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NIA Project Registration and PEA Document

Date of Submission

May 2024

Project Reference Number

NIA2_NGET0061

Project Registration

Project Title

Tunnel power cables earthing, safety and protection under electromagnetic transient voltages and currents (TunCab)

Project Reference Number

NIA2_NGET0061

Project Licensee(s)

National Grid Electricity Transmission

Project Start

May 2024

Project Duration

1 year and 11 months

Nominated Project Contact(s)

Kerri Hayes

Project Budget

£456,000.00

Summary

LPT2 will comprise 30km of cable tunnels stretching from Wimbledon in south-west London to Crayford in south-east London. When de-energising a circuit for maintenance the absence of earth bars in the tunnels removes the possibility for locally-earthed safe working, being the preferred method under NSI5. It has been determined separately that earth rods installed in the tunnel present an inadequate control measure, installation of rods through tunnel walls is undesirable for reasons of wayleave, hydrostatic pressure and corrosion. This project seeks to evaluate the alternative working methods for implementation on LPT2 by June 2025, in the first instance in preparation for energising Hurst-Newcross cct 2. Further detailed investigations will be carried out to consider various scenarios. Furthermore, magnetic field exposure will need to be determined and ensure that that they are within the allowed limits.

Third Party Collaborators

Cardiff University

Nominated Contact Email Address(es)

box.NG.ETInnovation@nationalgrid.com

Problem Being Solved

Considering the advances in new cables circuits installed in deep underground tunnels in urban areas, it is clear that they have specific safety aspects that are not well understood to devise practical solutions. For example, the London Power Tunnel (LPT2) will comprise 30km of cable tunnels stretching from Wimbledon in south-west London to Crayford in south-east London. Tunnels will be up to four metres in diameter and largely be buried deep beneath street level, and carry two circuits, transposed at regular cable jointing bays. When de-energising a circuit for maintenance, the length of the tunnel sections (18.5km Newcross – Hurst, 12.5km Wimbledon – Newcross) and physical arrangement of the phases will lead to induced voltages due to the imbalanced current flowing in the live circuit. The induced voltages are expected to rise significantly in the event of a fault, and safe working on the de-energised circuit must account for this. The absence of earth bars in the tunnels also removes the possibility for locally-earthed safe working, being the

preferred method under National Safety Instructions NSI5. It has been determined separately that earth rods installed in the tunnel present an inadequate control measure, installation of rods through tunnel walls is undesirable for reasons of wayleave, hydrostatic pressure and corrosion. Existing knowledge and recommendations require extending to include the specific peculiarities of modern cable circuits in tunnels. CIGRE TB801 presents alternative working arrangements for cable maintenance (earthed working with currents and insulated working) which may present suitable alternatives to the NSI5 standard working practices. Furthermore, magnetic field exposure will need to be determined and ensure that that their magnitudes are within the allowed limits.

Method(s)

Work has been done on the safety aspects of cable circuits, and CIGRE TB801 contains some possible generic arrangements. However, the specific configuration in modern cables circuits in tunnels introduces new challenges for safety and integrity of the circuits under fault conditions.

In this project we propose to address the following:

- Review NSI5 and CIGRE TB801 working methods: This is to evaluate applicable aspects of the document to the modern cable tunnel options. Also, explore any previous work for critical evaluation. This will allow improved models to study the new configurations.
- Earthing studies and induced voltage evaluations will be carried out and comparison with similar studies will be undertaken.
- We will seek to extend the results of the preliminary studies by means of CDEGS simulations of the induced effects in cable sheaths under different earthing configurations in both steady-state and transient conditions. Models will incorporate phase transposition arrangements as specified in the modern tunnel layout design drawings.
- Electromagnetic transient ~(EMT) modelling of cable circuit conductors and their earthing system.
- A full electromagnetic transient model of the cable tunnel circuit, cable sheaths and Sheath Voltage Limiters (SVLs) is necessary for the evaluation of the transient induced voltages. This work will build a detailed EMT model of the cable in tunnel circuits using LPT2 as an example, Model behaviour will be benchmarked against the steady-state studies and expanded to include lightning and switching transiens propagation in the energised circuit.
- Using the developed CDEGS and EMTP system models, the impact of adding or removing the NSI5-mandated equipotential mat on induced voltages at the work area may be quantified. The removal of equipotential mats requires consideration of capacitive currents and electromagnetic transient cases that can only be fully studied in a suitable EMT package. The result of this study may enable insulated working to be undertaken outside of the current NSI5 guidance.
- We will also investigate the consequence of the systematic removal of sheath voltage limiters from the tunnels. SVLs are specified to limit differential voltages under an insulated working regime and are in the designs specified for installation at 2 in every 3 cable jointing bays. This study will investigate the systematic removal of SVLs and its impact on induced voltages in the transient and fault conditions previously investigated.

