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 Annual Progress Report Document

Date of Submission

Dec 2024

Project Reference Number

NIA2_NGESO033

Project Progress

Project Title

Co-optimisation of Energy and Frequency-containment services (COEF)

Project Reference Number

NIA2_NGESO033

Funding Licensee(s)

NESO - National Energy System Operator

Project Start Date

January 2023

Project Duration

1 year and 6 months

Nominated Project Contact(s)

Colin Webb

Scope

This project will develop a novel software tool, integrating mathematical models previously investigated to achieve co-optimisation of energy and frequency control services. The tool will link the technical and temporal characteristics of different services, as well as spatial variations in frequency across the network, with the goal of operating the national electricity grid more cost effectively.

The prototype tool will be developed and tested through engagement with the ESO Balancing Programme and a roadmap for future development into a fully operational model within the Control Room will be produced.

Objectives

- Define the required capabilities and characteristics that the software tool developed should meet for compatibility with control room practices.
- Develop a working prototype software tool to co-optimise energy and frequency-containment services.
- Complete testing of the prototype software tool in coordination with control room engineers.
- Define the needs and requirements to evolve the prototype software tool into a fully operational tool for future integration into the control room.

Success Criteria

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

- The project delivers against objectives, timescales and budgets as defined in the proposal.
- Novel software tool developed to use mathematical models to achieve co-optimisation of energy and frequency-containment

services.

- Fully tested prototype of software tool, including evaluation of capabilities and performance by ESO control room engineers.
- Clear roadmap for further development to achieve an operational tool in the control room.

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

Performance compared to the aims
The aim of the project was to develop a novel prototype software tool for achieving co-optimisation of energy and frequency control services, integrating the mathematical models previously investigated within Imperial College London's research activities. This software tool will explicitly link the technical and temporal characteristics of the different services with the aim to operate the national electricity grid more cost effectively.

Currently, no system operator in the world fully co-optimises different frequency-containment services, this work is intended to lead to the development of a world-first tool to achieve this. The purpose of the COEF model is to minimise the total system operation cost while ensuring the frequency security in both regions. To progress that towards this, Imperial College has created a novel software tool that Optimises Frequency Response and Energy simultaneously to provide system requirements at minimum cost. This is achieved using a methodology called Co-Optimisation of Energy and Frequency Response Services (COEF) in four different ways:

Self-Dispatch using the Uniform Frequency Model
Self-Dispatch using the Regional Frequency Model
Centralised-Dispatch using the Uniform Frequency Model
Centralised-Dispatch using the Regional Frequency Model

The solution of COEF presented here is novel because co-optimisation is not something that is currently undertaken by the System Operator, neither does the System Operator consider regional frequency response when calculating requirements. The testing that has been undertaken with comparison to real life events shows that it produces valid requirements (i.e., not under holding and not excessively overholding), with similar outputs to actual values held on the system. The modelling was repeated for each of the 4 different methods listed above with varying results.

The tool is flexible, and permits all the input parameters to be changed, this is particularly important for the minimum system inertia, where the requirement changes according the FRCR recommendations, and can change each year.

All the following work packages have now been completed and within the specified time frame and the corresponding reports, tools and relevant documentation have been delivered. The project is going through it’s final review phase prior to project closure.

Progress against objectives:
All the objectives have been met:
Define the required capabilities and characteristics that the software tool developed should meet for compatibility with control room practices:

The report for work package 1 details 12 capabilities and characteristics of the software tool, including:
Time Coupled Unit Commitment
Dynamic Frequency Requirements

Value of Inertia
Co-optimisation of DC with Inertia and PFR
Optimisation of Interconnector Outputs to Reduced Largest Loss
Co-optimisation of both Low and High Frequency Security
Modelling of Transmission Network Constraints
Distinct Regional Frequencies
Synthetic Inertia Modelling

The report also details numerous references to many studies undertaken on the subject matter by other organisations and institutions. Much of the methodology presented has been created from the findings of different studies from these diverse sources.

Develop a working prototype software tool to co-optimise energy and frequency-containment services.

Imperial college delivered a fully working prototype of the tool with all the above functions. The code was developed in Python, with a requirement to import additional Python and Python related libraries and a separate library for the Optimisation Engine used to run the tool called Gurobi. The delivered prototype comprised 4 files with the code, which required further compilation in order to create the required binary executable files to run the model.
They also included the documentation for how to use the tool, input files and output data from their own sample testing. The initial intent was for the ESO to run the tool on internal systems, however, further investigation of this approach resulted in the ESO having to request that Imperial College perform the testing on their site, due to the extensive IT security checks required to implement it on the ESO system, and possibly extending the project duration by double or triple the planned time.
Complete testing of the prototype software tool in coordination with control room engineers.

