Notes on Completion: Please refer to the appropriate NIA Governance Document to assist in the completion of this form. The full completed submission should not exceed 6 pages in total.

NIA Project Registration and PEA Document

Date of Submission

Oct 2026

Project Reference Number

NIA3_NESO012

Project Registration

Project Title

FastFlow

Project Reference Number

NIA3_NESO012

Project Licensee(s)

National Energy System Operator

Project Start

January 2027

Project Duration

2 years and 1 month

Nominated Project Contact(s)

Innovation@neso.energy

Project Budget

£480,000.00

Summary

FastFlow investigates whether physics-constrained artificial intelligence can accelerate Alternating Current power flow and optimal power flow studies used for transmission planning and operational decision support. The project will develop graph neural network and Transformer-based surrogate models using IEEE benchmark systems and GB transmission data. Models will embed power-system physics and operational constraints and be tested under varying network conditions. Work is organised into four packages and outputs include validated datasets, trained models, evaluation reports, user interface for model interaction, user guidance and a final report. Performance will be benchmarked against conventional PF and AC-OPF solvers for accuracy, runtime, scalability and topology generalisation. Risks include data availability, quality and model performance. These will be managed through validation, testing and comparison with established tools. Outputs are intended to complement existing solvers.

Third Party Collaborators

University of Warwick

Nominated Contact Email Address(es)

Innovation@neso.energy

Problem Being Solved

Power flow (PF) and Optimal power flow (OPF) calculations are core analytical methods used by NESO for grid-security assessment,

reactive-power and network-asset dispatch, connection and contingency studies, and operational planning. Conventional Newton-Raphson PF and interior-point AC-OPF methods are reliable and well understood, but each material change in generation, demand or network topology normally requires another iterative solve. Large multi-scenario and N-1/N-k studies therefore require many repeated calculations and associated engineering effort.

As the GB electricity system becomes more renewable-led, the number and diversity of operating conditions, outages, switching configurations and future network states that may need to be assessed continues to increase. The current approach constrains study throughput and can limit the number of scenarios explored within planning and operational decision windows. AI-based PF and OPF surrogates may materially reduce per-case runtime after training, but current evidence is dominated by academic benchmark systems and fixed or limited topology conditions. Their accuracy, physical feasibility, robustness and scalability have not yet been established for operational-scale GB transmission applications.

FastFlow seeks to address this evidence gap. It will attempt to determine whether constraint-aware (Graph Neural Network) and Transformer models can produce sufficiently accurate, feasible and robust PF/OPF estimates at GB scale and under unseen topologies, while delivering a meaningful runtime improvement. The project is deliberately structured as development and validation rather than live operational deployment. Conventional solvers remain the benchmark and assurance route throughout.

Method(s)

WP1 - Dataset preparation (Months 1-7)

Collect, clean and validate approximately one year of historical GB network operating points and relevant day-ahead data. Build IEEE 118-bus and 300-bus benchmark cases and conventional PF/OPF reference solutions. Check voltages, flows, topology, dispatch and physical consistency. Deliver raw and processed repositories, benchmark solutions and the WP1 report.

WP2 - AI-based power-flow model (Months 8-14)

Develop a constraint-aware GNN/Transformer PF surrogate. Candidate architectures include GAT (Graph Attention Network), GraphSAGE and Transformer variants. Embed power-balance relationships in training, split datasets by topology, and assess unseen configurations. Evaluate voltage magnitude and angle accuracy, maximum bus error, constraint compliance, runtime and scalability. Deliver the trained model, evaluation report and WP2 report.

WP3 - AI-based optimal-power-flow model (Months 15-22)

Extend the graph-based approach to OPF for reactive-power and network-asset dispatch. Use OPF-specific output heads and projection or refinement methods to improve feasibility. Benchmark against an interior-point AC-OPF solver for optimality gap, operating-limit compliance, runtime and scalability. Deliver the trained OPF model, evaluation report and WP3 report.

WP4 - Interface, dissemination and close-out (Months 23-24)

Develop a lightweight interface that reads standard network snapshots and returns PF/OPF results. Complete code handover, user guidance, final workshop, NIA progress and closure material, and a final report setting out performance, limitations, deployment options and recommended next steps.

