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

Dec 2025

Project Reference Number

NIA2_NESO087

Project Progress

Project Title

Network Topology Optimisation

Project Reference Number

NIA2_NESO087

Funding Licensee(s)

NESO - National Energy System Operator

Project Start Date

June 2025

Project Duration

0 years and 5 months

Nominated Project Contact(s)

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Scope

This project will investigate global progress in the development of automated Network Topology Optimisation (NTO), including available technologies emerging from research that could support its implementation. It will also examine technologies and systems developed in other sectors that may be transferable to electricity networks. The research will review activities undertaken by Transmission System Operators (TSOs), Distribution System Operators (DSOs), and other System Operators (SOs) worldwide to evaluate current practices and advancements in the international landscape.

Objectives

The objectives of this project are:

- Understand and discover all work that has been done around automated Network Topology Optimisation (NTO) to date
- To Ascertain if there are any tools, processes, methodologies of otherwise currently in use that could be adopted by NESO.
- Understand the technologies that are available, or could be leverages for this application
- Understand the costs and benefits that an automated NTO tool would bring

- Understand that if a tool would need to be created, what would be involved

Success Criteria

The project can be deemed successful if:

- Currently available technologies for network topology optimisation (NTO) have been identified and evaluated

- A clear programme of work to transition technology from research to operations have been established.
- Discovery phase for the development of NTO tools have been conducted
- Rule set for real time operations as an input for tool has been incorporated
- Recommendations for optimisation as an output to engineers in planning or real time operations has been provided.

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

The original aim of the project was to investigate what has been done globally with regards to automated Network Topology Optimisation (NTO), and what technologies are available that could be used for this application from research. The investigation aimed to cover technology and systems that have been developed for other areas and industries that could be applied to electricity networks. The research aimed to consist of what Transmission System Operators (TSOs), Distribution System Operators (DSOs), and other forms of System Operators (SOs) have done in the area around the world, or what is currently being done, so that progress in the landscape and the international stage can be evaluated.

The project aimed to investigate and report on the current state of NTO and identify activities required to create an NTO solution that meets future needs. The project was divided into 4 work packages (WPs):

WP1: Literature Review and Benchmarking
WP2: Current State Assessment
WP3: Gap Analysis
WP4: Implementation Plan

The project involved close collaboration between EY (Ernst & Young) and EPRI for the delivery of WP1, where a detailed literature review was conducted. The investigation demonstrated that NTO solutions are partially developed and operational across 13 TSOs in Europe, Asia and the USA, with up to $100m in cost reductions evidenced, based on the utilisation of basic NTO solutions deployed for control room support. We estimate that investment towards full automation in this area is likely to require between £50–100m over multiple years, with the benefits of full NTO Business as Usual (BaU) solutions exceeding the cost reductions evidenced to date. Operational planning at intra- and inter-day timescales is the dominant development area for these solutions and mostly requires a manual transition from a control room support team to run the simulations and advise operators. Scaled BaU implementation remains a key challenge, as the design of a pragmatic NTO algorithm must be embedded and synchronised within a TSO's digital estate.

WP2-WP4, through engagement with key stakeholders from planning and control room, delivered the key outcomes summarised below:

WP2: assessed NESOs NTO capabilities, and interviewed vendors and TSOs
WP3: performed a gap analysis, delineated across five solution areas
WP4: generated a solution implementation plan and next steps

The investigation performed indicated that no NTO solution yet addresses thermal, voltage, and stability constraints automatically, accurately, and at scale across multiple scenarios. This project's analysis showed that, while NTO trials are promising, current solutions remain confined to test environments or limited control room support. The implications of a consistent data model and existing data management must be considered when packaging an NTO solution. The NTO solution is expected to work alongside existing planning and operational tools.

In each of the key NTO technology categories, the following results were found:

Topology: There is no dominant mathematical routine in NTO. A handful of TSOs are in early, promising stages of implementing machine learning.
Power Flow: All vendors studied had an approach to optimising congestion. Linear mathematical formulations addressing real power congestions are the most mature method and universally available for implementation to alleviate thermal constraints.
Computation: Use of GPUs are limited within NTO solvers. Underutilisation of available CPU resources was observed.
UI & UX: User interfaces are underdeveloped for control room applications.
Implementation: NTO solutions developed are not integrated with TSO's digital estate such as EMS (Energy Management System) and SCADA (Supervisory Control and Data Acquisition).

The final report published drew upon an extensive research approach encompassing three key strands: a detailed analysis of global academic literature on NTO, a review of best practices within the transmission sector, and a benchmarking exercise comparing NESO's NTO practices against industry standards.