The ESO provided detailed data to enable the testing to be undertaken. This included historic metering data from 8 transient and 8 steady state frequency fault events, that both required additional frequency response and reserve. This made it straight forward to compare the performance of the tool with the actual frequency performance from the outturn data, across all the tool's functionality. Note that some of the test data was found to be unusable, and Imperial College was advised to exclude testing for those respective days.
Almost all the data provided including frequency, RoCoF (which was calculated from frequency), Generator active power flows (wind, interconnector and other generation), were readily available as public data on the BMRS (Balancing Mechanism Reporting Site) or the ESO Data Portal. Reserve and Response data (including Dynamic Containment) is also publicly available as aggregated data, therefore the ESO also needed to provide a detailed breakdown of the data used; it was not necessary to provide specific generator name data or their frequency performance charts therefore this information was not included.
The timescales for the modelling were during the day-ahead period, for 24 hours, dividing into 30 minute time steps. The outcome of the testing performed solely by Imperial College showed that the tool accuracy is to within ±0.1Hz.The sensitivity analysis showed that up to approximate 2GW of Dynamic Containment, the annual cost of securing the system falls at the rate of £ 1.08bn / GW. After 2 GW, there is no further improvement in annual operational costs with increasing Dynamic Containment.
The analysis also showed that up to approximate 2GW of Dynamic Containment, the cost of frequency services alone falls at the rate of £ 0.82bn / GW. After 2 GW, there is no further improvement in the cost of frequency services with increasing Dynamic Containment.
The reasons for these results are further explained in the final report which will be published on the smarter networks portal.
Define the needs and requirements to evolve the prototype software tool into a fully operational tool for future integration into the control room.

The following narrative has been provided by Imperial College:

"The current COEF model is run in a day-ahead fashion with a half-an-hour resolution. However, in current operational practices, NESO still takes balancing actions from gate closure, 89 minutes ahead of real time down to real time. Thus, it is possible to further modify the tool to allow it to be run every hour or every half-an-hour for the next 24 hours, after receiving all the necessary input data. Considering the high complexity of current model (e.g., detailed UC setup for around 600 generators, consideration of preventive control, reserve, etc.), it may be necessary to simplify certain embedded functions to speed up the model solving procedure, e.g., reducing the number of generators, simplifying the UC setup, etc., which can shorten model solving time and allow it to be run every hour or every half-an-hour. The developed COEF model is equipped with the function of 'reserve modelling' including both 'up reserve' for generation drop and 'down reserve' for demand reduction, which can be used to balance the risk of uncertainty at day-ahead. Additionally, as aforementioned, the model can be potentially run every hour or every half-an-hour rather than only 'day-ahead', which can also mitigate the influence of uncertainties. To fully integrate the tool into the NESO Control Room, it is very necessary to conduct system tests and system integration tests."

From the ESO's perspective, to deploy the tool on a large scale, the sensitivity analysis may be repeated, to demonstrate the cost savings that could be gained over the duration of a year, with further financial appraisal annually over the previous decade. This work can be performed in conjunction with a similar calculation for the system over the previous decade and figures compared. It is recommended that a decision how the tool would be used in an operational context would likely be based on a comparison the results of such an economic assessment, with due regard to any additional risks introduced by its accuracy level.

Throughout the project, there were regular schedules progress meetings and opportunities for more comprehensive updates on project progress with more detailed reports and presentations. The operation of the tool was demonstrated, with a video created for ESO to illustrate how it would be operated.

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

The provision of adding reserve services to the project original scope of co-optimising the energy and frequency response requirements has been discussed with Imperial College team. This, in theory, would provide higher savings and reduce the overall cost to the end consumers compared to the current sequential procurement.

The Imperial College team has confirmed that the task of incorporating reserve services to the original project scope should not have a material impact on the project budget or timeline.

No further modifications to the planned deliverables, timelines, or cost are planned or required at this stage of the project.