Measurement Quality Statement

Performance will be measured through repeatable simulation and benchmarking against conventional PF and AC-OPF solutions on IEEE and representative GB-scale cases. The test protocol will report dataset partitions, topology coverage, hardware, solver settings and all post-processing time. Metrics will include mean and maximum bus errors, optimality gaps, constraint violations by type and magnitude, runtime distributions, scalability with system size, and degradation under unseen topologies. Results will be reviewed with NESO against agreed tolerances. Limitations include dependence on the representativeness of the available data, benchmark-solver settings, hardware comparability and the fact that successful offline validation does not by itself demonstrate suitability for live operation

Data Quality Statement

The project will use IEEE benchmark systems and approximately one year of historical GB transmission network operating points, including node voltages, branch flows, generator dispatch, relevant demand and generation data, network topology and asset parameters such as line data and transformer settings. Data completeness, consistency, topology integrity and physical plausibility will

be assessed in WP1. Suspect or incomplete records will be identified, documented and handled through agreed cleansing or exclusion rules. Reference PF/OPF solutions will be reproduced using conventional tools. Known gaps, assumptions and transformations will be recorded in the WP1 report and model documentation. Commercially sensitive NESO data will be handled under the agreed security and data-sharing arrangements and will not be released publicly in raw form.

In line with the ENA's ENIP document, the risk rating is scored 6.

TRL Steps = 1 (2 TRL Steps)

Cost = 1 (£480k)

Suppliers = 1 (1 supplier)

Data Assumptions = 3 (High)

Total = 6 (Low)

Scope

In scope: development and validation of physics-constrained AI surrogate models for Alternating Current (AC) PF and AC OPF on benchmark and operational GB transmission datasets; data preparation and validation; testing under changing topologies, outages, switching and unseen operating conditions; benchmarking against conventional solvers for accuracy, feasibility, runtime and scalability; prototype interface development; documentation, knowledge sharing and recommendations for future deployment.

Out of scope: creation of new conventional PF/OPF solver algorithms; connection to live SCADA or other operational systems; replacement of existing operational tools; productionisation, Business as usual (BAU) support and live operational deployment; applications beyond the defined PF and OPF use cases; changes to operational policies or decision frameworks; and commercialisation of project outputs during the project.

Objective(s)

The objectives of this project are to:

> Develop and validate an AI-based Power Flow (PF) and Optimal Power Flow (OPF)model capable of producing operationally credible PF solutions and reactive power dispatch and network asset settings respectively.

> Demonstrate approximately 10x reduction in PF/OPF runtime compared with conventional solver approaches while maintaining acceptable accuracy and feasibility.

>Achieve PF accuracy broadly consistent with NESO operational requirements, including voltage magnitude errors around 0.005 p.u. and voltage angle errors around 1° against conventional solver results.

>Demonstrate OPF feasibility with at least 99% operational constraint satisfaction and an average optimality gap of less than 0.5% relative to benchmark AC-OPF solutions.

>Demonstrate robust model performance under changing network topologies, outages, switching actions and previously unseen operating conditions without full retraining.

>Deliver a prototype interface capable of reading standard GB network snapshots and returning PF and OPF results suitable for future operational and planning workflows.

Consumer Vulnerability Impact Assessment

FastFlow is a transmission-system modelling and analytical research project. It does not directly target, collect data about, or change services for consumers in vulnerable situations. No direct differential technical or wellbeing impact is expected during the project because the outputs will be offline models, evidence and a prototype rather than an operational service or customer-facing intervention.

Success Criteria

Project key output and success criteria:

1. Validated data and benchmark solutions: processed PF/OPF datasets and IEEE reference cases are sufficiently complete, consistent and reproducible for model development, with quality and coverage approved by NESO.

2. PF model: voltage magnitude MAE (Mean Absolute Error) around 0.005 p.u. and voltage angle MAE around 1 degree against conventional PF, maximum bus errors reported, and measurable runtime improvement on comparable hardware and cases.

3.OPF model: average optimality gap below 0.5% against benchmark AC-OPF, with high-percentile and worst-case results reported; at least 99% of operational constraints satisfied before correction and residual violations quantified.

4.Topology generalisation: limited, bounded and explainable performance degradation on held-out N-1/N-k, switching and maintenance topologies without full retraining.

5.Scalability and runtime: performance remains within agreed tolerance from benchmark networks to GB-scale models, with approximately 10x end-to-end runtime improvement targeted and all post-processing included.

