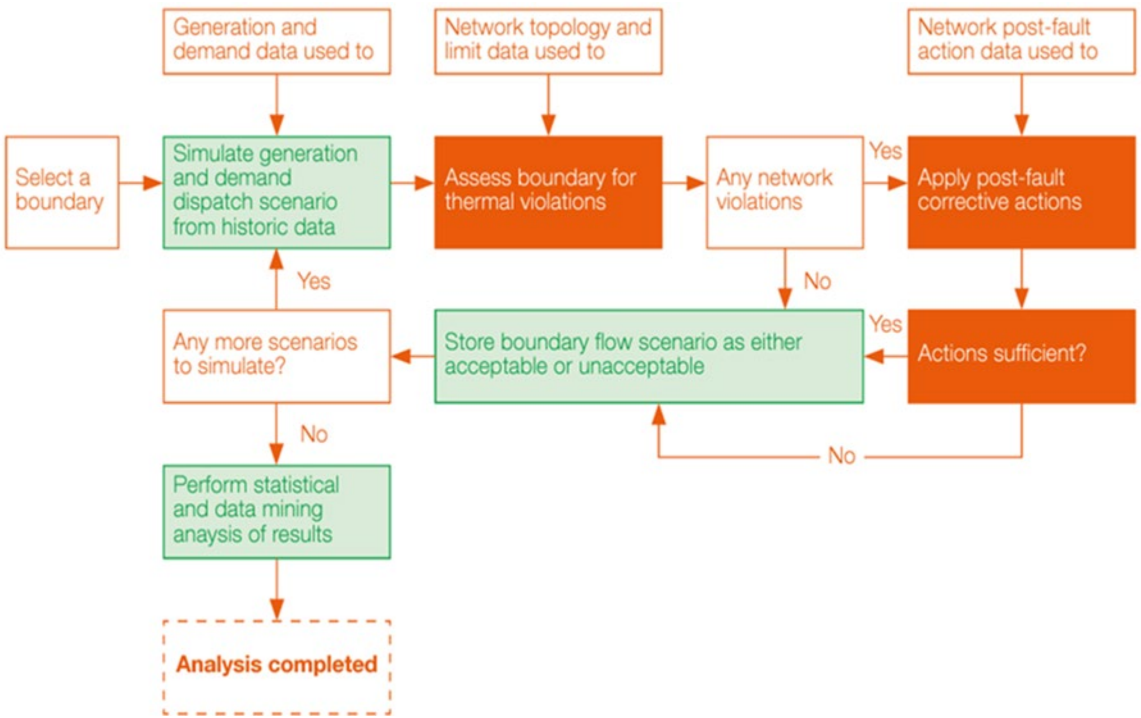
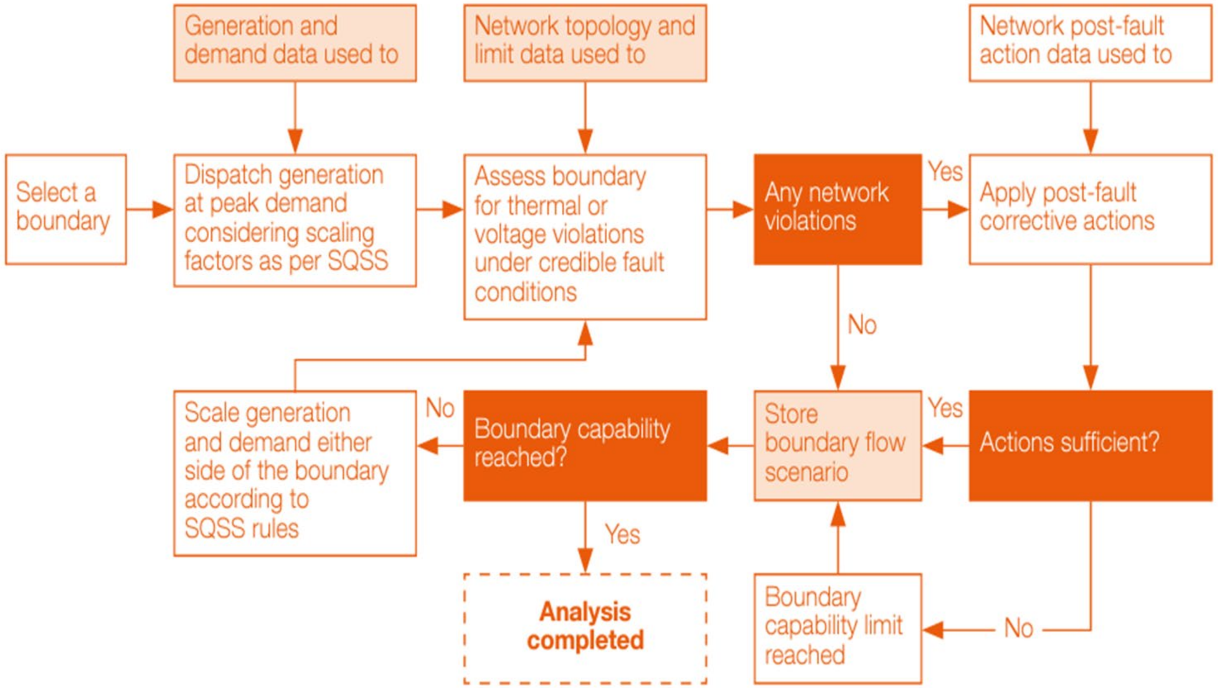


Figure 2: deterministic analysis process



POUYA traditional deterministic SQSS module

Although we've developed POUYA with probabilistic modelling capability to perform year-round analysis, we've also developed the deterministic SQSS approach into our POUYA module to (1) validate the tool and (2) automate the process and add optimisation modules for optimising power flow control devices (PSTs, QBs, Smart-wires, and DC links).

This will eventually allow us to study more cases in less time and provide more information for the *NOA* cost benefit analysis.

