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.

NIA Project Registration and PEA Document

Date of Submission

Jul 2023

Project Reference Number

NIA2_NGESO037

Project Registration

Project Title

Forecasting the Risk of Congestion

Project Reference Number

NIA2_NGESO037

Project Licensee(s)

National Grid Electricity System Operator

Project Start

June 2023

Project Duration

0 years and 7 months

Nominated Project Contact(s)

Colin Webb & Hazem Karbouj

Project Budget

£300,000.00

Summary

The UK power grid is becoming more interconnected and this, together with increased contribution from renewable energy sources, poses some challenges in the anticipation of energy flows. The volatility inherent to interconnections and renewable energy increases the uncertainty of physical energy flows, complicating the anticipation of internal congestion in the day-ahead market and resulting in more decisions needed within day by the control room to overcome congestions. This project focuses on the probabilistic forecasting of congestion after the clearing of the day-ahead market, assuming that the day-ahead scheduled flows are known at the forecasting time. By quantifying the possible deviations between the scheduled flows and the physical flows, the project will assess the impact of congestion across the network and predict the probabilistic risk of congestion on specific branches of the power grid.

Nominated Contact Email Address(es)

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Problem Being Solved

The UK power grid is becoming more interconnected to neighbouring countries and this, together with increased contribution from renewable energy sources, poses some challenges in the anticipation of energy flows. The volatility inherent to interconnections and renewable energy increases the uncertainty of physical energy flows, complicating the anticipation of congestion in the day-ahead market and resulting in more decisions needed within day by the control room to overcome congestions.

The large capacity of interconnections combined with possible energy market changes after day-ahead clearing implies that the deviations of energy flows between scheduled exchanges and the physical flows can be sizable. Considering this, the forecast of expected power flows values becomes less meaningful when forecast uncertainties are large, adding to the challenge of anticipating and managing congestions on power grid branches while operating the system.

Method(s)

This project focuses on the probabilistic forecasting of congestion after the clearing of the day-ahead market, assuming that the day-ahead scheduled flows are known at the forecasting time. By quantifying the possible deviations between the scheduled flows and the physical flows, the project will assess the impact of congestion across the network and predict the probabilistic risk of congestion on specific branches of the power grid. Overall the project aims to provide a methodology and associated tool to assess the risk of congestion, also considering the uncertainties in the nodal physical flows. The project will assume that the day ahead scheduled flows are known at the forecasting time, with the hourly nodal injections and offtakes resulting from clearing of the day ahead market of the next day are known.

The main deliverable will be a report documenting the methodology, the application to the UK power grid, and the analysis of the results. The developed tool will be tested on a sample of weeks and will provide the congestion risk profile for each pair of critical contingencies (i.e. assets considered for unplanned outages) and critical branches (i.e. transmission lines, cables, transformers monitored against overloading) identified during the project. Each risk profile will give both the risk of exceeding the thermal limit of the line, and the different excess scenarios with their respective probabilities. This risk profile will be compared against the binary contingency analysis of the Day Ahead Congestion Forecast, and the predicted risk will be tested against the congestion outcome from historical physical flows.

Where confidential data sharing is required, the relevant data sharing requirements and procedures shall be followed.

The following work packages (WP) will be completed:

Work Package 1 – Development of forecasters for the interconnectors
A supervised learning model to predict the probabilities of the physical flow deviations with respect to the day-ahead scheduled flows. This will focus on the interconnectors between the UK and EU countries with at least 2 years of operating time to give a good size of training data.

