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# NIA Project Close Down Report Document

### Date of Submission

Mar 2025

### 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 7 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.

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 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 to the Frequency Control and Risk Report recommendations, and can change each year.

All of the work packages have now been completed and within the specified time frame and the corresponding reports, tools and relevant documentation have been delivered.

**Progress against objectives**:

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

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

3. Complete testing of the prototype software tool in coordination with control room engineers.

4. 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 the partner:

*"The current COEF model is run in a day-ahead fashion with a half-an-hour resolution. However, in current operational practices, ESO 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 allowit 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 ESO 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.

**Progress against success criteria:**

The project has delivered against the following Success Criteria:

*The project delivers against objectives, timescales and budgets as defined in the proposal*:

The project has delivered what was reasonably expected within the available time frame.

*Novel software tool developed to use mathematical models to achieve co-optimisation of energy and frequency-containment services*:

The tool developed is unique because it calculates requirements based on two separate regions, something that is not currently done in the ESO. Numerous papers have been studied and different techniques from the findings of the studies have been employed to create a unique mathematical model.

*Fully tested prototype of software tool, including evaluation of capabilities and performance by ESO control room engineers*:

The period from April 2024 to the end of June 2024 was spent testing the prototype extensively, with data solely provided by the ESO. This data is derived from both submitted data and metered data during times of system stress, and therefore the results provide a good indication of the performance of the tool during the most challenging operational periods.

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. Consideration may be given to other possible solutions which can also be used in conjunction with the tool and that can also be viewed as innovative, where responsibility is shared with a broader range of industry participants to achieve the same outcome, e.g. a requirement for renewable and energy storage units to meet certain criteria that ensures they adopt the best available technology to simulate inertia, where their assets do not have this inherent capability; and the best available technology is used to achieve this, so it would invariably be a novel solution, which has not been tried before.

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's capability of modelling transmission constraints is something that is already undertaken by power system engineers as part of system security assessments, this process is completed before the requirements for frequency and energy calculations are considered. Further work is required to better understand how this capability in the tool adds value to the 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 study in the use of the objective functions is required to determine if the options to use the two approaches of Centralised-Dispatch and Self-Despatch separately and independently, is the best approach to model how the GB market works.

The case studies shown indicate that the volume of procured Dynamic Containment directly reduces the annual system operation and frequency services costs. The results imply that this trend continues up to a maximum volume of DC. It may be useful to have further functionality that provides details of the level of DC beyond which there is no further cost saving or improved system security and therefore no additional benefit, for all contexts. The threshold value of 2GW obtained in these tests is limited to the test data that was initially provided.

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. Synchronous condensers can also increase the network voltage levels, which may or may not be desirable, depending on the system conditions at the time. If this approach was used, what would be the required balance between system inertia and system voltage levels, whilst still meeting system security requirements. If increased compensation is required for voltage as a result of the additional synchronous condensers, what would be the additional costs of this.

In the concluding paragraph on the section of "Choice of Optimised Largest Loss", the implication is 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 frequency deviation permitted for system security purposes is generally ± 1% of 50Hz or 0.5Hz. The model therefore is expected to be accurate in calculating the frequency well within this tolerance. To gain confidence in the accuracy of the model, Imperial College were asked to perform a validation exercise of the model, through frequency simulation exercises based on real life system faults. Although the frequency simulation exercises have been completed and the deviation from the measured frequency value has been calculated for real life events, showing relatively small differences with actual frequency (the largest deviation presented in the report is 0.1Hz), it is still not clear how accurate the model is on average, because a ± accuracy figure has not been given as a percentage value. The risk of this is frequency response calculations recommended by the model to arrest a frequency fall for example to 49.5Hz, may be insufficient and the frequency may still fall further to 49.4Hz, for which recovery to above 49.5Hz within 60s would be necessary. Therefore, further developments are required under the model validation. It may also be prudent to show how the % value is calculated if presented at a later stage.

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 Frequency Risk and Control Report 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. How would the tool 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 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 is also heavily context driven, and greater consideration to the bigger picture may improve the tool further.

## 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 the partner. 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**

1.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.

2. 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.

3. 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).

4.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.

5. 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.

6. 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.

7. 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 also be modified as part of further work in future, as an input parameter, depending on assumptions.

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

9. 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.

10. 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.

11. 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).

12. 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.

13. 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.

14. 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.

15. 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.

16. 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 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 have been 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

## Planned Implementation

Further work to assess the tool's potential for implementation is required. It is recommended that it would include the following:

· A repeat of the **sensitivity analysis** on a more detailed level to demonstrate the cost savings that could be gained over the duration of a year

· A **financial appraisal** (over the previous 10 years using historic data) to determine the levels of energy for frequency response and reserve that the tool would have calculated, had the tool been in use during that time; further to this a comparison of the actual level of response and reserve energy held with the levels calculated from the tool, to provide a **% accuracy figure**. This would also include the time and costs of implementing the tool and the additional time of the control engineer (if there is any increase from normal operation) to run the model. This would be conducted for each of the 4 methodologies.

o Where there is significant deviation which shows a lower cost using the tool's outputs, this would help to determine the final value the COEF tool would deliver.

o Where there is significant deviation which shows a higher cost using the tool's outputs, this would require a review on the algorithm employed and what changes to the algorithm would be needed to reflect actual market practices whilst still providing lower costs and response and energy requirements.

· A detailed **risk assessment** of the use of the tool in the control center, which would also include

o Assessment of the unit commitment functionality, as the tool may recommend the re-position of generators that are not normally instructable (e.g. nuclear units and units that exclude themselves from market operation).

o The use of Open Source software to create the tool and the possible security issues that can arise from the use of Open Source software

· A detailed **roadmap** that outlines the steps to make towards addressing the above points.

· Where the financial appraisal shows the tool is capable of adding significant value, a **gap analysis** of existing processes and systems would be performed to determine how it can be integrated into existing control center processes.

## Net Benefit Statement

The potential benefits of the COEF tool include:

· Possible reduction in the time taken to complete a day ahead schedule, freeing up the control engineer's time to perform other duties. Currently, the tool takes between 10 and 20 minutes to generate the results, and this does not include the time taken for the engineer to prepare the input data for the tool. This benefit may only be achieved with significant changes to the tool coding and more automated processing of the input data.

· Possible reduction in human error due to the increased automation used to calculate the energy and response requirements – this would depend on the extent of integration of the tool with existing processes and systems.

· The final report shows a potential reduction in the cost of frequency response services, as these costs are offset by increasing Dynamic Containment at a rate of £0.82bn / GW for the first 2GW (further calculations can be performed to determine the value this adds in practice over previous years of frequency response utilisation). Where the conditions on the system yields the same results as those from the sensitivity analysis in the report, this would be expected to achieve some quantifiable benefit.

## 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