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

Jun 2022

Project Reference Number

NIA2_NGET0023

Project Registration

Project Title

Cable Alternative Cooling Technologies for Underground Systems (CACTUS)

Project Reference Number

NIA2_NGET0023

Project Licensee(s)

National Grid Electricity Transmission

Project Start

July 2022

Project Duration

2 years and 0 months

Nominated Project Contact(s)

Siyu Gao (Box.NG.ETInnovation@nationalgrid.com)

Project Budget

£517,000.00

Summary

The power flow capacity of high voltage cables is limited by heat dissipation. Cable installed within tunnels are often a thermally limiting section of circuits due to the relatively poor heat transfer through the air surrounding the cables. When reinforcement is required, this can necessitate the construction of additional tunnels which are highly costly. This project will investigate, through bespoke FEA simulations and targeted experiments, the capability of alternative cooling methods to enhance cable ratings in tunnels. The first stage of the project will investigate the use of established technologies, such as chilling inlet air, which are nevertheless novel for cable tunnel applications. Subsequently more exotic techniques, such as liquid nitrogen cooling systems, will be considered.

Third Party Collaborators

University of Southampton

Nominated Contact Email Address(es)

box.NG.ETInnovation@nationalgrid.com

Problem Being Solved

The power flow capacity of high voltage cables is limited by heat dissipation. Cable installed within tunnels are often a thermally limiting section of circuits due to the relatively poor heat transfer through the air surrounding the cables. When reinforcement is required, this can necessitate the construction of additional tunnels which may cost in the range of hundreds of millions.

For example:

· The Lower Lea Valley cable tunnel costed £130M for a 6km route.

· The cost for Phase One of the London Power Tunnels is £1B for 32.5km.

Besides the substantial financial costs, new cable installations commonly have long lead time, e.g., the construction of Phase One of the London Power Tunnels is expected to last for at least 7 years. While awaiting for such long term reinforcements to come into effect, short term events could well lead to rapid increase in demand which could put the whole electricity system on great strain. One example would be the fast adoption of Electric Vehicles, which would in turn require the system to provide significantly higher capacity in a short window of time. This kind of challenges could not be sufficiently met by conventional, construction based reinforcements, especially not when the prices for essential commodities and raw materials, such as petrol and copper, are at record high due the international energy crisis inflicted by unpredictable geo-political events. The alternative cooling methods proposed in the project, if proven feasible, could have the potential to address the short-term challenges with relatively much shorter lead time and at much lower costs.

Method(s)

The first stage of the project will investigate the use of established technologies, such as chilling inlet air, which are nevertheless novel for cable tunnel applications. A cable circuit in the area of Greater London has been identified as an ideal candidate for these investigations as, with improved cooling systems, it may be possible to avoid the installation of an additional cable circuit, and instead uprate existing infrastructure. Subsequently more exotic techniques, such as liquid nitrogen cooling systems, will be considered. Understanding the practical implication of such systems, including health and safety, CAPEX and OPEX estimates, and site footprint is of paramount importance.

This project will develop purpose-built FEA models to investigate the cooling methods. Some experiments would also be carried out to investigate the possible thermal and mechanical complications.

Data Quality Statement (DQS):

The project will be delivered under the NIA framework in line with OFGEM, ENA and NGET internal policy. Data produced as part of this project will be subject to quality assurance to ensure that the information produced with each deliverable is accurate to the best of our knowledge and sources of information are appropriately documented. All deliverables and project outputs will be stored on our internal sharepoint platform ensuring access control, backup and version management. Deliverables will be shared with other network licensees through following channels:

o Closedown reports on the Smarter Networks Portal.

Measurement Quality Statement (MQS):

The methodology used in this project will be subject to supplier’s own quality assurance regime. Quality assurance processes and the source of data, measurement processes and equipment as well as data processing will be clearly documented and verifiable. The measurements, designs and economic assessments will also be clearly documented in the relevant deliverables and final project report and will be made available for review.

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

TRL Steps = 1 (2 TRL steps)

Cost = 2 (£500,000 - £1m)

Suppliers = 1 (1 supplier)

Data Assumption = 2 (Assumptions known but will be defined within project)

Scope

The project is scoped into 5 work streams (WSs).

