Notes on Completion: Please refer to the appropriate NIA Governance Document to assist in the completion of this form. The full completed submission should not exceed 6 pages in total. Network Licensees must publish the required Project Progress information on the Smarter Networks Portal by 31st July 2014 and each year thereafter. The Network Licensee(s) must publish Project Progress information for each NIA Project that has developed new learning in the preceding relevant year.

NIA Project Close Down Report Document

Date of Submission

Jul 2025

Project Reference Number

NIA2_NGESO037

Project Progress

Project Title

Forecasting the Risk of Congestion

Project Reference Number

NIA2_NGESO037

Funding Licensee(s)

NESO - National Energy System Operator

Project Start Date

June 2023

Project Duration

2 years and 2 months

Nominated Project Contact(s)

Innovation@neso.energy

Scope

This project will develop new probabilistic forecasts to anticipate the possible spread of values between the day ahead scheduled energy flows and the actual energy flows. The project will first consider development of forecasters for the interconnectors, with the addition of uncertainties from key wind generation units in the final work package. The associated probabilities as well as the correlation between the spread values at different nodes of the grid will also be tracked.

The goal is to predict the risk of congestion on specific branches of the power grid with a probabilistic approach. This will be done by using power flow models to propagate the probabilities of injections and offtakes at different nodes of the grid and applying them into current scenarios on internal lines of the power grid.

Objectives

- Forecast probabilities of deviations between day ahead scheduled flows and actual energy flow for each interconnector connected to the EU
- Critical contingency and critical branch pairs identified for analysis within the project
- Generate a sample of scenarios suitable for analysis of the load flow solver
- Develop a tool tested on a sample of weeks and provide the congestion risk profile for each pair of contingency and critical branches identified
- Interface load flow tool with network topological changes, and generation and demand profiles, ensuring solver can run in timescales suitable for operational use
- Compare results from probabilistic distribution for congestions with existing point forecast, and consider impact on potential operator actions

- Update overall procedure to include uncertainties from key wind generation units

Success Criteria

The following will be considered when assessing whether the project is successful:

- The project develops a model to predict probabilities of the interconnector physical flow deviations with respect to the day ahead scheduled flows
- Explicit day ahead scenarios for the physical interconnector flows successfully generated and interface with the power flow model is proposed
- Probability distribution reconstructed for the loading of the line for each contingency and each critical branch identified as in scope for the project
- Probabilistic congestion forecast better anticipates historical N-1 congested cases compared to the point forecast
- Project delivers on against objectives, timescales and budgets as defined in the proposal

Performance Compared to the Original Project Aims, Objectives and Success Criteria

Phase I

This phase of the project dealt with the development of forecasting models to predict the physical flow accurately on different interconnectors. In contrast to point forecasting, the models developed withing the scope of this project were probabilistic. This enabled us to assess, in later phases, the impact of uncertainties from interconnectors on congestion across the GB power grid. Moreover, the developed models also allowed for probabilistic inference and were an asset in themselves. In addition to RMSE (Root Mean Square Error), we assessed bias and variance. Regarding bias and variance, all interconnectors demonstrated satisfactory performance, with the IFA interconnector exhibiting the highest bias. The bias remained low throughout the testing period. Furthermore, in conjunction with a notable reduction in variance, we concluded that the developed forecasting models accurately capture the uncertainties stemming from the interconnectors. This outcome affirmed the effectiveness of the models in handling and representing the inherent uncertainties in a precise manner.

Phase II

This phase of the project focused on the generation of explicit scenarios for the physical flows on the different interconnectors. Two key learnings from this work were presented:

- It was possible to build scenarios for the physical flows, using a procedure that both keeps track of all the correlations across interconnectors and preserves the accuracy of the single-target model presented in Phase I,
- The number of scenarios is generally large (~3700 scenarios per time unit on average), but it can be reduced by assuming a finite resolution in the flow values. The trade-off between reducing the number of scenarios while keeping sufficient accuracy was further assessed in Phase III.

In conclusion, the objectives of Phase II were successfully achieved, and the generation of scenarios was sufficiently mature to address the requirements of Phase III.

Phase III

In this phase, several challenges were faced in the collection of input data required for this project. Several adjustments were required to process the power grid model shared for a single time unit in CGMES file format. The topological actions on the grid were not shared in this project, so we could not build scenarios of topological changes for the period in scope. Active power scenarios for demand and generation could be retrieved from Elexon, but the mapping onto the power grid was possible only at the substation level.

