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NIA Project Registration and PEA Document

Date of Submission

Jun 2026

Project Reference Number

NIA3_NGET0004

Project Registration

Project Title

HarMonAI (Physics-Informed Deep Learning-based Harmonics Monitoring and Assessment for Transmission Network)

Project Reference Number

NIA3_NGET0004

Project Licensee(s)

National Grid Electricity Transmission

Project Start

August 2026

Project Duration

1 year and 7 months

Nominated Project Contact(s)

Xin Wang, Yue Feng

Project Budget

£684,848.00

Summary

This project develops a physics-informed deep learning framework (PINNs) to estimate harmonic voltages and currents across transmission networks using limited power quality monitor data. By combining sparse measurements with network models, it enables real-time harmonic “heat maps” and visibility at unmonitored nodes. The scalable software solution improves accuracy, supports optimal monitor placement, and enhances compliance and planning. It reduces reliance on costly monitoring infrastructure while improving power quality management and facilitating integration of inverter-based and low-carbon technologies.

Nominated Contact Email Address(es)

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Problem Being Solved

The rapid integration of inverter-based resources (IBRs) such as renewables, power electronics, and HVDC systems is increasing harmonic distortion across transmission networks. These harmonics can degrade power quality, accelerate asset ageing, trigger protection issues, and lead to non-compliance with Grid Code limits.

A key challenge is the limited availability of real-time harmonic measurements. Existing power quality monitors (PQMs) cover only a small fraction of substations, leaving many network nodes unobserved. While portable monitors can be deployed, they provide only temporary and discontinuous data. Expanding PQM coverage across the entire network is costly and constrained by installation, operational, and logistical challenges.

Current approaches rely heavily on offline simulations and simplified assumptions, which often lack accuracy and fail to reflect real system conditions. These methods struggle to integrate sparse measurement data, handle bad or inconsistent data, and scale effectively with network growth. As a result, network operators face uncertainty in harmonic assessment, increasing the risk of incorrect specifications for new connections, delays in project delivery, and inefficient investment decisions.

Without improved visibility of harmonic conditions across the full network, it is difficult to identify emerging issues, locate sources of distortion, or ensure compliance in real time. This creates growing operational, financial, and regulatory risks, particularly as the power system transitions toward a more complex, inverter‑dominated future.

Method(s)

The project method is to develop and validate a PINN-based harmonic state estimation framework. The method will first prepare the required model and data inputs: transmission topology, line and transformer parameters, bus connectivity, switching context where available, and PQM voltage/current measurements from fixed and portable devices. PQM datasets will be cleaned, checked for bad data, time-aligned and mapped to the relevant network buses. Harmonic quantities will be represented across the target frequency range up to the 100th harmonic order.

A harmonic network model will then be built using frequency-dependent admittance matrices. These matrices will be incorporated into the PINN training and inference process so that estimates are not driven only by statistical pattern matching, but also by physical network relationships. The loss function will include measurement fit terms, physics consistency terms and compliance-aware terms linked to Grid Code/G5/5 thresholds. This should allow the model to infer plausible harmonic voltages and currents at unmonitored buses while reducing the risk of physically inconsistent outputs.

Two scenarios will be assessed. Scenario A uses fixed PQM data only, testing the minimum measurement configuration and quantifying how well the method fills monitoring gaps. Scenario B adds discontinuous portable PQM data. For this scenario, the project will develop a placement approach using observability or sensitivity indicators and a weighting method that gives suitable value to recent, frequent and relevant portable measurements while still using historic snapshots. The final method will be packaged into a prototype tool with heat-map visualisation, reporting/export functions and source identification support.

Scope

The scope is an 18-month innovation project delivered in a PC-based simulation and prototype software environment. It will focus on a representative area of the GB electricity transmission network rather than a full operational rollout. The project will use available transmission network model data, simulated harmonic cases and PQM datasets to build, train and validate the method. The intended technology progression is from TRL 3 proof of concept to TRL 6 large-scale validation in a relevant environment.