The module runs the current processes of the *ETYS*/*NOA* wider Boundary capability analysis utilising POUYA environment rather than traditional tools such as Power Factory or PSS/E. The module is still an ongoing development. However, this module can benefit the boundary analysis processes in number of areas:

- High level of automation added to the boundary analysis process including saving large amounts of time and cutting the study period
- Automated post fault actions application and optimisation (PSTs, QB, Smart-wires, DC links)
- Interconnector sensitivity analysis

This module has been used to validate the network analysis module of POUYA against our traditional power system analysis tool and results are presented in chapter 3. The benefit that this module provides as summarised above has been realised via proof of concept analysis. The performance of the tool can be improved and will be working and engaging with TOs to prioritise developments based on any new or additional requirements on the current version and the other modules of POUYA.

Data analysis following the probabilistic approach

In the probabilistic approach, we consider about 10 samples an hour or 87,600 year-round scenarios, using the Monte-Carlo historical data sampling algorithm. This leads to 87600 network flows per studied boundary when it is intact. When contingencies are considered against a boundary, we can generate 87,600 network flows multiplied by the number of contingencies considered.

We use these outcomes to perform analysis of network thermal requirements and cluster outcomes based on whether they're acceptable or unacceptable. If under either intact or fault conditions any of the recorded lines within a boundary region results in an overload, then the flow across the boundary is deemed to be unacceptable. If under either intact or fault conditions any of the recorded lines within a boundary region did not result in an overload, then the flow across the boundary is deemed as acceptable.

When this clustering analysis for a studied boundary is completed, typically within 10 minutes, we can generate a large dataset of results. Drawing out useful insight about network performance and requirements from this data becomes difficult with manual analysis techniques. To overcome this, we have developed a data analytics module to perform statistical analysis to summarise the data.

Chapter 3

Probabilistic modelling progress against our ESO ambition

In line with our ESO business plan, we're developing POUYA to enhance our capability to be able to manage the rising number of scenarios and increased modelling complexity that are driven by the growing interaction between different network needs. The better we understand likely needs, the better we can identify where and when to efficiently invest.

As earlier discussed, we've modelled POUYA to allow us to perform detailed year-round statistical analysis of network flows and other system conditions. It is a significant step forward, as we will be able to not just understand that a circuit is overloaded, but also when, how often and under what prevailing conditions. This will support better decision making to prevent over or under-investment.

The development of the POUYA tool is one part of the year-round analysis capability that we're developing. Data is also an important part of the probabilistic modelling requirements. Work is under way to develop data gathering processes that will feed into the POUYA tool so that we can perform year-round analysis. To the right is a summary of the data gathering that has been completed.

Network development input data

Historical electricity prices for transmission connected generation of all types (except wind and solar)	Historical hourly gross demand data	Embedded generation and dispatch data	Historical generator operational data for all generation types e.g. availability rates
Historical wind data to determine transmission connected wind dispatch	Network contingencies	UK-Europe interconnector dispatches	Historical solar data to determine transmission connected solar dispatch

As we work toward integrating probabilistic analysis into the *ETYS* and the *NOA* we are further developing processes to gather and structure data to account for year-round network outages.

This way we will be able to integrate this tool with our other network planning tools, which will better optimise our decision-making process by combining the economic and technical studies within a single platform. However, as the process to gather network outage data is not yet complete, the results we present in chapter 4 demonstrate proof of concept with the data we've been able to gather.

Learnings from the POUYA Network Analyser Proof of Concept Study

It has been useful to perform proof of concept because it has allowed us to validate our tool. We have validated its ability to replicate historical data as well as its ability to compute network power flows. Also, from our proof of concept work we have explored a variety of techniques to enable us to evaluate boundary performance against requirements.

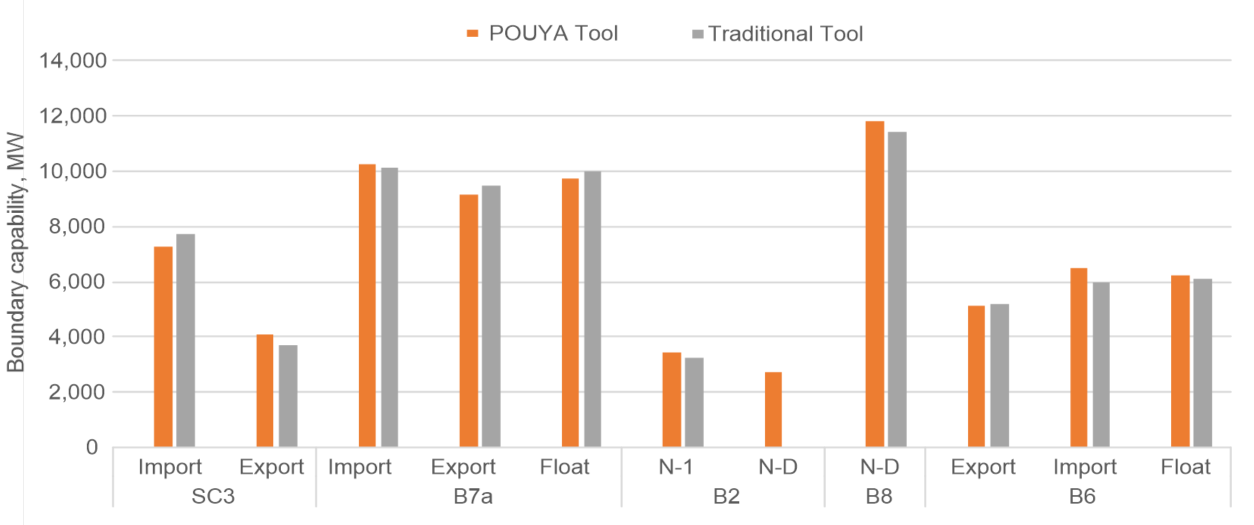
Having considered a few ways to summarise boundary performance, we have chosen to describe boundary performance through statistical distribution plots. Finally from this proof of concept analysis we have concluded that we need to add further POUYA functionality that takes us a step closer toward modelling a bespoke joint market and network tool for GB thermal constraint analysis would need in order to facilitate integration of the year-round technical analysis into *ETYS* and *NOA* processes. We discuss this in detail in chapter 5.