The decision to switch to the DC approximation was also made given the absence of scenarios for reactive power. By improving the mapping for generation and load units lying in the reduced area of the network, we succeeded in reducing the power imbalance over the region in scope.
Given the above limitations, a module was built to handle the stochastic security analysis within the DC approximation. Leveraging the linearity of the power flow in DC, we reached a very good performance for the time efficiency of the stochastic load flow solver. In order to proceed with the analysis of congestion cases, we had to identify the relevant system boundaries and contingencies. The system boundaries of interest were communicated by the business, while we identified the relevant contingencies by simulating all relevant N-2 incidents. The loading profiles for the selected system boundaries under the impactful N-2 contingencies were generated by means of the stochastic load flow solver. Finally, the performance metrics showed that the bias of the predicted distributions was small, and the variance (characterising the level of uncertainty) varied across the different time units. Within the above working assumptions, we demonstrated the possibility of reconstructing congestion profiles with efficient execution times, and accurate performance metrics (small biases).

Phase IV

The probabilistic congestion forecast was successfully compared with the day-ahead point forecast used by the DACF team at NESO with the goal to highlight potential benefits of the probabilistic approach. At least based on the two system boundaries studied within the scope of this project, it was not possible to prove the ability of the probabilistic congestion forecast to better anticipate historical N-1 congested cases compared to the current day-ahead point forecast. The reason behind this was that the occurrence of congestion on the two boundaries SC2 and SC3 was heavily driven by the position of the interconnectors. In all cases, congestion occurred when HVDCs were importing electricity from Europe, a configuration characterized by a relatively low level of predicted uncertainty. In that situation, it became a challenge to extract most value out of the probabilistic forecast, as its value depended on the ability to anticipate uncertainties, which were minimal during some periods and substantial during others. No congestion occurred under export configurations.

A possible benefit discussed in this phase was the opportunity to leverage the predicted uncertainties provided by the probabilistic forecast in order to fine-tune the day-ahead point forecast using a dynamic reliability margin. This reliability margin, which can be added on top of the point forecast, aimed to account for predicted uncertainties associated with both wind generation and HVDCs flows. We evaluated the accuracy of the day-ahead point forecast by incorporating a dynamic margin. Although the consideration of the dynamic margin resulted in a slight improvement, it was not statistically significant.

Discrepancies between peak load and congestion were also assessed: the comparison revealed large deviations between the “congestion peak” and “peak load”, suggesting a potential improvement opportunity in the point-forecast to better anticipate highly congested cases.

Finally, two alternative approaches were proposed to generate critical scenarios to improve upon the reference scenarios used in production (which have some limitations). The first approach involved using a single scenario associated with a point forecast fitted with a reliability margin which accounts for uncertainties, providing a simpler, easier to implement method. The second method employed probabilistic forecasting to generate multiple critical scenarios for each combination of system boundary and contingency, which, although potentially more accurate due to addressing uncertainties in the nodal power profiles, could lead to complexity in operational processing due to the high number of scenarios generated.

Phase V

This phase of the project dealt with the development of forecasting models to predict the wind generation on three wind farms. In contrast to point forecasting, the models developed within the scope of this project were probabilistic. This enabled us in later phases of the project to assess the impact of uncertainties arising from the wind farms on the congestion throughout the GB power grid. Moreover, the developed models also allowed for probabilistic inference and were a valuable asset in themselves.

In this phase, we also introduced the different performance metrics that were used to measure the performance. Apart from the RMSE, the bias and variance were also assessed. During the testing period from January to May 2023, East Anglia One demonstrated the lowest forecast accuracy, while Greater Gabbard exhibits the most accurate forecasts. Standardising RMSE per capacity unit revealed similar accuracy for Greater Gabbard and London Array. However, East Anglia One still showed slightly lower accuracy. Overall, forecast errors correspond to 12-15% of total capacity for Greater Gabbard and London Array, and slightly wider (12-18%) for East Anglia One.

In terms of bias and variance, all wind farms showed satisfactory performance, with Greater Gabbard displaying the highest bias, although it was still insignificant. For the two other wind farms, the bias remained low throughout the testing period. Alongside a significant reduction in variance, we concluded that the developed forecasting models accurately capture the uncertainties stemming from the wind farms. This outcome highlights the effectiveness of the models in precisely representing the inherent uncertainties.

In terms of influential factors on the predictions, hourly wind speed data from the Cambridge wind park stood out as the most impactful feature in the model, emphasising its substantial impact on East Anglia One's electricity generation, alongside other wind speed features from different locations, UK wind generation predictions, temperature forecasts, and trends, providing valuable insights into the model's predictive drivers.