Required Modifications, 2024 reporting

At the request of the ESO, all the functions and capabilities detailed in the initial report were reviewed and Imperial College selected a handful of the highest priority functions that would deliver the most value for testing. They did this by ranking the functions in order of those that gave the most value.
The three agreed functions that were tested were:
Model Validation
Dynamic Frequency Requirements
Co-optimisation of Dynamic Containment with Inertia and Primary and High Frequency Response

Lessons Learnt for Future Projects

Initial analysis has demonstrated significant benefits of coordinating frequency regulation services and energy delivery, while considering changes in system inertia. Detailed analysis of the potential benefits is planned in the upcoming work packages. A full list of lessons learnt will be published when the project is completed.

Lessons learnt, 2024 reporting

There may be potential value in regional frequency modelling, as the model suggests, it may be possible to secure the whole system based on a single region. How the region to be secured is determined as being most optimal is still not fully understood.

More consideration is needed on the work required to evolve the solution to a practical production system that can be used in a live environment. Further explanation on how the most optimal region to secure is determined and how this can be better presented to the user in the output results would be a meaningful output. Currently the results show that securing the system on a regional basis result in a slightly higher cost than securing on a whole system basis; more detailed analysis on whether this is the case all of the time or only in specific situations (and if so which situations) is needed.

In general, the COEF model can consider the security of both regions (e.g., England and Scotland). Also, securing both regions will lead to slightly higher costs than securing on a single system basis, due to the consideration of regional frequency oscillations (this may require more frequency ancillary services).

The initial intent was for the ESO to run the tool on internal systems, however, further investigation of this approach resulted in the ESO having to request that Imperial College performed the testing on their site, due to the extensive IT security checks required to implement it on the ESO system, and possibly extending the project duration by double or triple the planned duration. Additional time or provision for a standardised process for remote server access to a vendor's IT systems may be beneficial for future projects of this type.

The methodology presented places the responsibility for solving the problem solely within the domain of the System Operator. The industry comprises the SO, Generators, DSOs, DNOs, Consumers, Suppliers, Traders and other participants. alternative consideration to other possible solutions which can also be used in conjunction with the tool and that can also be considered innovative, where responsibility is shared with a broader range of industry participants to achieve the same outcome. The model is capable of considering flexibility services from different resources (e.g., storage, demand-side response, synthetic inertia, etc.) and then appropriately co-optimise application of these resources.

Further study would need to be undertaken on the process used to calculate the largest loss in the model. Currently the assumption in the tool is that it is a variable that changes with the largest generation or demand asset. However, this is not always the case, and can depend on other factors.

The largest credible loss may be affected by certain rules and exemptions or derogations which change from time to time. Therefore, the ability of the tool to enable to user to ensure the largest loss is selected correctly requires further work. The tool assumes that largest loss is a decision variable, but it could be also be modified as part of further work in future, as an input parameter, depending on assumptions.

The tool offers the functionality to model Transmission Constraints and N-1 Contingencies. This process is already been undertaken by power system engineers, prior to performing response, reserve and energy scheduling, the functionality can be potentially removed from the COEF model

The GB market is a liberalised energy market, that operates primarily as a 'Self-Dispatch' market, where generators or demand sites determine when to generate or consume energy, in order to meet their contractual positions. 'Centralised-Dispatch' typically occurs after gate close, when the balancing mechanism operates to ensure that the total system generation equals demand. Further work is required to determine how the tool can be used to co-optimise using both approaches as a staggered process.

The section on Synthetic Inertia is particularly interesting, because the idea presented here is very new - that batteries could be connected to synchronous condensers, specifically for the purpose of increasing system inertia. This may be further developed to determine the effect of additional synchronous condensers on the rest of the network. If increased compensation is required for voltage as a result of the additional synchronous condensers, what would be the additional costs of this; this assessment (impact on voltage levels) was not in the scope of the project.

The findings in the report imply that Nuclear Units can be dispatched. Due to the nature of Nuclear Power Generation, these units are entirely Self-Dispatch and can only be instructed during an emergency. Therefore, enabling functionality in the tool to modify the output of Inflexible Nuclear Units may not be beneficial, even if it would be a lower cost than scheduling more DC, because the output results would be invalid (unusable).

The report includes a sensitivity analysis showing that using a 'Regional' Frequency model may result in higher balancing costs than using the uniform frequency model, whilst having a lower inertia limit reduces balancing costs. The specific percentage changes in costs are presented in the report. Further insights from the sensitivity analysis may give some indication of the direction of possible new markets, e.g. Demand Side Inertia or Wind Inertia, however further investigation would be recommended to validate the outputs from the report. It can also provide the basis for the direction of the level of minimum inertia for future FRCR Assessments.