POUYA network analyser validation results

Before performing a year-round analysis, we validated POUYA's ability in two ways:

- Its ability to compute power system network analysis similarly to our winter peak traditional analysis
- Its ability to accurately generate realistic year-round generation and demand data that aligns with historical data.

To validate the first point above, we used boundary capability as a comparative measure and to validate the second point we compare POUYA dispatch output against the historical data used to produce it.



We validated the ability of the POUYA tool to compute deterministic capabilities against our traditional SQSS approach used in Power Factory for the *ETYS*. The data used for this exercise was 2021/22 winter peak generation and demand data used in the *ETYS* publication.

This exercise was completed against selected boundaries. The results from this validation exercise with the boundary capabilities computed from our POUYA tool are summarised in the figure above.

POUYA network analyser validation results

As the previous results show, the computed boundary capabilities closely align with those computed from our traditional approach and tools. Not only are the capability values close the POUYA tool reproduced the limiting contingencies and circuit data with very good accuracy.

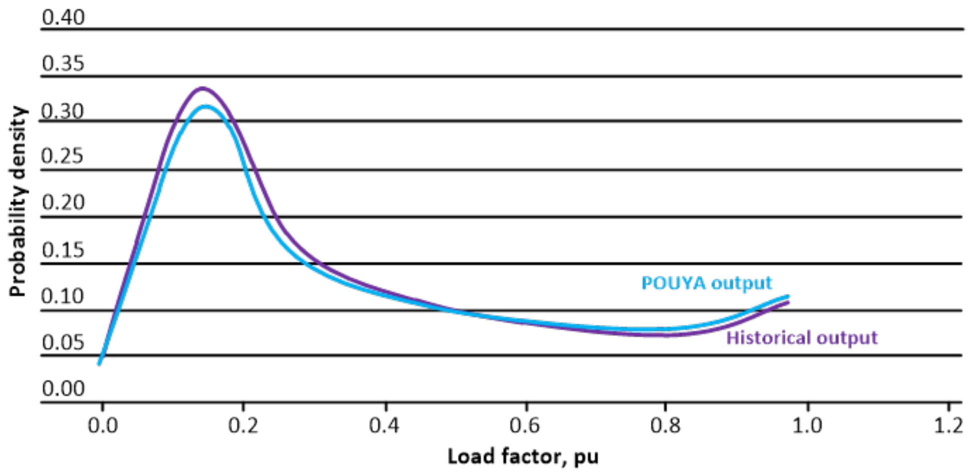
However, we are unable to publish these in accordance with our System Operator Functional Information (SOFI) obligations as per our Electricity System Operator (ESO) licence requirement.

We will continue to make improvements to the POUYA tool to achieve even higher accuracy in the future. However, given the currently high level of alignment and accuracy with the traditional deterministic approach we are confident in the capability of POUYA to conduct year-round thermal analysis.

Year-round thermal analysis scenario background generation validation

Our 2021/22 winter peak study case has a generation capacity mix composed of about 68 per cent thermal, 21 per cent wind, 6 per cent interconnector and the remaining 5 per cent composed of various storage and renewable energy technologies – to supply the GB winter peak demand. These technologies are spread across the network. We apply a probabilistic analysis across the entire winter season considering these conditions.

We have collected a database of historical information relating to hourly regional wind and solar profiles, plant availability (both forced and random outage data), and hydro and pumped storage typical loading patterns.



This data has been used by the Monte Carlo sampling algorithm to produce dispatches that reflect our year-round conditions. Also, using our modelling of the European market dispatch, we have generated typical interconnector dispatches as well as energy storage charging and discharging cycles. To validate the dispatches created by our probabilistic approach, we have compared our sampled Monte Carlo generation and demand dispatches with the historical data input. For our validation exercise, we compared the distribution of inputs against the distribution of outputs of generation plants.

We have completed the validation exercise for all generation types and the results obtained confirmed that the tool's outputs reproduced input data with very good alignment with less than 3% error. However, we are unable to fully publish these results as they may expose third party confidential information. We are unable to publish detailed results as they may expose third party confidential information. However, in the left figure, we show a general comparison of POUYA output dispatch vs historical output of a selected group of generators over their load factor output range

Chapter 4

Probabilistic thermal year-round analysis

In the latest *ETYS* publication, it was observed that growth in north-south power flows have continued and occurring with high variability. Also, it was communicated that the GB electricity transmission system will face growing needs in several regions in the years to come.

These observations were made following our traditional winter peak analysis approach. It is important to further understand the impact of these observations over the course of a year and not simply at winter peak.

Year-round thermal analysis case study background

The *ETYS* observed growing needs for power transfer through the electricity system. These needs are not impacting every region of the network equally. This means we need to identify those regions on the network where we're likely to see high power transfer requirements. A tripling of wind generation connected across the Scottish networks by 2030 means the Scottish region will see increased power transfer requirements.

This will also result in a doubling of transfer requirements from northern Scotland to the Midlands over the next 10 years.

Finally, the growing number of interconnectors with Europe will place increased requirements on the transmission network, especially as interconnector capacity is anticipated to exceed transmission connected generation in the South of England.

This means we need to go a step further than understanding transmission requirements at winter peak and understand the year-round transmission needs. To align with the *ETYS* key messages we selected the boundaries B4, B6 and SC3 representing the Scottish Highlands, the Anglo-Scottish border, and the South East of England areas respectively.

