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_NGESO041

Project Progress

Project Title

Model-driven Strategy for Balancing Optimisation (MSBO)

Project Reference Number

NIA2_NGESO041

Funding Licensee(s)

NESO - National Energy System Operator

Project Start Date

April 2023

Project Duration

1 year and 4 months

Nominated Project Contact(s)

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Scope

This project will formulate the energy balancing system holistically, aiming to develop a UBM and map existing manual processes to analytical equations. This will consider a top-down approach and articulate the entire balancing problem with a bespoke mathematically rooted language. By acquiring critical understanding for the ESO of the significant complexities in the current and future balancing system and markets, the project will enable the development of the analogous future strategy for balancing optimisation functionality to sit alongside the existing IT strategy for hardware and architecture.

Objectives

- Construct the UBM using analytical equations to articulate the current balancing programme
- Articulate future system design based on top-level view afforded by the UBM
- Deliver design specific problem formulation for current and future balancing system design

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
- Development of analytical articulation of the energy balancing system, including manual interventions
- Delivery of a clear strategic approach to incorporate balancing challenges and needs of the control room in a modelling framework

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

As grid operations evolve, NESO requires a comprehensive understanding of balancing as a whole. The Model-driven Strategy for Balancing Optimisation (MSBO) was developed to advance this holistic understanding of grid balancing—both in its current form and as it may develop in the future. MSBO delivered value on two fronts:

1 a high-level mathematical model of the balancing problem, and
2 a detailed mapping of the system components involved in balancing.

Together, these enabled NESO to identify the strengths and vulnerabilities of current balancing operations and provided a strong foundation for designing the future of balancing.

Work Package 1: Underpinning Balancing Model (UBM)

Objective: Formulate a mathematical model of balancing and explore future system design possibilities.

Deliverables and Achievements:
Initial UBM Formulation: A high-level mathematical model was developed to represent the balancing problem, capturing the core dynamics of the current system.
System Mapping: A detailed mapping of the current balancing system was completed, including roles, tasks, and information flows.
Component Modelling: Key components of the balancing system were mathematically formulated, enabling precise analysis of their function and limitations.
Future System Design: Candidate designs for future balancing systems were proposed, incorporating new components and addressing emerging control room challenges.
Iterative Refinement: The UBM was refined through multiple iterations, integrating feedback from NESO and expanding to include new system elements.
Playback Sessions: Regular playback sessions with NESO ensured alignment, transparency, and validation of the evolving model.

Outcome:
This work package delivered a comprehensive and adaptable mathematical framework that not only reflects the current balancing system but also exposes its simplifications and limitations. The UBM has proven instrumental in identifying opportunities for system improvement and innovation. It provides a rigorous foundation for evaluating future system designs, enabling NESO to make informed decisions about architectural changes, operational trade-offs, and optimisation strategies. The model is already being used to inform the development of future balancing tools and control room configurations, demonstrating its practical value and strategic relevance.

Work Package 2: Knowledge Graph of Balancing System Components

Objective: Support decision-making by structuring system knowledge and optimisation strategies.

Deliverables and Achievements:
Holistic System Formulation: A comprehensive view of the current balancing system was developed, identifying how it can be decomposed into optimisable sub-systems.
Optimisation Problem Design: Mathematical formulations for individual sub-system optimisation problems were created, along with a design for how these problems interact.
Future System Mapping: The same approach was applied to future system designs, enabling a comparative analysis of trade-offs and performance.
Knowledge Graph Development: A structured knowledge graph was built to represent system components, their relationships, and

optimisation logic.

Outcome:
This work package successfully delivered a powerful decision-support tool in the form of a knowledge graph, which enhances understanding of the balancing system's structure and interdependencies. The graph was implemented using Neo4j, enabling intuitive visualisation and exploration of system components and their interactions. It was demoed to the ENCC team, who provided very positive feedback on its clarity, usability, and potential for supporting training, system design, and operational decision-making. The knowledge graph is now positioned as a key asset for ongoing system evolution and knowledge transfer.

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

During the MSBO project, Smith Institute consultants worked closely with NESO transition, balancing, control room and innovation stakeholders to build a deep understanding of the intricacies and information flows in balancing. Further feedback around system balancing for the project was gathered from industry stakeholders at a Balancing Programme Engagement Event. The project has also aligned and collaborated with other parallel innovation projects including Dispatch Optimiser Transformation (NIA2_NGESO044) to ensure the immediate and future outputs of MSBO meet the needs and requirements identified in these workstreams.