Technical scope includes data ingestion, data cleaning, time synchronisation, bad data handling, mapping measurements to network buses, creation of harmonic admittance matrices, PINN architecture design, physics-informed loss functions, fixed-only PQM estimation, portable PQM integration, optimal portable monitor placement, harmonic heat-map visualisation, compliance margin reporting and likely harmonic source identification. Harmonic orders from the 2nd to the 100th are in scope so that both lower-order and higher-frequency distortion relevant to G5/5 can be considered.

Out of scope for this project is full enterprise deployment into live operational control systems, procurement and installation of a complete new PQM estate, or business-as-usual compliance study delivery. The project will instead produce a validated prototype, learning outputs, validation evidence and an integration roadmap that can inform a later deployment decision.

The deliverables include the following:

Harmonic State Estimation Software Package
- Modular design, able to integrate into NGET's existing PQM and operational systems.
- Includes data ingestion, cleaning, state estimation, and results visualisation.

Network Harmonic Heat Map Tool
- Real-time visualisation of harmonic levels across the network.
- Customisable views by harmonic order, voltage/current, and time window.

Optimal PQM Placement Module
- Sensitivity-based strategy for locating portable and future fixed PQMs (existing fixed PQMs remain in place).
- Outputs ranked substation list for deployment priority.

Harmonic source identification
- Incorporate functionality for identifying the most likely major harmonic sources within the network

Validation Report

- Technical performance assessment against simulated and real-world events.

- performance benchmarks for both operating scenarios.

Grid Code–Compliant Actionable Information
- Incorporate Grid Code and G5.5 planning/capability limits. The real-time heatmap and reporting interface will highlight compliance margins and potential breaches, providing actionable information for system operators in line with G5.5 requirements.

Scalability and Integration Plan
- Pathway for extending to larger or more complex networks.

- Recommendations for integration into operational workflows.

Objective(s)

The objective of this project is to develop and validate a PINNs-based framework for harmonic monitoring and assessment in the GB transmission network. Specifically, the project aims to:

• Deliver real-time harmonic state estimation for all network buses using limited permanent PQMs and supplementary portable monitors.

• Develop a scalable software package that can support NGET workflows, including harmonic heat maps covering the 2nd-100th harmonic orders in line with Grid Code and G5/5 planning limits.

• Provide a G5/5-compliant harmonic specification and assessment toolbox for connection and planning studies.

• Enable optimal placement and utilisation of permanent and portable PQMs, turning discontinuous data into longer-term insight through weighted indexing and PINNs training.

• Enhance compliance and decision-making by identifying critical nodes, compliance margins and potential harmonic sources.

• Lay the foundation for future extensions, including joint state-and-parameter estimation to update biased network model parameters.

Consumer Vulnerability Impact Assessment

The project has an indirect but meaningful consumer vulnerability benefit. Vulnerable consumers are often more exposed to the consequences of interruptions, poor supply quality or increased energy system costs. HarMonAI supports earlier detection of harmonic and power quality risks, which can reduce the likelihood that emerging issues develop into asset stress, equipment malfunction, connection delays or wider reliability problems.

The project also supports cost control. Full physical monitoring coverage across the transmission network would be expensive and may not be practical at every site. A software-led approach that improves the value of existing and portable PQMs can reduce unnecessary capital expenditure and improve the targeting of future monitoring investment. Lower network costs help limit pressure on consumer bills, including bills paid by consumers in vulnerable situations.

Finally, the project supports the low-carbon transition by enabling better integration of renewables, HVDC and inverter-based technologies while maintaining power quality. A more reliable and efficient transition benefits all consumers, and particularly those less able to absorb the cost or disruption of network constraints, outages or delayed decarbonisation.

Success Criteria

The project will be considered successful if it meets the following criteria:

• Accurate harmonic state estimation is demonstrated across the target harmonic spectrum from the 2nd to the 100th order, with defined validation metrics and acceptable error margins.

• Grid Code and G5/5 compliance assessment is demonstrated through harmonic heat maps, compliance margin outputs and reporting functions.

• The prototype software package is validated on representative transmission network models and PQM datasets.

• Both fixed-only PQM operation and fixed-plus-portable PQM operation are tested, with the improvement from portable monitor data quantified.

• A ranked permanent and portable PQM placement method is produced, showing where temporary monitors add the greatest observability value.

• The tool demonstrates practical outputs for planners and operators, including exportable reports and likely harmonic source identification.