Year-round thermal analysis case study background

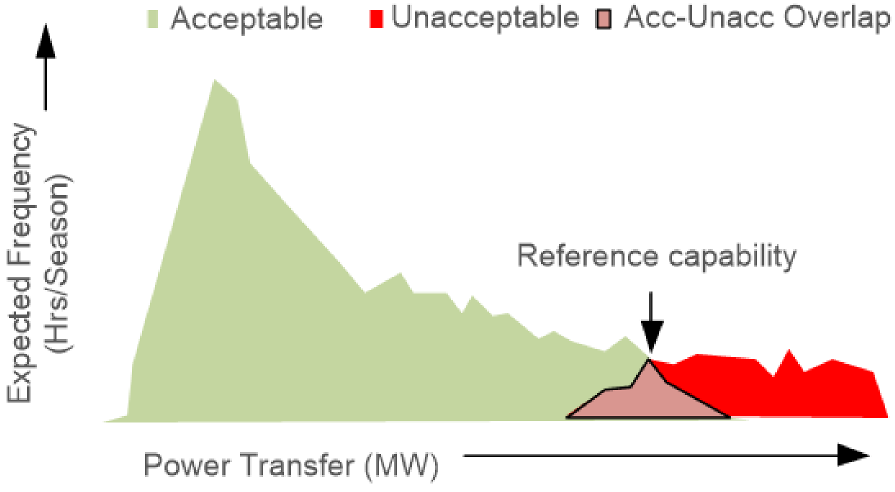
We conduct a year-round analysis for the 2021/22 period to compare with the *ETYS* winter peak results and provide further insight on the year-round requirements. For our 2021/22 year-round analysis, we generated around 87,600 scenarios of generation and demand dispatches.

From this, considering both intact and contingency network conditions, we produced on average around 876,000 network flows, per individual boundary. However, to speed up the analysis we used clustering techniques (to combine similar generation and demand dispatch scenarios) to lower the analysis studied by a factor of 10. This resulted in enhanced computation speed and around 87,600 network flow scenarios on average, per boundary, without loss of accuracy in the results.

The thermal loadings on lines within a two-substation distance of a studied boundary were recorded. If under either intact or fault conditions any of the recorded lines resulted in an overload, then the flow across the boundary was recorded and assigned as unacceptable. If under either intact or fault conditions any of the recorded lines did not result in an overload, then the flow across the boundary was recorded and assigned as acceptable. We use these results to present three main case studies in this chapter performed on boundaries B4, B6 and SC3.

Case study boundaries and interpretation of results

In our case study examples, we use the *ETYS* calculated winter peak capabilities across B4, B6 and SC3 to represent a reference capability to be met across the season. As an illustration and proof of concept, for each of these boundaries, the winter peak capabilities will be plotted against the distribution of acceptable and unacceptable plots that represent the statistical summary of year-round boundary performance. This is illustrated below, with the *ETYS* calculated reference boundary capability superimposed on the year-round distribution plot.



As shown in the plot, the reference boundary capability may lie in the region where acceptable and unacceptable outcomes overlap and, as such, there will be instances below that capability where unacceptable outcomes will have to be quantified.

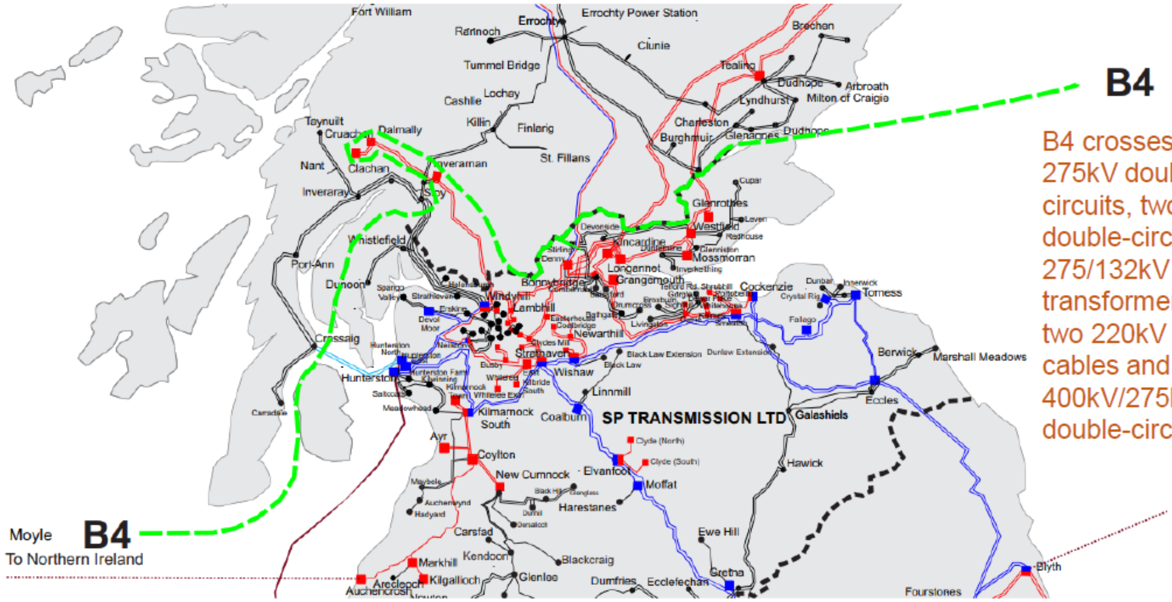
In this way a boundary capability can be defined by ensuring that the likelihood of unacceptable occurrence is low compared to the acceptable outcome, thus ensuring that the network constraints associated with these outcomes will be for a shorter duration. Therefore, the additional (to the winter peak) year-round requirements can be understood in terms of their duration and magnitude and appropriate solutions can be designed to mitigate them if deemed economic.

In the results that we will show, the reference capabilities have been calculated accounting for network outage conditions. However, our season round distribution plots have been calculated without accounting for network outage data. However, this is an area we're looking to improve upon going forward in chapter 5.

B4 results

The year-round boundary performance for B4 is presented on the next page through seasonal plots of acceptable and unacceptable power flow distributions. The reason for this is because we've traditionally calculated seasonal capabilities to account for the seasonal variation in thermal ratings. This way we can compare how the seasonal peak thermal capability ratings (superimposed on the plots below) compare with the season round boundary performance.

We initially note that in the spring and summer seasons, the peak calculated capability lies in the acceptable region of the plot. This entails that the peak capability is sufficient to satisfy the boundary's requirements during these seasons. However, it must be mentioned that in a complete analysis, network outage data would have to be considered to better understand how the performance of the network would be impacted during these seasons.