Scope

An initial review of NSI5 and CIGRE TB 801 suggests earthed working by creating a local equipotential zone using earthing mats may work (a temporary earth is required instead of a permanent earth). Detailed EMT studies are required to confirm all scenarios under normal operation and fault conditions. In addition, there may be no need for SVLs (Sheath Voltage Limiter) since there is no earthing point in the tunnels.

Objective(s)

The project aims to:

- review current knowledge and build on current recommendations of NSI5, CIGRE TB801, IEC 60617 and 60417
- develop a model for transient studies and SVL requirements in cables circuits in tunnels
- develop electromagnetic models of cable circuits in tunnels
- develop earthing system models for earthing performance
- develop evaluation techniques for new mitigation options for SVL use and earth farms.

Consumer Vulnerability Impact Assessment (RIIO-2 Projects Only)

An assessment of distributional impacts (technical, financial and wellbeing related) for this project has been carried out using a bespoke assessment tool, which assesses the project as having a positive, negative or neutral effect on consumers in vulnerable situations. To help inform the assessment, this tool considers the categories of consumers identified in the Priority Services Register.

This project has been assessed as having an overall positive impact on consumers in vulnerable situations. The assessment has identified that this project will look to enhance the costs for households, improve the exchange of information between networks and customers while reducing the amount of disruptions to them in the home.

Success Criteria

We aim to implement a novel earthing solution – the tunnel earthing mats. From analysis undertaken we believe this solution would be a more efficient solution than building earthing rods. Allowing the removal of earth rods through the tunnel wall and provide more value for money for consumers due to cost savings vs installing earthing rods. If we prove the earthing mat (Equipotential working) technology works. If successful we would intend to use this innovation for future tunnels projects which are being scoped for T3 and beyond and all required feasibility and information will be delivered to LPT2 to allow them to progress with earthing mat installation.

- Investigate remove SVL units from LPT2
- Complete EMT analysis
- Extended technique to other tunnels
- Remove SVL units from buried routes and reduce link boxes / pillars
- Reduce capital and maintenance cost of future circuits, improve safety (no SVL units to fail), and easier route as no link pillars / boxes

Project Partners and External Funding

N/A

Potential for New Learning

New knowledge will be developed in understanding the safety aspects of cable circuits in deep urban tunnels. Paper publications at national and international events, ENA innovation conference, CIGRE conference and other academic conference. Also, a dissemination workshop will be organised at the end of the project which will be open to other utilities and third parties.

Scale of Project

The project is planned to last 24 months

WP1: Review NS15 and CIGRE TB 801 working methods and review IEC 60417 and IEC 60617
WP2: Validation of previous work and consideration of CIGRE TB 801 methods
WP3: Earthing system modelling for induced/impressed voltages
WP4: EMT modelling of LPT2 circuits and earthing systems
WP5: Investigation of the removal of SVLs from LPT2

Technology Readiness at Start

TRL6 Large Scale

Technology Readiness at End

TRL8 Active Commissioning

Geographical Area

The modelling work will be carried out at Cardiff University and London Power Tunnel LPT2 will be used as a case study for the work with options to take measurements.

Revenue Allowed for the RIIO Settlement

N/A

Indicative Total NIA Project Expenditure

Total NIA expenditure is: £410,400

Project Eligibility Assessment Part 1

There are slightly differing requirements for RIIO-1 and RIIO-2 NIA projects. This is noted in each case, with the requirement numbers listed for both where they differ (shown as RIIO-2 / RIIO-1).

Requirement 1

Facilitate the energy system transition and/or benefit consumers in vulnerable situations (Please complete sections 3.1.1 and 3.1.2 for RIIO-2 projects only)

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

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

The increasing electricity consumption particularly in large urban centres necessitates reinforcement and or construction of new electricity transmission lines. For this, overhead lines are very hard to build due to planning permission and negative public perception.

Underground power cable, despite their relatively higher costs than overhead lines, are more acceptable for the public as they have no visual impact. However, burying such cable circuits in cities and town could cause major disturbances, affecting traffic, business and the public. The most viable solution that satisfies most of the above challenges is to install the cable circuits in deep tunnels under the streets of the cities. In this way, access to bulk electrical power and its transport around is possible. With adequate sizing of the tunnels, maintenance and fault finding becomes highly feasible.