• Project learning, limitations and an integration roadmap are documented clearly enough to support NGET review and wider network-licensee dissemination.

Project Partners and External Funding

The lead funding licensee is National Grid Electricity Transmission. The named NGET project contacts in the available project information are Xin Wang and Yue Feng. Hylectra Ltd is identified as the third-party collaborator and technical delivery partner, bringing expertise in physics-informed deep learning, power system modelling, harmonic assessment and software development.

No confirmed external funding contribution is identified in the project files. The proposed funding mechanism is NIA_RIIO-3 with an indicative total project expenditure of GBP 684,848. Collaboration is noted as open to networks, and the learning is expected to be relevant to other electricity transmission and distribution network licensees with harmonic monitoring challenges.

Potential for New Learning

The project will generate learning on whether physics-informed neural networks can provide reliable harmonic state estimation when PQM coverage is sparse. This includes learning on model accuracy, confidence levels, sensitivity to data quality, treatment of missing or bad data, and the balance between measured data and embedded network physics.

It will also generate learning on the practical value of portable PQMs. Portable monitors are discontinuous by nature, so the project will test how historic and short-duration measurements can be weighted and combined with fixed monitors to improve network observability. The monitor placement work will provide learning on which substations or areas provide the greatest additional information.

Further learning will cover how harmonic heat maps, compliance margins and source identification outputs can be used by planners and operators. This includes understanding how the method could reduce manual effort, improve connection studies, support future PQM investment and scale to larger network areas as new data sources become available.

Scale of Project

The project is sized as an 18-month NIA innovation project. It will be delivered in a PC-based simulation and prototype environment using a representative GB transmission network area, available PQM data, simulated harmonic cases and stakeholder review. This scale is appropriate for moving from proof of concept to pilot-scale validation without committing to full operational deployment before the method has been proven.

The starting technology readiness level is TRL 3, reflecting a concept and early proof-of-concept stage for applying PINNs to this transmission harmonic estimation use case. The target end point is TRL 6, with the method validated in a relevant environment through prototype software, scenario testing and documented performance results.

Technology Readiness at Start

TRL3 Proof of Concept

Technology Readiness at End

TRL6 Large Scale

Geographical Area

The project relates to the Great Britain electricity transmission network and will focus on a representative NGET network region for development and validation. The learning is expected to be relevant across GB transmission areas and potentially to electricity distribution networks facing similar harmonic visibility issues from inverter-based resources.

Revenue Allowed for the RIIO Settlement

NIA_RIIO-3

Indicative Total NIA Project Expenditure

The indicative total project cost is £684,848.

The cost breakdown is: Supplier Cost £498,953; Internal Cost £48,000; Indirect Cost £ 88,000; and Contingency Funding £49,895.

The expenditure covers supplier delivery of the PINNs-based harmonic monitoring and assessment framework, NGET internal input, IT and integration engagement, network harmonic modelling, PQM data preparation, fixed and portable PQM scenario testing, portable PQM placement methodology, prototype software development, harmonic heat-map visualisation, reporting/export functions, source identification, stakeholder workshops, training and integration planning.

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 energy system transition depends on connecting and operating increasing volumes of renewable generation, HVDC links, power electronic converters, storage and other inverter-based technologies. These assets are essential for decarbonisation, but they can also increase the complexity and variability of harmonic distortion on the transmission network. Better harmonic visibility is therefore a practical enabler of the transition: it helps NGET maintain power quality while allowing low-carbon technologies to connect and operate efficiently.It also helps NGET improve the efficiency of the connection compliance process, enabling low‑carbon technologies to be integrated into the system more smoothly.

HarMonAI facilitates this by creating a method to estimate harmonic conditions across the network from sparse measurements. Instead of relying only on fixed monitors at selected sites and offline studies with conservative assumptions, the project will test a physics-informed AI approach that can infer harmonic voltages and currents at unmonitored buses. This should improve the evidence base for compliance assessment, connection studies and operational investigations.

The project also supports efficient network investment. By identifying where harmonic risks are emerging and where portable or future fixed PQMs would add most value, NGET can target monitoring and mitigation more effectively. This reduces the risk that harmonic uncertainty becomes a barrier to new low-carbon connections or leads to unnecessary reinforcement, over-conservative limits or delayed decisions.