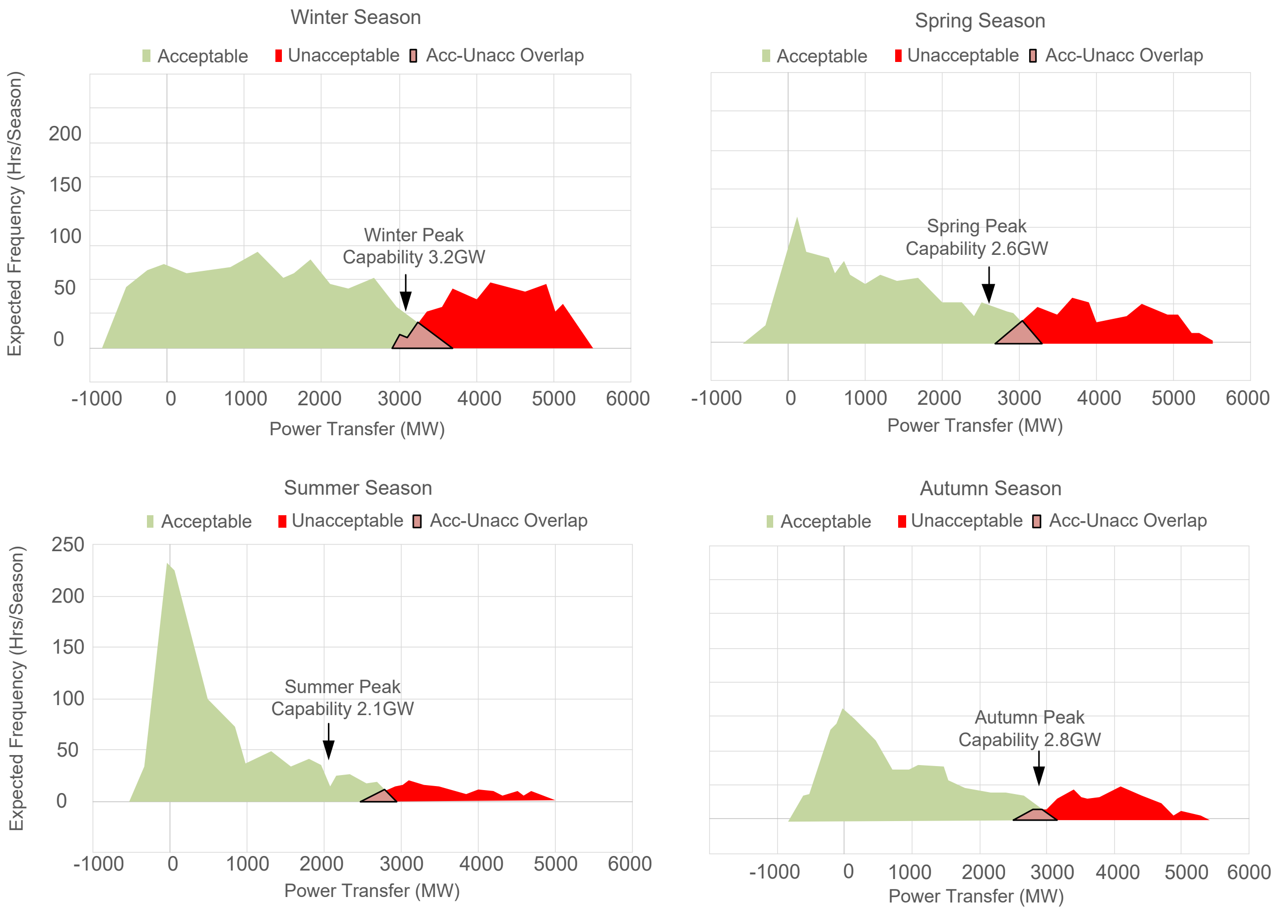
B4 crosses two 275kV double-circuits, two 132kV double-circuits, two 275/132kV auto-transformer circuits, two 220kV subsea cables and a 400kV/275kV double-circuit

Further analysis of the winter and autumn seasons reveal that the peak capabilities lie in the overlapping region of the acceptable and unacceptable plots.

B4 results

This means that for around 36 hours during the winter season the peak capability is insufficient to meet the seasonal requirements, and in the autumn the peak capability is insufficient to meet seasonal requirements for around 13 hours. This means that for a total duration of 49 hours (i.e. 0.56% of the time) over the course of the year, additional boundary capacity would be required. However, because this additional capacity requirement is not persistent throughout the season, short-term operational activities e.g. via the balancing mechanism would satisfy this requirement.

These results illustrate that we can identify the seasons when additional requirements to the peak capability are needed, as well as for how long i.e., their duration. As we consider future years this approach would prove useful in quantifying possibly even higher magnitude and likelihood of events on the NETS throughout a year and lead us to more informed network investment and operational planning decisions, with clear cost/risk measures being applied.