This WP will include the following tasks:

1. **Data mining** – to build the input features of the model, an extensive set of time series data will be mined. When the data are collected, they will be stored in a clean and structured database that can be referenced by the forecasting solution. All-time series data will be cast in the standard format using UTC timestamps
2. **Processing of input features** – once required manipulations have been performed, new data can be engineered from the existing data so that it can be used by the forecasting solution. A selection of time series used as input features will be built, and for each time feature the time lags used are specified.
3. **Development of the forecasting algorithm** – select the relevant approach for the development of the algorithm to ensure that the chosen technology fulfils the project use case requirements. Anticipation that tree-based regression techniques are well-positioned to deliver the highest quality probabilistic forecast, performance will be compared against other multivariate models that also pass the identified use case requirement criteria.
4. **Testing of the model** – the testing of the AI model must be done following strict rules to ensure the results are reliable and reproducible. A proportion of the dataset will be set aside and never used in the testing of the models until the very end, this is normally chosen as the chronologically last 20% of the dataset. To ensure model accuracy is not determined on the same data as the model is trained on, the remaining dataset will be further divided up into multiple training and validation datasets.
5. **Storage of the predictions, performance analysis and reporting** – for the time-period in scope, the model will generate the probability distribution for the spread between the physical flow and scheduled flow for each interconnector between UK and an EU country, for each hour of the day, to be stored in the database. Model performance can be evaluated based on accuracy of the percentile predictions. With a focus on bias and variance, an analysis of the model performance will be conducted and summarised in a report.

Work Package 2 – Generation of scenarios
Generate explicit possible day-ahead scenarios for the physical interconnector flows, filter the produced scenarios, check the correlations, and interface the scenarios with the power grid model.

This WP will include the following tasks:

1. **Generation of scenarios for physical flows associated with interconnectors** – A sample of scenarios for physical flows will be generated to ensure the spread between generated flows and scheduled flows is distributed according to the AI models built in WP1. In this task it is more practical to work with unweighted scenarios, so scenarios will be generated with the same weight.
2. **Post-processing and testing of the scenarios** – filter the scenarios to keep only the relevant information and reduce the burden of performing many load flow analyses in later WPs, and perform the necessary sanity checks on the filtered sample of scenarios. To perform reduction of scenarios without affecting the distributions, events in the higher probability region will be filtered out and weight of events kept in the sample will be rescaled using techniques in Monte Carlo generation. Tests will be documented to validate both the generation and filtering of scenarios.
3. **Preparation of interface with the power grid model** – write scenarios in a format that can be analysed by the load flow solver module and interfaced with the power grid model

Work Package 3 – Load flow analysis

Reconstruct the probability distribution for the loading of the line for each contingency and each critical branch within the project scope.

This WP will include the following tasks:

1. **Check load flow with solver** – run the flow solver on the received grid model, checking the convergence for contingencies and validation of the power flow based on key reported physical quantities (voltage, power values, thermal limits of transmission lines)
2. **Interface with network topological changes** – validated version of the grid model will be complemented with scenario data that represents changes in network topology over time. This includes but is not limited to changes in topology of the grid, elements in outage, and re-adjustment of operational setpoints of controllable assets in the system. To ease integration with the grid model, a consistent format must be defined to represent evolution of the network over different time stamps.
3. **Interface with generation and demand profiles** – validated scenario module capable of adjusting the demand and generation profiles associated with the day ahead scheduled exchanges for each hour in scope. This includes but is not limited to load and generation scenarios, simplifications to consolidate different generation units, and changes in the flow via interconnectors with EU countries.
4. **Load flow sanity checks** – validate power flow results are consolidating the model grid with the scenario data from task 2 & 3 above. A set of criteria for acceptance must be defined at the start of this task to characterise the required level of accuracy underlying the power grid model with scenario data adapted in this project.
5. **Build the custom load flow solver for the generated scenarios –** load flow will be assessed in the scope of the steady-state power flows. Depending on the number of scenarios for the physical flows, running an exact AC power flow for each scenario and contingency may be slow, techniques to overcome this speed issue will be investigated if required.
6. **Reconstruction of the risk of congestion** – risk profiles associated with the loading of each critical branch and contingency in scope. Process the outcome of the power flow, collect the loadings of the critical lines under different scenarios and contingencies, and store results in a database using a suitable format.