The outcome of the research was tested by interviewing 9 TSOs globally and 6 prominent vendors. The research and outcome of the analysis were further validated with EPRI. Analysis was further supplemented with desktop research on a more extensive group of global TSOs. Current developments and future plans surrounding NTO solutions were also captured. Two prominent academics from Imperial College London also performed Quality Assurance in the final report published.

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

No modifications were implemented to the planned approach during the course of the project; the project achieved its aimed deliverables.

Lessons Learnt for Future Projects

Implementing the NTO programme over a 10-year horizon represents a complex transformation initiative that demands substantial expertise and resources. Lessons Learnt on an approach that best release value up to March 2028 is:
> NTO is not a commercialoff the shelf product available for implementation, meaning NTO cannot have a 'plug-in' implementation. Rather, solutions require a level of customisation to cater to individual TSO business practices, but the core solution features can be shared across multiple TSOs.
> Based on the TSOs interviewed & desktop research conducted, a full NTO solution addressing all types of constraints including thermal, voltage and dynamic stability implemented as a decision support tool does not exist.
> Vendors have developed linear mathematical formulations addressing mainly thermal constraints, areas of voltage and dynamic stability congestion management are largely unexplored. These unexplored areas must be further developed to ensure a full workable NTO solution is available for control room applications. This includes formulation of fast and full AC solvers, which are essential for capturing these complexities.

> NTO solutions have been formulated using a single mathematical formulation, using Mixed Integer Programmes (MIP). However, MIP ultimately accommodates the continuous and discrete variable types seen in NTO, only in a manner that increases computational intensity. Modern developments in solutions have focused on dual formulations of Topology Actions (TA) and power flow as enables more scalability, customisation and streamlining of methods.
> Limited number of Topology Actions (TA) have been incorporated in NTO formulations to date, future work should expand these techniques to include a wider range of simultaneous TAs such as busbar couplers, switches, reactive power devices, dynamic line ratings, VAR compensators, tripping schemes, and active network management.
> Vendors and TSOs have primarily developed solvers for CPU-based environments. Tests on large-scale networks (e.g. >10,000 buses) reveal underutilisation of available CPU resources. To improve performance, future implementations should incorporate multi-threading, multi-processing, and full workload distribution across cores.
> GPUs grant faster computational; speed leading to more Topology Actions (TA) sets to be optimised in less time. Future work should seek to solve AC PF with a linear treatment, or a partial linear-nonlinear treatment where GPUs and CPUs work in parallel.
> Vendors and TSOs have mainly focused on development of UI tools for control support applications. Full automated UI and UX deployments are in the early stages, and a wide gap has been observed for usability among control room operators.
> Vendors and TSOs have not fully integrated NTO solutions into existing IT and OT platforms. Automated data orchestration are in the early stages.
> Data and model alignment remain an important enabler for scaled deployment of NTO into control room as a workable decision support tool. Input data and quality of model alignment can impact significantly on the accuracy of the output of NTO solutions.

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

This project conducted a detailed literature review by interviewing six leading NTO vendors and nine TSOs across Europe, USA, Asia, and Australia. Analysis was further supplemented with desktop research on a more extensive group of global TSOs. Current developments were captured and future plans surrounding NTO solutions. Following the literature review, a current state assessment of prominent NTO technologies and capabilities available to date was conducted. Based on the information gathered from the vendor & TSO interview sessions, a spectrum of five categories was defined for assessing the maturity of NTO solutions, this led to development of current state technology assessment and best in class NTO solution. These investigations and analysis revealed that development of NTO solution is in early stages, hence we determined the gaps in each of the of five categories defined for assessing the maturity of NTO solutions. The estimated cost of developing the NTO solution across a multi-year program was captured, and the estimation of value to TSOs and consumers. Finally, we concluded the project by developing an implementation plan which recommends establishing a global community for the development of a usable, scalable and pragmatic NTO solution for control room applications available to all TSOs.

The information and analysis captured during this project has been collated into a report.

The outcome of this project demonstrated that NTO as a decision support tool will be an essential and daily part of power system operations, part-and-parcel of the management of a large-scale network with complex thermal, voltage and dynamic stability constraints.

This project demonstrated that the availability of a workable NTO tool in the control room will enable control room operators to study more network scenarios and topological actions. Manual methods for determining the best topological actions are more complex when two or three Topology Actions (Tas) start to be considered, and it is estimated that this number of TAs alone could add a further 1–3% of savings, complex NTO aside. For NESO, this can be equivalent to £75m per year in cost reduction when considered against current balancing costs.