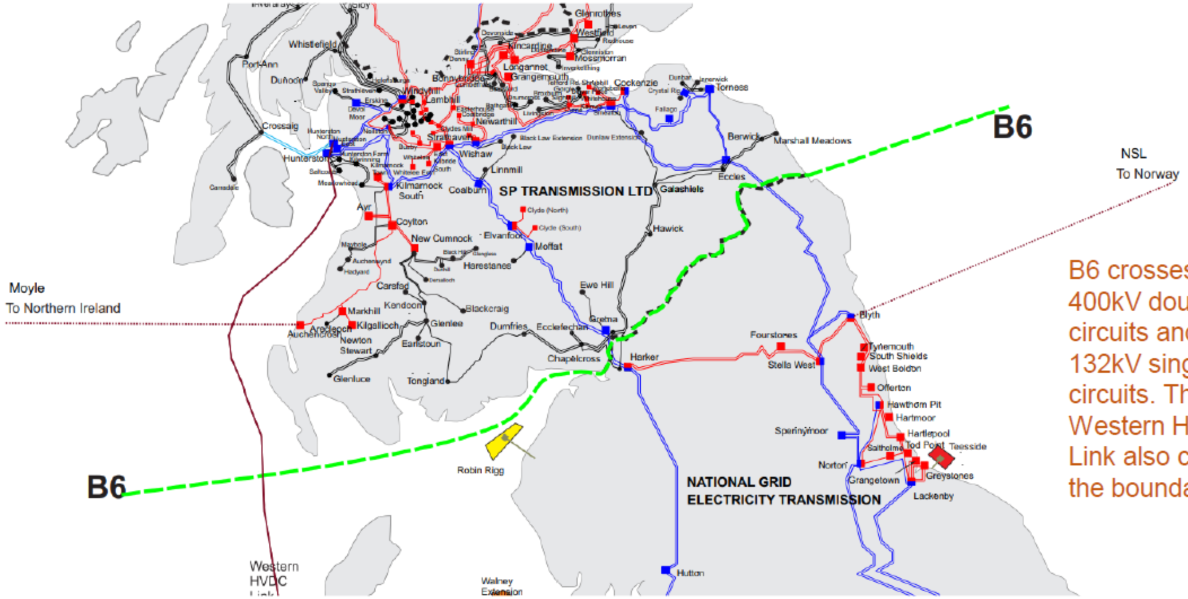


We are improving our network modelling approach to further test our approach on future study years, considering network outage information.

B6 results

The year-round boundary performance for B6 is presented [on the next page](#) through seasonal plots of acceptable and unacceptable power flow distributions.

Similarly, to B4 analysis, we note that in the spring and summer seasons, the peak calculated capability lies in the acceptable region of the plot. This entails that the peak capability is sufficient to satisfy the boundary's requirements during these seasons. However, it must be mentioned that in a complete analysis, network outage data would have to be considered to better understand how the performance of the network would be impacted during these seasons.

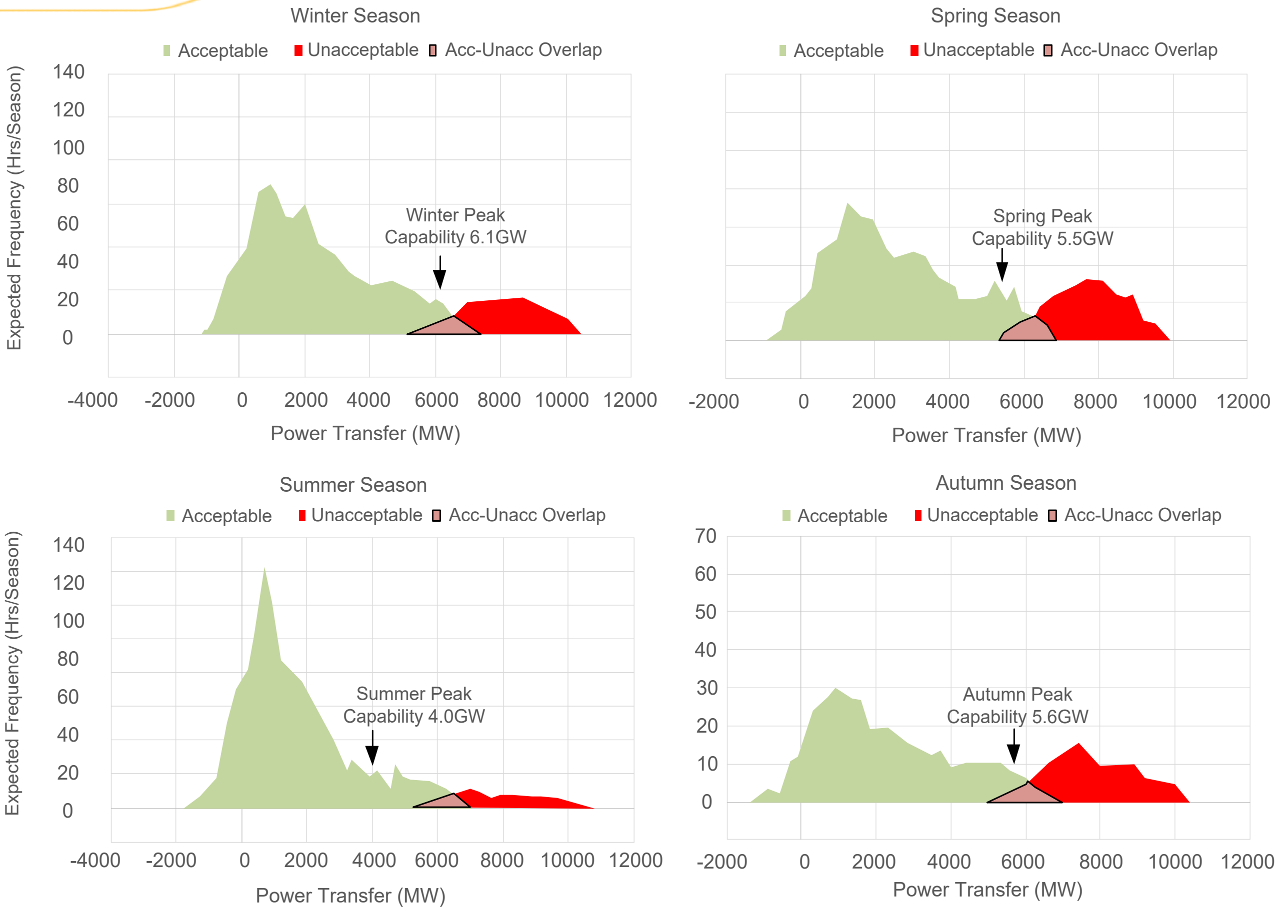


B6 crosses two 400kV double-circuits and two 132kV single-circuits. The Western HVDC Link also crosses the boundary.

B6 results

Further analysis of the winter and autumn seasons reveal that the peak capabilities lie in the overlapping region of the acceptable and unacceptable plots. This means that for around 21 hours during the winter season the peak capability is insufficient to meet the seasonal requirements, and in the autumn the peak capability is insufficient to meet seasonal requirements for around 11 hours. This means that for a total duration of 33 hours (i.e. 0.38% of the time) over the course of the year, additional boundary capacity would be required. However, because this additional capacity requirement is not persistent throughout the year, short-term operational activities e.g. via the balancing mechanism would satisfy this requirement.