Work Package 4 – Analysis of results and benefits

Analyse the predicted probability distribution for congestions, run the comparison with the outcome from the point forecast and assess the ability of the probabilistic congestion forecast to better anticipate historical N-1 congested cases.

This WP will include the following tasks:

1. **Comparison with current Day Ahead Congestion Forecasts** – quantitative assessment of the congested lines in the probabilistic approach, compared with the assessment in the current congestion point forecast
2. **Comparison with congestion resulting from physical flows** – quantitative comparison between anticipated risk of congestion based on the probabilistic forecast, and the security analysis based on the actual physical flows in the interconnectors
3. **Check actions of the operator** – for selected cases, feedback from the control room operators on what may have been the different actions triggered by the probabilistic forecast had it been available. Actions taken by operators are based on a high level of skills and experience, so it may be challenging to quantify this impact.

Work Package 5 – Address uncertainties from wind generation

Update the overall procedure leading to the prediction of the congestion risk profile for each contingency and critical branch in scope to include uncertainties from key wind generation units.

This WP will include the following tasks:

1. **Update the probabilistic forecasting model** – forecast algorithm upgraded with the prediction of the spread for key wind generation units
2. **Update the scenario data** – regenerate scenario data covering the uncertainties in the physical flows for key wind generation units
3. **Load flow analysis and impact on the congestion risk** – updated congestion risk profiles after folding the uncertainties from wind generation, and quantification of the impact from the wind. This includes re-running the load flow solver on the new set of scenarios, reconstructing the congestion risk profiles for all critical branches and contingencies in scope, and assessing the extent the resulting congestion risk profiles differ from those obtained from just uncertainties from interconnectors.

In line with the ENA's ENIP document, the risk rating is scored Low:

- TRL Steps = 1 (2 TRL steps)
- Cost = 1 (<£500k)
- Suppliers = 1 (1 supplier)
- Data Assumptions = 2

- Total = 5 (Low)

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.

Objective(s)

- 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

Consumer Vulnerability Impact Assessment (RIIO-2 Projects Only)

The ESO does not have a direct connection to consumers, and therefore is unable to differentiate the impact on consumers and those in vulnerable situations.

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

Project Partners and External Funding

N-SIDE, no external funding.

Potential for New Learning

The project aims to quantify possible deviations between scheduled flows and physical flows, assessing the impact on the risk of congestion in the power grid. The project will test the following hypotheses:

- To which extend the physical nodal injections/offtakes can be anticipated based on the day ahead conditions, and can the probabilities of deviations be predicted by AI models built upon supervised learning?
- Is it possible to generate explicit scenarios for the physical nodal injections/offtakes according to the predictions of the AI models, and can the correlations between deviations of the physical flows on different nodes of the power grid be captured accurately in the generate scenarios?
- Can the steady-state power flow be solved efficiently for each generated scenario, to assess the loading on internal transmission lines for the relevant contingencies and within an execution time compatible with practical use cases within day ahead?
- Eventually, can congestions with the probabilistic forecast be better anticipated, that would otherwise be missed when only looking at the scheduled flows?

By testing these, this project aims to provide a methodology and associated tool to assess the risk of congestions considering the uncertainties in the nodal power flows.

Learnings from the project will be disseminated through project reports uploaded to the Smarter Networks Portal.

Scale of Project

The project will be conducted over nine months by N-SIDE in close collaboration with the ESO. The project will focus on analysis of uncertainties to power profiles at the nodal level and proof of concept will be carried out for a given list of critical branches and contingencies to be defined as part of the project.

Technology Readiness at Start

TRL2 Invention and Research

Technology Readiness at End

TRL4 Bench Scale Research

Geographical Area

This project will be based in the GB ESO area of operations, first considering congestions within the England South-East boundary due to number of interconnectors and constraints within this area.

Revenue Allowed for the RIIO Settlement

None

Indicative Total NIA Project Expenditure

£300,000

Project Eligibility Assessment Part 1

There are slightly differing requirements for RIIO-1 and RIIO-2 NIA projects. This is noted in each case, with the requirement numbers listed for both where they differ (shown as RIIO-2 / RIIO-1).