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

The project benefits consumers in vulnerable situations primarily through reliability, power quality and cost impacts. Consumers who depend on electricity for medical equipment, heating, communications or other essential needs can be more severely affected by supply interruptions or poor power quality. Earlier identification of harmonic risks gives NGET a better opportunity to investigate and manage issues before they contribute to asset stress, maloperation or customer-impacting events.

HarMonAI can also help reduce unnecessary network costs. Installing PQMs everywhere is costly and may be limited by site space, outages, compatibility and installation constraints. A software method that improves the value of existing and portable monitoring can reduce or defer some monitoring expenditure and target future investment to the most useful locations. Avoiding inefficient expenditure helps reduce pressure on network charges and consumer bills.

In addition, the project supports a smoother transition to a low-carbon electricity system. Vulnerable consumers may have less ability to respond to high bills, unreliable supply or delayed decarbonisation benefits. By helping NGET integrate inverter-based and renewable technologies while maintaining compliance with harmonic limits, the project supports a cleaner and more resilient system for all consumers.

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

The expected annual benefit identified in the project information is £471,400. The benefit case is based on a combination of avoided or deferred monitoring expenditure, reduced manual engineering effort, faster compliance and connection assessments, better targeting of portable PQM campaigns and reduced risk of harmonic exceedance impacts. The total project expenditure is estimated at GBP 684,848, so the annual benefit is material compared with the project cost if the method proves successful and is adopted.

A key source of value is avoiding a strategy that relies only on physical monitor rollout to gain network-wide visibility. Full PQM coverage is expensive and difficult because monitors require suitable bays, space, compatibility, outages and project timing. HarMonAI does not remove the need for PQMs, but it can increase the value of each monitor by using physics-informed estimation to infer harmonic levels at unmonitored nodes. It can also support better decisions on where future monitors should be installed.

Further benefits come from operational efficiency. Engineers currently need to gather, clean and interpret limited PQM data and run offline studies to assess harmonic compliance. A tool that produces heat maps, compliance margins and likely source indicators can reduce repeated manual effort and shorten investigations. Earlier visibility may also reduce the cost of late issue discovery, over-conservative connection requirements or reactive portable monitoring campaigns.

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

The method is expected to be highly replicable across GB electricity transmission networks because it is software-led and based on data types that are common across licensees: network topology, asset parameters, harmonic model data, fixed PQM measurements, portable PQM measurements and operating context. The exact model configuration would need to be adapted for each network area, but the underlying workflow of data preparation, harmonic admittance modelling, PINN training and heat-map visualisation is transferable.

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

Replicability is strengthened by the modular design proposed in the project. The framework will use structured data formats such as CSV/JSON for network and measurement inputs, making it easier to adapt as network models change or more PQMs are added. Other GB network licensees with sparse power quality monitoring could apply the same learning to estimate harmonic conditions, improve monitor placement strategies and assess compliance risks.

The main replication requirements are access to suitable network model data, PQM data quality sufficient for validation, and local engineering review of assumptions and outputs. These are implementation tasks rather than fundamental barriers. Distribution networks may need adaptation because of different topology, monitoring density and voltage levels, but the learning on sparse-data harmonic estimation and physics-informed modelling should still be relevant.

GB rollout costs would mainly be software configuration, data integration, validation and change management costs rather than large new hardware costs. For each additional network area, the method would need local topology and asset data preparation, harmonic model generation, PQM mapping, data quality checks, model training or calibration, validation against local cases and user acceptance testing. Integration with NGET or other licensee systems would also require IT security, hosting, access control and support arrangements.

In summary, the rollout cost is estimated £20,000 over 10 years, which includes software interface cost £5000, AI workstation setup cost £7000, and maintenance cost £1000/year.

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

Relevant network licensees can use the learning to understand whether physics-informed AI is a practical way to improve harmonic visibility without installing monitors at every site. The project will provide evidence on model accuracy, data requirements, validation methods, uncertainty drivers, use of fixed versus portable PQM data and how network physics can be embedded into AI-based estimation.

Licensees can apply this learning to power quality monitoring strategies. In particular, the portable PQM placement and weighting work can help licensees decide where temporary monitors are most useful, how to combine short-duration campaigns with permanent monitors, and how to prioritise future monitoring investment. This is valuable where site constraints, cost or outage requirements limit conventional monitor rollout.