The predictions generated by the developed algorithms, together with the interconnector flow probabilistic predictions, will be used to create a diverse range of scenarios for power flow simulations. By sampling various values from the predicted distribution, we can evaluate the effects of uncertainties in the wind farms on congestion within the GB power grid.

Required Modifications to the Planned Approach During the Course of the Project

Change request to include Phase 2 work package, additional costs and timescales
The above change cost an additional €180,652.04 EUR and increased the duration of the project by 6 months.

Lessons Learnt for Future Projects

- The probabilistic forecasting work, specifically around the interconnectors are worth considering in more depth and that only looking at the South-East interconnectors was too narrow. There are factors more than just congestion that impact interconnector behaviour, and this is something that is worth investigation further
- Power flow models were challenging to get accurate, and the challenges on this came from NESO's side. This could indicate that NESO's power flow modelling capability may impact future work
- Because NESO took action to manage the network, the models were skewed from those actions and these actions could be input back into the models to mitigate this impact
- Testing the impact of the model against real time actions would have been a useful activity to inform of further outputs that could be fed back into the project such that discrepancies in modelling or impacts from actions could be accounted for

Note: The following sections are only required for those projects which have been completed since 1st April 2013, or since the previous Project Progress information was reported.

The Outcomes of the Project

- Introduction of different performance metrics that were used to measure the performance.
- Generation of explicit scenarios for the physical flows on different interconnectors were produced.
- A module was built to handle the stochastic security analysis within the DC approximation.
- The probabilistic congestion forecast was successful compared with the day-ahead point forecast used by the DACF (day ahead congestion forecast) team at NESO with the goal to highlight potential benefits of the probabilistic approach.
- The development of forecast models was carried out which predicted the wind generation on three wind farms. Moreover, the developed models also allowed for probabilistic interference and are a valuable asset in themselves.
- A follow-on project is being developed that will investigate more of the interconnector modelling work that was undertaken in this project

Data Access

Details on how network or consumption data arising in the course of NIA funded projects can be requested by interested parties, and the terms on which such data will be made available by NESO can be found in our publicly available "Data sharing policy related to NIA projects (and formerly NIC)" and [Innovation | National Energy System Operator](#).

National Energy System Operator already publishes much of the data arising from our NIA projects at [www.smarternetworks.org](#). You may wish to check this website before making an application under this policy, in case the data which you are seeking has already been published.

Foreground IPR

- Phase I Report: Probabilistic Congestion Management – Forecasting Method Evaluation
- Phase II Report: Probabilistic Congestion Management – Interconnector Forecasting

- Phase III Report: Load Flow Analysis
- Phase IV Report: Analysis of Results and Benefits

Any available documentation will be published on ENA Smarter Network Portal.

Planned Implementation

A follow-on project is being developed that will investigate more of the interconnector modelling work that was undertaken in this project

Net Benefit Statement

- This project has led to the development of a follow-on project looking at forecasting interconnector moves. The project has provided with a stronger understanding of the impacts and risks of congestion, specifically at the Southeast corner of the GB electricity system. It was decided not to expand this investigation further as the outputs were more valuable feeding into the upcoming interconnector project.
- This project generated the explicit scenarios for the physical flows on different interconnectors and a module was built to handle the stochastic security analysis within the DC approximation.
- The different performance metrics introduced in this project, enabled the project team to assess the impact of arising uncertainties from the interconnectors on the congestion throughout the GB power grid.
- There were several challenges faced too especially in the collection of the input data required for this project.
- Several manipulations were needed in order to process the power grid model shared for a single time unit in CGMES format.
- Active power scenarios for demand and generation could be retrieved from Elexon, but mapping onto the power grid was possible only at the substation level.

Other Comments

The Project outcomes and results contain confidential information and intellectual property rights that cannot be disclosed in this Report due to their proprietary nature. Should the viewer of this Report ("Viewer") require further details this may be provided on a case by case basis following consultation of all Publishers. In the event such further information is provided each and any Publisher that owns such confidential information or intellectual property rights shall be entitled to request the Viewer enter into terms that govern the sharing of such confidential information and/ or intellectual property rights including where appropriate formal licence terms or confidentiality provisions. Dependent upon the nature of such request the Publishers may be entitled to request a fee from the Viewer in respect of such confidential information or intellectual property rights.

Standards Documents

N/A