6.Prototype and usability: the interface successfully reads agreed standard-format snapshots, returns PF/OPF outputs, and is delivered with code, user guidance, known limitations and reproducible execution instructions.

7.Learning and close-out: evaluation reports, WP reports, final technical report, NIA reports and dissemination activities are completed and accepted by NESO, with clear recommendations on use cases, limitations and next steps.

Project Partners and External Funding

1 external partner: University of Warwick

No external funding

Potential for New Learning

The project will generate new evidence on whether physics-constrained GNN and Transformer models can reproduce PF and OPF results at operational GB transmission scale; how topology-based dataset splitting affects measured generalisation; which constraints and refinement methods are needed for feasible OPF outputs; where runtime benefits survive end-to-end processing; and which use cases are appropriate for AI-assisted screening rather than conventional analysis.

Learning will be shared through work-package and final technical reports, an end-of-project workshop, engagement with relevant NESO teams, NIA progress and closure reporting, and publication of non-sensitive findings through the ENA Smarter Networks Portal. Academic publication may also be used where consistent with NESO security, confidentiality and IPR requirements. Public material will describe methods, results, limitations and recommended next steps without exposing security-classified or commercially sensitive network data.

Scale of Project

FastFlow is a Research and Development(RD&D) project that will be delivered over a 24-month period as a desk-based activity.

Technology Readiness at Start

TRL3 Proof of Concept

Technology Readiness at End

TRL5 Pilot Scale

Geographical Area

Great Britain - model development and validation will use GB transmission-system data. Research delivery will take place within NESOs GB area of operation.

Revenue Allowed for the RIIO Settlement

None

Indicative Total NIA Project Expenditure

Project spent broken down by work package:

- WP1 - Dataset Preparation: £102,500.98

- WP2 - AI-Based Power Flow Solver: £122,458.58
- WP3 - AI-Based Optimal Power Flow Solver: £139,952.67
- WP4 - Interface and Dissemination: £34,988.17
- External delivery total: £399,900.40
- Indicative total project cost: £480k

The costs presented by work package reflect the direct project delivery activities. In accordance with the NIA Governance and Licence Condition requirements (including the provision for up to 25% of project costs for internal expenditure), the total reported project cost may differ from the sum of work package costs outlined above. All costs are reported to Ofgem in full through formal regulatory reporting at the end of each financial year.

Project Eligibility Assessment Part 1

Requirement 1

Facilitate the energy system transition and/or benefit consumers in vulnerable situations

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

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

The transition to a renewable-led electricity system increases variation in generation, demand and power flows and creates a larger range of credible operating conditions and network configurations. NESO must assess more scenarios, connections, outages and more network configuration while maintaining system security. FastFlow will test whether AI surrogates can accelerate repeated PF and OPF calculations without losing the accuracy, physical consistency and constraint awareness needed for credible engineering analysis. If successful and subsequently deployed, the method could enable wider scenario coverage within existing decision windows, improve visibility of constraints and flexibility, and support planning and operation of a more complex decarbonised system. The project therefore facilitates the energy-system transition by developing and validating digital analytical capability needed to manage growing system complexity

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

N/A

Requirement 2 / 2b

Has the potential to deliver net benefits to consumers

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

Please provide an estimate of the saving if the Problem is solved

n/a

Please provide a calculation and/or description of the expected benefits of the solution

No quantitative benefit calculation has been undertaken at this stage, as the expected benefits of FastFlow are primarily technical and evidence-based.

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

The method is designed for the GB transmission system rather than one local asset or geography. The graph representation, standard snapshot interface, topology-aware testing and separation of training from inference support application across different GB network areas and operating conditions. Replication will still require access to representative data, retraining or calibration when system characteristics change materially, validation against the relevant network model and operational tolerances, suitable compute infrastructure, and local governance and assurance. The learning may also be relevant to distribution licensees, but distribution-network replication is not demonstrated within this project and would require separate data and validation.

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

Rollout cost is not yet sufficiently defined for a reliable quantified estimate. The project delivers a validated prototype rather than a production service. Full rollout would require production engineering, data-pipeline automation, interfaces to NESO modelling and data environments, cyber-security and model assurance, testing, hosting or GPU capacity, monitoring, support, user training, documentation, change control and ongoing model maintenance. The project final report will identify the implementation gap and provide evidence needed for a subsequent costed deployment plan.