This project demonstrated that NTO is not a commercial off-the-shelf product, meaning NTO cannot have a ‘plug-in’ implementation. Rather, solutions require a level of customisation to cater individual TSO business practices, but the core solution features can be shared across multiple TSOs. NTO goes far beyond system design and implementation. It requires reimagining control room processes to standardise and optimise control room operations. This project demonstrated the importance of an expert team that understands the linkage between technology and business will add significant value when developing a workable NTO solution. Designing an NTO solution requires a multidisciplinary team with expertise in power systems, data engineering, network modelling, data science, and programme management. This will ensure a technically skilled team can manage and coordinate the implementation end-to-end, and that relevant departments within NESO & wider global community are active participants.

Data Access

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

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

Foreground IPR

This project conducted a global literature review, interviews and assessment of NTO technologies as well as capabilities. We identified the following technological findings:

> NTO solution can be Formulated as a Dual Problem (i.e. Topology Actions and Power Flow), Increasing Pragmatism.
> Graph theory and not just Power Flow must be engineered to manage network constraints and increasingly support voltage and dynamic stability. These methods simplify complex transmission networks by representing system components and control variables as nodes and edges.
> Fast and Full AC solvers are essential for NTO solution to address all types of constraints including voltage and dynamic stability.
> Computational speed of NTO algorithms can be further increased by multi-threading, multi-processing, and full workload distribution across CPU cores. Also, CPU cores working in parallel with GPUs can grant faster computational speed.

The full outcomes of the project are available within a published report.

Planned Implementation

It is recommended that the NTO solution should target NESO's priorities in a phased deployment over the next 10 years, with following key features per technology category:

Topology: An advanced graph heuristic model that contains multiple, detailed TA types that can simulate key constraints.
Power Flow: Use of full AC load flow models to calculation of reactive power flows and voltage profiles.
Computation: Fast calculation of multiple constraints, cardinal points, and timescales through use of a complete network model.
UI/UX: Control room approved UI and solver support embedded in BaU processes.
Implementation: Solution is cohesive with OT and IT estate, fully automating a data pipeline for input and output.

Following the delivery of this project, NESO, subject to agreeing funding, will start working on development of an NTO solution with following Minimum Viable Product capabilities, targeting March 2028 delivery:

> DC optimisation of topology for thermal constraints at the full-GB network level.
> A workable UI for operation at feasible near-term timescales,

Simultaneously, NESO will help with establishing, funding and coordinating a global innovation community to develop the following key NTO features over a longer 10 years' timescale:

> Enduring UI and UX visualisation integrate SCADA and EMS
> An AC PF and OPF solver
> A Dynamic stability assessment module

Net Benefit Statement

Operational and Planning Advantages
This project has identified that NTO offers clear operational benefits. One of the most valuable benefits is its ability to support rapid assessment and restoration of system topology following a transmission fault. This helps operators return the grid to its desired state more efficiently, adding significant risk management value. Additionally, NTO can act as a decision support tool for congestion management, helping operators reduce grid congestion — though the impact varies depending on market design. When deployed during planning timescales, NTO enables operators to review a significantly greater number of scenarios, improving the quality of outage planning. This leads to topology efficiency when managing complex combinations of operating scenarios and can result in further cost reductions for the end consumer.

How Does This Translate Into Cost Savings?
In 2020/21 NESO ran an ad-hoc optimisation service from NewGrid alongside their short-term planning process. This routinely confirmed NewGrid optimisations to be effective, including a
single optimisation that saved £425k. It was also effective in highlighting how multiple topology changes across a wider geographical area can potentially lead to a more optimised result.

All nine TSOs interviewed in this project view NTO as a lever to reduce costs from grid congestion. Beyond balancing cost savings, the tool's ability to streamline fault recovery and improve planning contributes to its overall value.

Manual topology control — where one or two pre-identified Topology Actions (Tas) are executed — has long been practiced by NESO and other TSOs. Manual calculation starts to become prohibitively complex when just two or three TAs are simulated, whereas directing an NTO solution at this "simpler" number of TAs is projected to generate 1-3% in cost savings, equivalent to £75 million per year for NESO when compared to current balancing costs [1].

Research by European universities has demonstrated that computationally intensive NTO solvers can achieve up to 50% reductions in constraint costs. However, these approaches require long simulation times and high numbers of simultaneous TAs, which are impractical for control room operators and negate many of the operational advantages [2].

In North America, a vendor-supplied NTO decision support tool for thermal congestion management has delivered $100 million in savings, while also increasing reliability and minimising renewable curtailment impacts — demonstrating the tangible value of NTO when implemented effectively [3].

[1] NESO NTO initial testing results with NewGrid solution, 2020-2021.

[2] Investigating Network Topology Optimisation in the German Transmission Grid Using Real Operational Planning Data, F. Preuschoff & C. Fester, VDE Netzregelung & Systemfuhrung, Munchen, 2024.

[3] MISO implementation of the NewGrid NTO solution, presented in Topology Optimisation Symposium, Berlin, 25th of September 2025.

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

Link to the final report which is on ENA Smarter Network Portal.