Requirement 1

Facilitate the energy system transition and/or benefit consumers in vulnerable situations (Please complete sections 3.1.1 and 3.1.2 for RIIO-2 projects only)

Please answer **at least one** of the following:

How the Project has the potential to facilitate the energy system transition:

As we transition to a zero-carbon energy system, the growing contribution from renewable energy, together with a greater number of interconnections between countries increases the uncertainty of physical energy flows across the electricity network. This complicates the anticipation of internal congestion in the day-ahead market, resulting in more decisions made within day and higher constraint costs from curtailment and redispatch. By having a more accurate forecast of expected physical energy flows and probability of constraints, operators will be able to make more informed decisions to operate the system more efficiently.

Overall better optimised operations arrangements should result in more capacity to transport due to lower constraint costs, leading to a lower carbon operation and improved security of supply.

How the Project has potential to benefit consumer in vulnerable situations:

N/A

Requirement 2 / 2b

Has the potential to deliver net benefits to consumers

Project must have the potential to deliver a Solution that delivers a net benefit to consumers of the Gas Transporter and/or Electricity Transmission or Electricity Distribution licensee, as the context requires. This could include delivering a Solution at a lower cost than the most efficient Method currently in use on the GB Gas Transportation System, the Gas Transporter's and/or Electricity Transmission or Electricity Distribution licensee's network, or wider benefits, such as social or environmental.

Please provide an estimate of the saving if the Problem is solved (RIIO-1 projects only)

N/A

Please provide a calculation of the expected benefits the Solution

The growing contribution from renewable energy combined with the greater number of interconnections between countries, means the anticipation of internal congestion in the day-ahead market has become more complex, resulting in more decisions occurring within day and higher constraint costs from curtailment and redispatch. With GB thermal constraint costs forecast to be between £500m to £3bn annually out to 2030 (Modelled Constraint Costs NOA 2021/22 Refresh – August 2022), optimised operations arrangements should result in more capacity to transport due to lower constraint costs, leading to a lower carbon operation and improved security of supply.

Please provide an estimate of how replicable the Method is across GB

The methodology developed within this project considered the impact of interconnectors and renewable generation on constraints within GB, it is anticipated that the methods developed will be replicable across the GB network.

Please provide an outline of the costs of rolling out the Method across GB.

At this stage the costs are unknown for rolling out the Method into further development.

Requirement 3 / 1

Involve Research, Development or Demonstration

A RIIO-1 NIA Project must have the potential to have a Direct Impact on a Network Licensee's network or the operations of the System

Operator and involve the Research, Development, or Demonstration of at least one of the following (please tick which applies):

☐ A specific piece of new (i.e. unproven in GB, or where a method has been trialled outside GB the Network Licensee must justify repeating it as part of a project) equipment (including control and communications system software).

☐ A specific novel arrangement or application of existing licensee equipment (including control and/or communications systems and/or software)

☐ A specific novel operational practice directly related to the operation of the Network Licensees system

☐ A specific novel commercial arrangement

RIIO-2 Projects

☐ A specific piece of new equipment (including monitoring, control and communications systems and software)

☑ A specific piece of new technology (including analysis and modelling systems or software), in relation to which the Method is unproven

☑ A new methodology (including the identification of specific new procedures or techniques used to identify, select, process, and analyse information)

☐ A specific novel arrangement or application of existing gas transportation, electricity transmission or electricity distribution equipment, technology or methodology

☐ A specific novel operational practice directly related to the operation of the GB Gas Transportation System, electricity transmission or electricity distribution

☐ A specific novel commercial arrangement

Specific Requirements 4 / 2a

Please explain how the learning that will be generated could be used by the relevant Network Licensees

This project has the potential to improve transparency around curtailment and re-dispatch within day, providing an indication of the likelihood of a congestion risk and therefore influencing priority actions within the control room. Learnings and recommendations will be disseminated to ensure that relevant Network Licenses can use and understand the methods developed within this project.