WS1: Identification of case study site(s) and collation of datasets including experimental samples

The initial work stream will comprise data gathering required for the simulation investigations. To construct the FEA model geometries, technical drawings of the tunnels, including relevant dimensions and locations of headhouses and risers will be required, in addition to cable design information. Relevant material properties will be taken from the IEC standards or using National Grid’s existing design values where appropriate.

To validate the FEA models, coincident measured datasets of load and DTS temperatures will be required. Analysis of such datasets will be undertaken, including whether additional measurements are required to ensure confidence in the simulation findings. Care will be taken to map recorded fibre data to position data along the tunnel route.

As part of this work stream, the project team would also seek to source cable samples from National Grid that are comparable to those used in the case study tunnel(s).

WS2: Development of FEA cable tunnel thermal model for existing cooling technologies

Using data collected in WS1, a fully three-dimensional model geometry of the case study (potentially a selected cable circuit in the area of Greater London) will be constructed. Temperature will be calculated by coupling a thermal model to a computational fluid dynamics simulation of tunnel air, including the consideration of naturally and forced cooling mechanisms as appropriate. Existing models developed for NGET projects, in particular "Ratings of Cables In Tunnels (RoCIT)" will be used as a starting point. These models will be validated using DTS and load data collected in WS1 to provide confidence.

Once the models have been validated, the implications of chilling inlet/outlet air into the tunnel on cable ratings will be investigated. Both continuous and dynamic calculations will be employed, and the cooling system requirements to produce a given rating will be determined. The models will also allow the thermal and mechanical stresses within the cable to be calculated. These may be more than those experienced typically, due to the higher thermal gradients within the cable caused by the lower tunnel temperatures.

WS3: Experimental investigations into cable system performance in novel thermal environments

This work stream will run in parallel with WS2 and WS4 and will determine the impact of the alternative cooling technologies on cable performance. At rated load, under typical installation conditions, the temperature difference between the cable conductor and sheath may be 10 - 15°C. However, if significantly higher loads are applied, combined by lower cable surface temperatures, the temperature gradients across the insulation may be significantly larger, potentially exceeding 90ºC.

A series of experimental investigations will determine whether electrical, mechanical or thermal performance of insulation material is compromised due to these thermal stresses. Conditions for these experiments will be specified using the outputs of WS2. It is proposed to utilise the cable samples sourced in WS1 for such investigations. Combined mechanical and thermal testings will be carried out, followed by forensic investigations into the samples. Measurements of key dielectric and mechanical properties will be undertaken. Specifically: tensile strength prior to and after thermal cycling; investigation of the morphology prior to and after thermal cycling; dielectric permittivity and loss factor prior to and after thermal cycling.

WS4: Development of FEA cable tunnel model for liquid nitrogen cooling systems

Having developed simulation models utilising established cooling technologies in WS2, this work stream will investigate the impact of more exotic liquid nitrogen systems. Liquid nitrogen has a boiling temperature of 77 K and is used both as a coolant and an electrical insulator for superconducting high voltage systems. The application of a liquid nitrogen cooling system to traditional cable systems, e.g. 400kV three phase XLPE, has yet to be attempted.

Simulation based investigations would initially assess the impact of chilling the inlet air into the tunnel, and the required system specifications to achieve this. Following this, the thermal impact of a cooling pipe installed within the tunnel will be examined. Finally, the influence of regularly misting nitrogen into the tunnel, causing warmer exhaust air to be removed due to the rapid thermal expansion, on cable temperatures will be quantified.

WS5: Recommendations to National Grid

The final work stream will combine findings from across the project into a report outlining recommendations to National Grid including an assessment of the practical implications of different cooling solutions, with a road map to implementation. Consideration will be given to health and safety, financial expenditure estimates, and site footprint. It is intended to collaborate with NGET staff in the production of this document to ensure that the recommendations provided can be utilised by NGET effectively, including the identification of any remaining unknowns or risks.

Objective(s)

The objective of this project is to assess the feasibilities of the aforementioned alternative cooling methods for underground transmission system. The key aspects are:

- Build accurate FEA models that can reproduce the thermal environment in an underground cable tunnel
- Find out to what extent can the cable ratings be increased by employing the alternative cooling methods
- Find out the thermal and mechanical conditions that the cable will experience due to the use of alternative cooling methods and the possible consequences of such conditions

- Find out the possible health and safety implications from the alternative cooling methods

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 a neutral impact on customers in vulnerable situations. This is because it is a transmission project.