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.

The project differs from conventional harmonic simulation tools because it combines measured PQM data with network physics and AI estimation. The available project materials do not identify an existing NIA, NIC, SIF, IFI or LCNF project delivering the same combination of sparse PQM harmonic state estimation, portable PQM weighting, heat-map visualisation, source identification and placement optimisation for NGET transmission harmonic management.

Not applicable as a duplication case. The closest identified related activity is the National Power Quality Monitoring Strategy project, but that activity is focused on monitoring strategy and PQM rollout rather than developing a new PINN-based harmonic state estimation method. HarMonAI is being undertaken because monitor rollout alone does not solve the full problem of estimating harmonic conditions at unmonitored nodes, making use of discontinuous portable data, or providing scalable heat-map and source-identification outputs.

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

Not applicable.

Additional Governance And Document Upload

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

The project is novel because it addresses several practical issues together: sparse fixed monitor coverage, discontinuous portable monitor datasets, bad data and time alignment, harmonic orders up to the 100th, compliance margin visualisation, optimal portable PQM placement and likely source identification. Treating these as an integrated software workflow is materially different from simply running harmonic load-flow simulations or installing more PQMs.

The method has not been proven for NGET's intended use case and operating context. Key uncertainties include accuracy under sparse measurements, robustness to data quality issues, scalability to larger networks, value of portable data and user confidence in AI-assisted compliance support. These uncertainties justify an innovation project before any business-as-usual adoption.

Relevant Foreground IPR

Expected relevant foreground IPR includes the project-specific PINN architecture and training workflow for harmonic state estimation; the physics-informed loss formulation using harmonic network equations and compliance-aware terms; data preparation, cleaning, synchronisation and bus-mapping workflows; methods for integrating and weighting discontinuous portable PQM data; portable PQM placement and observability methods; harmonic heat-map visualisation; reporting/export functions; and likely harmonic source identification algorithms or modules developed during the project.

Background IPR may include pre-existing Hylectra methods, libraries or know-how; NGET network models, data and operational knowledge; PQM datasets; and any existing tools used to prepare or validate harmonic models. Use of foreground IPR outside the project may therefore require appropriate access to background IP and data, subject to agreed terms, confidentiality, cyber security and data-sharing requirements.

All outputs will be made available in line with the default IPR arrangements, ensuring accessibility to other Network Licensees and stakeholders.

In the event that any Hylectra background intellectual property becomes necessary for the performance of this project or the use of project results, Hylectra agrees to provide a license to such intellectual property at a fair and reasonable rate under terms and conditions to be negotiated in good faith between the parties.

Data Access Details

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

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 Grid already publishes much of the data arising from our innovation projects here so you may wish to check this website before making an application.
Via our Innovation website at https://www.nationalgrid.com/uk/electricity-transmission/innovation
Via our managed mailbox box.NG.ETInnovation@nationalgrid.com

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

The project is not business-as-usual because the proposed method is unproven for this network use case and carries technical uncertainty. Routine activities include operating existing PQMs, conducting compliance studies, using established harmonic modelling tools and deploying monitors through planned programmes. HarMonAI goes beyond these activities by developing and validating a new physics-informed AI method for estimating harmonic states at unmonitored locations.

There are uncertainties around model accuracy, data quality, sparse monitor observability, integration of discontinuous portable PQM measurements, scalability to larger networks and the level of confidence engineers can place in AI-supported outputs. These uncertainties mean the method cannot yet be treated as an established operational tool or funded as routine delivery.

The project also creates wider learning for network licensees, not only a direct NGET operational output. It will test a method that could influence future monitoring strategy, connection assessment and power quality management across GB. NIA is therefore an appropriate route to explore the technical and operational risk before any later deployment or business-as-usual adoption.

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 needed because HarMonAI involves research, development and demonstration of an unproven method with potential consumer benefits but material delivery risk. The project must test whether PINNs can produce accurate, physically consistent harmonic estimates from sparse PQM data, whether portable monitor data can be integrated effectively, and whether heat-map and source-identification outputs are useful for real engineering decisions.

This project has been approved by a senior member of staff

☑ Yes