Or, please describe what specific challenge identified in the Network Licensee's innovation strategy that is being addressed by the project (RIIO-1 only)

N/A

Is the default IPR position being applied?

☑ Yes

Project Eligibility Assessment Part 2

Not lead to unnecessary duplication

A Project must not lead to unnecessary duplication of any other Project, including but not limited to IFI, LCNF, NIA, NIC or SIF projects already registered, being carried out or completed.

Please demonstrate below that no unnecessary duplication will occur as a result of the Project.

We are not aware of other projects looking to forecast congestions within the power grid. This project aligns with the ongoing work to develop the Virtual Energy System for GB and has the potential to feed into other future projects and use cases.

The previous NIA project, NIA2-NGESO013: Advanced Dispatch Optimisation (ADO), highlighted several gaps and areas for innovation within dispatch optimisation. The project detailed within this PEA document to develop a probabilistic congestion for within the day-ahead period has the potential to input into future development of advanced dispatch tools, providing the methodology to model congestions associated with nodal power flows to influence dispatch priorities.

If applicable, justify why you are undertaking a Project similar to those being carried out by any other Network Licensees.

N/A

Additional Governance And Document Upload

Please identify why the project is innovative and has not been tried before

The increase in complexity of the UK power grid, including more interconnections and a greater contribution from renewable energy sources, creates volatility and operational uncertainty in the anticipation of energy flows. Creating a probabilistic forecast of congestions after the clearing of the day-ahead market has not yet been attempted and may provide increased certainty around the potential volatility of energy flows across the power grid network. This project will consider the day-ahead probability distributions for nodal injections and offtakes and assess the feasibility of tracking the correlation between the congestion forecast spreads associated with the different nodes. The project will investigate if it is possible to input these probabilities into a power flow model to quantify the risk of congestion on a given branch under a given contingency.

Relevant Foreground IPR

1. The main deliverable will be a report documenting the methodology, the application to the UK power grid and the analysis of the results
2. If required during the project to effectively analyse results: custom load flow module with the appropriate speed functionality capable of handling the running of the N-1 security analysis for a large number of energy scenarios. This will be packaged as a python module or library for future use following project completion.

Data Access Details

Data for this project and all other projects funded under the Network Innovation Allowance (NIA), Network Innovation Competition (NIC) or the new Strategic Innovation Fund (SIF) can be found or requested in a number of ways:

1. A request for information via the Smarter Networks Portal at https://smarter.energynetworks.org, to contact select a project and click ‘Contact Lead Network’. National Grid ESO already publishes much of the data arising from our innovation projects here so you may wish to check this website before making an application.
2. Via the ESO Data Portal data.nationalgrideso.com
3. Via our Innovation website at https://www.nationalgrideso.com/future-energy/innovation
4. Via our managed mailbox innovation@nationalgrideso.com

Details on the terms on which such data will be made available by National Grid ESO can be found in our publicly available “Data sharing policy relating to NIC/NIA projects” at https://www.nationalgrideso.com/document/168191/download.

Please identify why the Network Licensees will not fund the project as apart of it's business and usual activities

Due to the nature of the project and that it is researching the potential of creating a probabilistic forecast for power flows and associated congestion risks, utilising machine learning techniques and building upon experience from other applications, this falls outside of BAU activities.

Please identify why the project can only be undertaken with the support of the NIA, including reference to the specific risks(e.g. commercial, technical, operational or regulatory) associated with the project

The TRL of the overall project is relatively low. Therefore, innovation funding is more suitable for exploring the potential of forecasting the risk of congestions on the network, increasing the TRL through proof-of-concept tools before considering further development.

Conducting this project with NIA funding will ensure that the project findings can be shared more widely with other interested Network Licensees and the wider industry.

This project has been approved by a senior member of staff

☑ Yes