It may also be beneficial to give further attention to the provision of data from the market about their intended day ahead positions, and how this may affect the Self-Dispatch algorithm. The current timestep of 30 minutes is sufficient for any day ahead assessments. Where the tool requires testing and validation (e.g. due to any future modifications to the algorithm), much shorter time resolution (i.e. 1 second or less) would be required to perform such testing. Therefore, the users would require the interfaces for the capability of reducing the time resolution for calculations and would also need functionality to operate the tool in 'reverse' - i.e. to inject values based on real life events into the tool to generate a simulated frequency profile for the purpose of validation and verification.

The current user interface requires heavy back-end programming and therefore any user would need to be skilled in the use of Python. Control engineers (even if skilled in the use of Python) are primarily focused on delivering multiple outputs for the preparation of the day ahead plan within a 2-hour window each day, typically during the morning shift period, and the use of the tool to deliver the mandatory and ancillary service requirements would make up a fraction of that time. The tool would need to be developed to minimise the effort and time required to generate the requirements, ensuring that it does not distract them from other tasks.

The tool takes approximately 10 minutes to run and produce results, however it is run 4 times, to output the complete set of results for the different options, which is a total of 40 minutes of the control engineer’s time. Further work is needed to improve the running time to comparable levels.

As part of the industry days facilitated by the ESO, it may be beneficial to have sessions, training vendors to better understand the ESO data sources available for performing innovation research work

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

The project outcomes so far include major enhancements to the Co-optimisation tool this includes:

Over 500 generators with comprehensive Unit commitment parameters (e.g., MNZT (Minimum Non-Zero Time), MZT (Minimum Zero Time), etc.) have been incorporated into the co-optimisation model.
All frequency-related constraints have been included in the tool for co-optimisation of Energy and Frequency (COEF) - Rate-of-Change-of-Frequency (RoCoF), Frequency Nadir, and quasi-steady-state requirements.
Frequency services related to inertia, primary frequency response (PFR), dynamic containment (DC), the influence of dynamic regulation (DR), dynamic moderation (DM), and the optimised largest power infeed/outfeed are involved in the co-optimisation model.

The interconnectors power flows (power import and export) are optimised in the model to minimize the whole-system costs are included to model the largest power infeed or outfeed, depending on its status of power import and export.
The model is now capable of capturing the influence of demand-side inertia.
Requirements for both Low and High Frequency Security have been included in the COEF model.
Operating reserve requirements have been included in the COEF model.
Work on incorporation transmission network constraints and line outages in the COEF model has started.
The influence of considering frequency-related constraints on operation cost and computing time is analysed. Under most cases, the computing time can be limited within 15 minutes.
The influence of minimum inertia limit is studied.

Outcomes

The COEF model can be considered as a novel tool that may provide cost optimal requirements for frequency and energy, by the application of the two-region model and the use of co-optimisation.

It must be emphasised that under the specific conditions for which the tool was tested, the cost of securing the system was found to be higher, where only one region is secured, using co-optimisation. The reasons for this are not fully understood and further work is needed to determine the context in which this occurs, and if there are other situations where the costs may be lower, therefore giving the option of a strategy that uses regional co-optimisation when it is most beneficial and using the existing process when it is not beneficial.

There is potential for the tool developed to be used to provide some fundamental evidence to Ofgem, DESNZ, industry etc., about the importance of co-optimisation between energy, reserve and frequency related ancillary services. Also, future market designs could be stated as future works, e.g., incentivising different stakeholders to contribute to the frequency security of the GB power system and co-optimisation process (e.g., currently there is no income for provision of inertia). In general, the COEF model is flexible enough to be used in different contexts.

Comprehensive details of the outcome of the project can be found in the final report delivered by Imperial College: “Development of a Novel Software Tool for Co-optimisation of Energy, Reserve and Frequency Ancillary Services. Tool for Co-optimisation of Energy and Frequency-containment Services, Funding Source: NIA, Sponsor organisation: National Grid ESO Imperial College Team, June 2024”.

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 National Grid can be found in our publicly available “Data sharing policy related to NIC/NIA projects” and www.nationalgrideso.com/innovation.

National Grid Electricity System Operator already publishes much of the data arising from our NIC/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

The following are expected to be delivered by this project:
Open-source tool, codes, data and tool documentation.
Short report on definition of capabilities and requirements for the software tool to be developed.
Final report on the tool performance and roadmap to fully operational tool.

The project reports will be uploaded to the Smarter Networks Portal