These results illustrate that we can identify the seasons when additional requirements to the peak capability are needed, as well as for how long i.e., their duration . As we consider future years this approach would prove useful in quantifying possibly even higher magnitude and likelihood of events on the NETS throughout a year and lead us to more informed network investment and operational planning decisions, with clear cost/risk measures being applied.

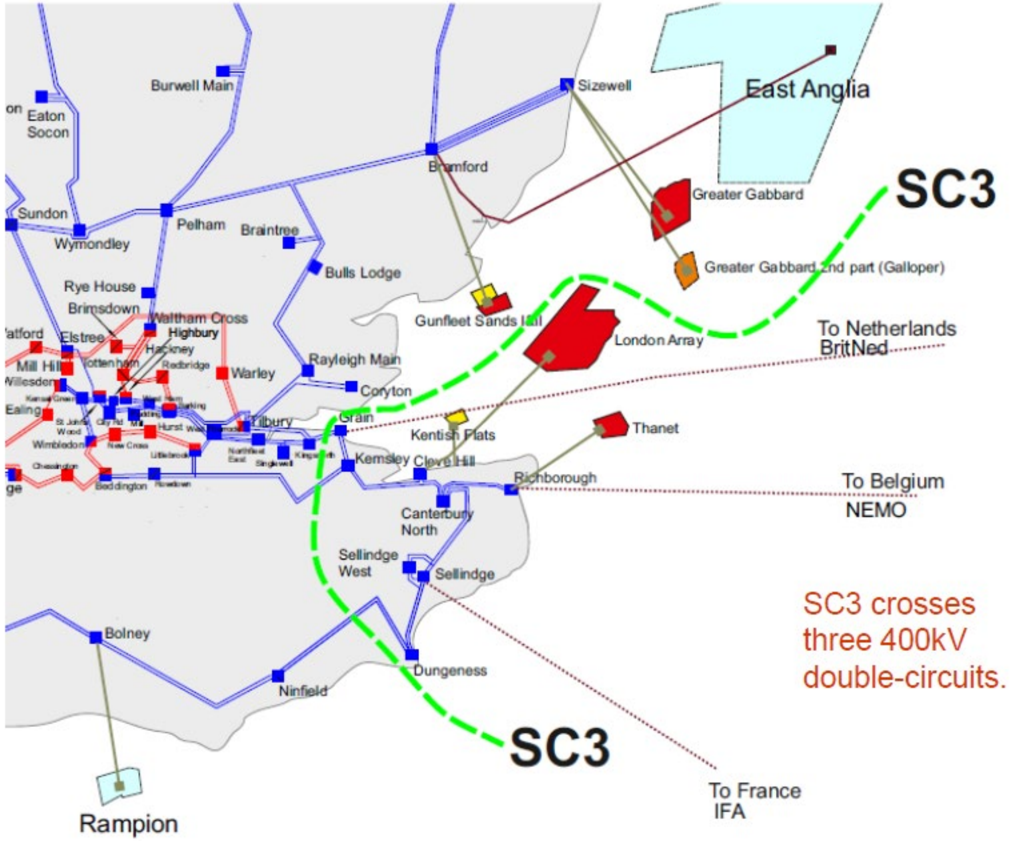


We are improving our network modelling approach to further test our approach on future study years, considering network outage information.

SC3 results

The year-round boundary performance for SC3 is presented on the next page through seasonal plots of acceptable and unacceptable power flow distributions.

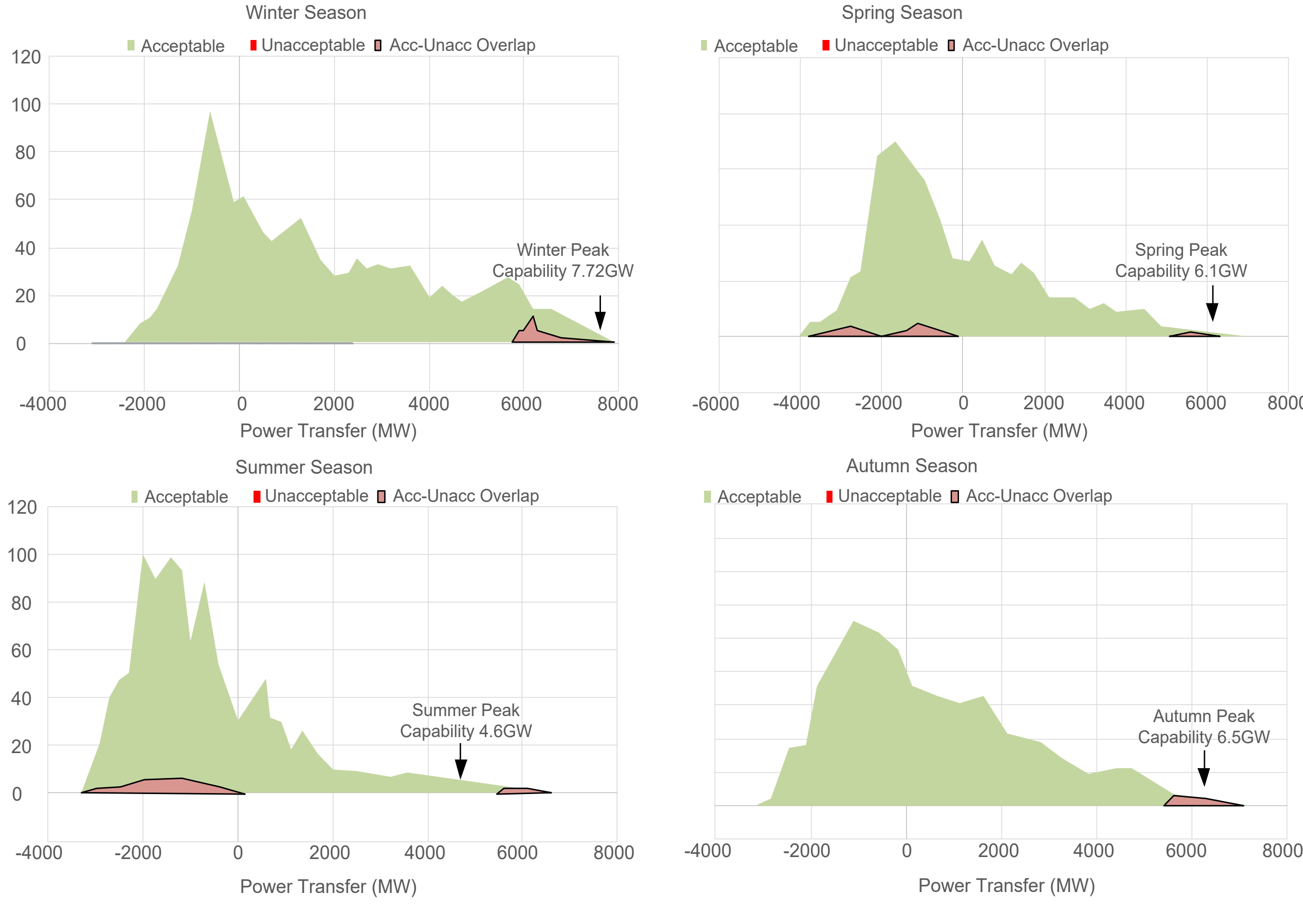
We note that in all seasons, different to the previous two studies, the unacceptable distribution plot lies within the acceptable distribution plot. This means that in the winter, spring, summer and autumn seasons, the respective peak capabilities will be insufficient to meet requirements for 133 hours, 56 hours, 62 hours and 17 hours for the respective seasons. Furthermore, we note that unacceptable power transfer situations can occur when the boundary is importing power into it (i.e., negative power transfer) or exporting power into it (i.e., positive power transfer)