Given the relatively high-power ratings and uniqueness of such circuits and tunnels, for 275kV and 400kV circuits, it is important to ensure that safety aspects are carefully investigated to understand details of voltages and currents that may appear on the earthing system and cable installations withing the tunnel. And associated circuits.

Facilitating such new tunnels, and ensuring their safety and reliability, will ensure that more low carbon energy is transported and distributed in a reliable way. Furthermore, the electrical circuits can be accessed quickly and easily for inspection, repair, upgrade or refurbishment with minimum disturbance to the consumers and the general public. From analysis undertaken we also believe this project solution would be a more efficient solution than building earthing rods and provide more value for money for consumers due to cost savings vs installing earthing rods.

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 (RIIO-1 projects only)

N/A

Please provide a calculation of the expected benefits the Solution

Two options have been considered for the NPV benefit calculation. For Option 1 (Baseline), it is assumed that this project would not be carried out and earth rods would be retrofitted to the LPT2 tunnels. Note that the risk for tunnel structural integrity is not taken into the calculation.

For Option 2 (Innovation), this project would be carried out and a novel method for managing the impress voltage would be found and there would be no need for retrofitting earth rods. The project is estimated to last for 24 months with a total Direct Cost of about £411k. Out of the £411k, £361.6k would be direct project cost billable by the supplier (Cardiff University). The remaining £49.4k would be NG internal costs accounting for time spent by one project lead (25 days per annum), one main stakeholder (15 days per annum) and one

supporting stakeholder (5 days per annum). This project is designed to be desktop based and there is no need for site access.

The NPV results are shown the NPV for Option 1 (Baseline) is -£1,971k while the NPV for Option 2 (Innovation) is -£407k. Thus, the net benefit for Option 2 is £1,564k.

This provides a project benefits ratio of 4.8:1.

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

It can be applied to distribution and transmission of electricity.

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

N/A

Requirement 3 / 1

Involve Research, Development or Demonstration

A RIIO-1 NIA Project 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

RIIO-2 Projects

☐ 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

The new knowledge to be generated from the project will benefit companies that use underground cable circuits for the transmission or distribution of electricity. Both the safety of people and equipment will be improved as a result. The particular application of cable circuits in tunnels is likely to increase in future due to increasing demand for electricity with electric transport and heating. The findings of this project are directly applicable to all tunnel applications.

Or, please describe what specific challenge identified in the Network Licensee's innovation strategy that is being addressed by the project (RIIO-1 only)

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.

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

Existing practice recommended in CIGRE Technical Brochures and IEC standards are very general to underground cable circuits. Applications in cable tunnels in urban areas require new investigations. As such, unnecessary duplications are not expected.

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

Deep Tunnels for double circuits transmission of bulk power have been proposed in the last decade to address the drive to reinforce the transmission system in large urban areas, which is fuelled by forecasted increases in electrical power demand. New modern tunnel construction methods have been proposed to enhance reliability and access to cable circuits. However, this has now led to new challenges related to safety and cable protection, which include earthing arrangements, quantifying induced electromagnetic effects and mitigation of the circulating currents in the cables under both steady state and fault conditions. This project is innovative as it is researching and modelling a novel solution to tunnel earthing and previous research in this space is limited or of generic nature that doesn't provide the required information to implement on a tunnel project.

Relevant Foreground IPR

N/A

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 apart of it's business and usual activities

The issues of safety and induced effects in cable circuits installed in tunnels requires in-depth investigations through modelling and measurements. The future cable tunnels introduce new innovations which require investigating to ensure safety of personnel and reliability of circuits. The innovative aspects of this project relate to developing new solutions to ensure safety and reliability of modern urban cable tunnels. Such solutions will be applicable to full scale cable tunnels and their associated circuits. In particular, the issue of using earth mats and frequency of Sheath Voltage Limiters (SVLs) will be optimised for fault and energisation scenarios. As a result, it is expected that safety instructions will be updated to include the new designs of urban cable tunnels.

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

This project aims to develop more understanding/solutions/mitigations that are applicable to underground cable circuits with particular focus on new cable circuits in tunnels for application in urban environments. It is unknown whether the proposed novel solution in this project will be a viable solution for underground cable tunnels, therefore innovation funding to de-risk the novel solution is appropriate.

This project has been approved by a senior member of staff

☑ Yes