In addition to the above collaborations for this project, we have realised that further steps are needed as follows:
Mapping of all NESO information into ontology:
• Comprehensive information for all eight roles in roles-and-task mapping spreadsheets encapsulated in ontology
• All tasks, tools and data for each role incorporated into ontology, as well as relationships to describe how tasks/tools/data interact
Determining final software package for visualisation and maintenance of knowledge graphs (KGs)
• Choice of final software package for interacting with knowledge graphs
• Support NESO in final software requirements

To achieve a flexible and future-proof mapping of the current and future balancing systems, the design and creation of a knowledge graph (KG) of balancing processes was decided on to complement the Underpinning Balancing Model (UBM).
KG was designed to be a maintainable, adaptable, long-term asset that will allow NESO to interactively explore the interdependencies in balancing and enable informed preparation for process changes.
The system mapping was delivered as an interactive proof of concept KG alongside the UBM. No additional costs were incurred as part of the changes for the project, but another work package was added and the costs spread from other activities to the additional deliverable, which was the knowledge graph. The project was also extended from the 31st July to the 30th September 2024, an increase of 2 months.

Lessons Learnt for Future Projects

All balancing actions that are taken in the control room were articulated, categorised by roles and mapped to relevant tools and applications. While it is valuable to have such articulation of balancing actions, it is still very complicated to comprehend and use for future design purposes. After several brainstorming sessions it was agreed to develop a dynamic visualisation tool (Knowledge graph) to improve the ease of use of the articulated actions.

For articulating the process in the control room, because of the complexity, a bottom-up approach was the best to take.

Through the course of the project, it was learned that creating a visual representation of the processes of the balancing programme was extremely valuable in helping to understand it.

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

1. Developed an underpinning balancing model that provides a mathematically rigorous description of balancing.
2. Formulated the overarching optimisation problem that ideally NESO would solve to optimally balance the grid.
3. Identified simplifications that have been made to the grand optimisation problem to reach a practically solvable problem that NESO currently tackles.
4. Showcased the impact that these simplifications have on the resulting system, the benefits and drawbacks of relaxing these simplifying assumptions, and suggestions on how to relax them.
5. Showcased how the underpinning balancing model can be expanded to include new actions, services and entities in the future that

do not currently exist.
6. Showcased how an optimiser design philosophy can be defined by consciously making decisions about the formulation of their optimisation problem.
7. Visualised the current process of balancing mechanism in GB's control room.

Data Access

Details on hownetwork 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

Mathematical formulation of the problem of balancing the GB electricity grid, linking the mathematics to the current approach taken to balance the GB electricity grid.

Planned Implementation

There are two aspects of this project that we will be taking forward.
> UBM (underpinning balancing model) will be used for balancing programme optimisation tools and all future control designs.
> Knowledge Graph will be productionised and embedded into our online system and will be used for several processes including training operations, system architecture expansion and knowledge sharing for future projects.

Net Benefit Statement

The MSBO project delivered a transformative benefit to NESO by establishing a rigorous mathematical foundation for understanding and improving electricity system balancing. By formally defining the balancing problem through the Underpinning Balancing Model (UBM), NESO was able to explicitly identify the full set of decisions involved in designing new optimisation tools-decisions that had previously been made implicitly or without full visibility of their impact.

This clarity enabled NESO to:
> Expose and evaluate simplifications embedded in current operational practices.
> Systematically explore and relax assumptions to enhance system performance and resilience.
> Prioritise high-impact areas for future development, including:
-Developing a complete set of entity models
-Accounting for stochastic aspects of the system
-Modelling network topology and the AC optimal power flow problem
-Incorporating non-linear dynamical systems directly into optimisation tools
-Reconsidering the separation of timescales
-Including inertia directly in optimisation formulations

These insights directly supported the design of future-ready balancing systems, enabling NESO to make informed trade-offs and architectural choices.
In parallel, the project delivered a Knowledge Graph (KG) of balancing system components, implemented using Neo4j. This visual, interactive tool supported decision-making by mapping system relationships and optimisation logic. It was successfully presented to the ENCC team, who provided very positive feedback on its clarity, usability, and potential for training and operational support.

Who Benefited and How

> NESO System Designers and Engineers
Gained a structured framework for evaluating and evolving balancing tools, with clear visibility into the trade-offs and assumptions underpinning system design

> Control Room Operators
Benefited from increased transparency into how their data and actions influenced system optimisation, and how new services would be integrated into operations.

>Suppliers and Consumers
Indirectly benefited from a more robust, secure, and economically efficient grid, as NESO applied these insights to develop next-generation balancing tools and processes.

>Future Control Room Staff
Were positioned to engage in virtual training and simulation using the UBM, enabling safe, scalable learning and experimentation with new tools and scenarios.

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.

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