Requirement 3 / 1

Involve Research, Development or Demonstration

Projects must have the potential to have a Direct Impact on a Network Licensee's network or the operations of the System Operator

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

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

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

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

☐ A specific novel commercial arrangement

Involve Research, Development or Demonstration - Please select all that apply

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

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

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

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

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

☐ A specific novel commercial arrangement

Specific Requirements 4 / 2a

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

Network Licensees can use the learning to assess the maturity, limitations and practical requirements of AI-assisted PF/OPF analysis; design topology-aware datasets and validation protocols; compare candidate models consistently against conventional solvers; define technical acceptance criteria; identify appropriate screening and decision-support use cases; and understand the controls needed before operational adoption. Reports and disseminated results will set out methods, performance, failure modes, data requirements and recommended next steps so that other licensees can reproduce the approach with their own network data, subject to security and licensing constraints.

n/a

Is the default IPR position being applied?

☑ Yes

Project Eligibility Assessment Part 2

Not lead to unnecessary duplication

A Project must not lead to unnecessary duplication of any other Project, including but not limited to IFI, LCNF, NIA, NIC or SIF projects already registered, being carried out or completed. Networks must explicitly mention similar projects that they have considered and how these differ.

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

NESO has considered earlier innovation activity applying machine learning to renewable-generation forecasting, interconnector-flow forecasting, congestion forecasting, probabilistic assessment and risk screening. These activities do not develop a learning-based surrogate for the Alternating Current (AC)PF and AC OPF calculations themselves. Academic learning-based PF/OPF research has also been considered, but it has predominantly used small benchmark networks, fixed or limited topologies and proof-of-concept validation.

FastFlow is distinct because it targets operational GB transmission scale; embeds Kirchhoff-law, power-balance and operating constraints; explicitly tests topology generalisation across outages, switching and maintenance configurations; addresses both PF and OPF in a consistent graph-based framework; and performs rigorous benchmarking against conventional solvers to establish operational confidence and limitations. Where useful, the project will reuse published methods and learning rather than repeat them.

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

N/A

Additional Governance And Document Upload

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

FastFlow moves beyond applying AI to forecasting or small test systems. It seeks to develop physics-constrained, topology-aware GNN and Transformer models for both Alternating Current (AC) PF and AC OPF and validate them on operational GB transmission data at scale. The project will use topology-partitioned testing rather than only random splits, quantify feasibility and residual violations, include refinement where required, and report end-to-end runtime including post-processing. The combination of GB-scale operational data, changing topology, physical constraints, PF/OPF coverage and solver-based assurance has not been demonstrated in the GB innovation activity reviewed by the project team.

Relevant Foreground IPR

Expected Relevant Foreground IPR comprises project-specific data-processing workflows and code; trained and calibrated PF and OPF models; model architectures or adaptations created specifically for FastFlow; feasibility projection or refinement components; prototype data-integration interface; test and benchmarking framework; model-performance and validation results; user guidance; and technical reports. Processed datasets derived from NESO data may form part of project outputs but remain subject to NESO data ownership, confidentiality, security and release restrictions.

Data Access Details

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

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

Details on the terms on which such data will be made available by National Energy System Operator can be found on our website: Data Sharing Approach | National Energy System Operator.

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

The project investigates an unproven analytical method rather than procuring or applying an established production capability. AI-based PF/OPF has not been validated as sufficiently accurate, feasible, robust or scalable for operational GB transmission use. There is a material possibility that the models will fail to meet NESO tolerances, degrade under unseen topologies, violate operational limits or deliver insufficient runtime benefit. The work therefore requires experimental model development, controlled access to operational-scale data, systematic benchmarking and publication of learning. Those activities and uncertainties fall outside routine operation, maintenance and incremental improvement of existing PF/OPF tools.

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

NIA support is required because the project addresses technical, operational, data and implementation uncertainties whose benefits cannot be guaranteed in advance. Technical risks include model accuracy, constraint satisfaction, scalability and topology generalisation. Data risks include access, completeness, consistency and security. Operational risk arises because incorrect PF/OPF outputs could not be relied upon without rigorous benchmarking and assurance. Commercial risk arises because the route from prototype to production, integration cost and eventual savings are not yet established. NIA enables these uncertainties to be investigated transparently while generating transferable learning for Network Licensees and consumers. Conventional solvers will remain the validation and assurance benchmark throughout, and live operational deployment is outside the project scope.

This project has been approved by a senior member of staff

☑ Yes