SC3 results

This means that for a total duration of 268 hours (i.e. 3.06% of the time) over the course of the year, additional boundary capacity would be required. However, because this additional capacity requirement is not persistent throughout the year, short-term operational activities e.g. via the balancing mechanism would satisfy this requirement.

These results illustrate that we can identify the seasons when additional requirements to the peak capability are needed, as well as for how long i.e., their duration. As we consider future years this approach would prove useful in quantifying possibly even higher magnitude and likelihood of events on the NETS throughout a year and lead us to more informed network investment and operational planning decisions, with clear cost/risk measures being applied.



We are improving our network modelling approach to further test our approach on future study years, considering network outage information.

Chapter 5

Way forward on the year-round thermal probabilistic analysis

We’ve presented the current state on our approach which allows us to perform detailed statistical analysis of network flows and other system conditions.

We’ve validated it capability with respect to its ability to model year-round background conditions based on historical data and to use this information to calculate network flows and summarise them statistically. It is a significant step forward, as we are be able to not just understand that a boundary is constrained, but also when, how often and under what prevailing conditions.

This outcome supports us with better decision making to prevent over or under-investment by generating additional snapshots to considered to our current *NOA* CBA process. This will allow more reinforcement paths to be explored as well as to model and assess potential alternatives to traditional transmission reinforcement. These include commercial options, flexible power-flow devices, and energy storage, which will enhance our capability to compare multiple options in the *NOA* process. Also, by integrating this tool with our other network planning tools (currently being developed via the NIA project discussed in the next chapter), we will better optimise the decision-making process by combining the economic and technical studies within a single platform.

By the fourth quarter of 2022/23 we expect to have gathered further year-round thermal probabilistic modelling requirements (including accounting for network outages). This will then be developed, tested, and implemented to completely account for the year-round background conditions that we need to consider in assessing the year-round the capability of the NETS.

Chapter 6

Update on our Network Innovation Allowance (NIA) projects

Probabilistic planning for stability constraints Network Innovation Allowance

This project, led by the consulting company TNEI, aims to explore, develop and test cutting-edge automated and probabilistic approaches for modelling of angular stability. This will enable year-round boundary capability calculation for stability accounting for several sources of variability and uncertainty and enabling ESO to consider the possible issues across the system.

The developed tools have proved the concept of the practicality of doing probabilistic stability analysis by utilizing automation and Machine Learning techniques. This is a step forward towards the capability of running year-round stability analysis and to be able to run for more boundaries and contingencies in the network.

The next steps are to ensure the scalability and accuracy of the tools in the full model, to align the tools with the existing planning tools in the ESO and to demonstrate the impact of the improved stability assessment in the long-term planning decision making (i.e., *NOA*).

Further updates on the progress of this project can be found here

Advanced Modelling for Network Planning under Uncertainty

This project was established and undertaken by the University of Melbourne, Australia, to independently validate the economic and technical aspects of our NOA methodology, compare our process to those used in other countries and to explore the potential for new analysis tool

Following this study some recommendations were made to further enhance the CBA processes. We've implemented a number of these recommendations and plan to showcase proof of concept in future publications. We've published the full document here.

Applications of convex optimisation to enhance National Grid's NOA process

We have successfully completed this NIA project with University of Strathclyde. This NIA project focuses on developing new tools and techniques to better assess GB year-round reactive power requirements.

A Python-based tool is now developed with multiple techniques to do year-round voltage assessment. Further on, we are going to do extensive tests and study using GB data to make the tool fit for purpose. Further details about this project can be found here.

Chapter 7

Stakeholder Engagement

The probabilistic work that we're doing is in response to the changing and more challenging network needs that we must meet, driven by the move towards zero carbon. Through the ambitions set out in the ESO's RIIO2 Business Plan, we are committed to improving our probabilistic modelling work. In this publication we've showcased the progress we've made in developing our modelling of thermal, voltage and stability analysis tools.

As we continue to develop our tools and publish outcomes, we would like to hear your views on how we should scope the analyses to better communicate network needs in a manner relevant to you, our stakeholders.

We'd also like to hear from you on what form you'd like our future publication to take, so that it is even more valuable for you and others to use as we aim to expand and make our work more relevant to a wider audience e.g., industry, consultants, and academia.

We encourage your views (especially on what works well and what we need to improve) to be shared with us via our mailing address: transmission.etys@nationalgrideso.com

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