Success Criteria

This project is deemed as successful if the objectives are achieved. In particular, the following outputs will be important when assessing the success of the project:

- Successful development of accurate FEA models that can be used to assess the alternative cooling methods
- Investigate the possible thermal and mechanical complications caused by the alternative cooling methods

Project Partners and External Funding

Not applicable

Potential for New Learning

The potential new learnings from this project are:

- The thermal and mechanical conditions that cable might experience due to the use of alternative cooling methods
- The insulation performance of the cable when it is subjected to the alternative cooling methods
- The mechanical integrity of the cable when it is subjected to the alternative cooling methods
- The integrity of other cable components when they are subjected to the alternative cooling methods

The learning will be disseminated through the publication of project progress and closedown reports on the ENA portal. Various workshops and dissemination events would also be planned.

Scale of Project

The scale of the project includes the following.

- Development of different FEA models and simulations for underground transmission system to assess the alternative cooling methods
- Site visits for data collection and possible sensor installations
- Experiments including thermal cycling on cable and other cable components
- Various document writing, presentations and disseminations

Technology Readiness at Start

TRL2 Invention and Research

Technology Readiness at End

TRL4 Bench Scale Research

Geographical Area

The project will mainly be carried out on the premises of the University of Southampton.

Revenue Allowed for the RIIO Settlement

Not Applicable

Indicative Total NIA Project Expenditure

Total NIA expenditure: £465,300

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 energy system transition will require more electrification of the society. The learning of this project could help to reduce the costs for capacity uplift for the underground transmission system and thus this project supports more electrification and better system access in general.

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

Not applicable

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)

Not applicable

Please provide a calculation of the expected benefits the Solution

A CBA has not been carried out due to the project is at low level TRL (2, Research).

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

The implementations of the proposed alternative cooling methods need to be specifically designed for specific circuits in order to achieve the desired effects. Network licensees that own underground transmission circuits, e.g., cable tunnels, could use the learning from this project to build their own specific implementations.

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

The costs of deploying the alternative cooling solutions are highly dependent on the specific circuits and the best form of implementation considering the specific environmental properties. The CAPEX and OPEX for the proposed alternative cooling methods will be studied in this project.

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 costs of deploying the alternative cooling solutions are highly dependent on the specific circuits and the best form of implementation considering the specific environmental properties. The CAPEX and OPEX for the proposed alternative cooling methods will be studied in this project.

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

Not applicable

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.

Despite their importance as a thermally limiting section of high voltage circuits, research into cable tunnel ratings is relatively niche. As an illustrative example, the key words “cable tunnel rating” produced 23 journal articles on IEEE Xplore at the time of writing. The same key words produced only 3 truly relevant projects on the ENA portal. Expertise in the ratings of cables in tunnels is confined to a relatively small number of research institutions. Any risk of duplication will be addressed through dissemination of progress with other licensees and being open to co-operate with licensees working in similar areas.

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

Despite their importance as a thermally limiting section of high voltage circuits, research into cable tunnel ratings is relatively niche. As an illustrative example, the key words “cable tunnel rating” produced only 23 journal articles on IEEE Xplore at the time of writing. Expertise in the ratings of cables in tunnels is confined to a relatively small number of research institutions. The novelty of the proposed approach, using alternative cooling systems for cable tunnels, combined with the niche position cable tunnel ratings research occupies, means that this project has not been tried before. Furthermore, there are likely to be practical obstacles that must be overcome for this technology to be applied to existing installations, especially for liquid nitrogen systems.

Relevant Foreground IPR

The foreground IPR will mainly be the various FEA models developed during the project, all the collected and generated data during the project, all the simulation and experimental results and all other documents generated during the project. The background IPR for the various tools, instrument and sensors will be contributed by the relevant manufacturers.

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 project involves a series of novel research and the outcomes are uncertain and guarantees no success. These are significant business risks and thus this project is not suitable for BaU.

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

The project can only be funded through the NIA as there are significant risks which warrant further investigation and development of this research area. The main risks are the technical challenges. The feasibility, efficacy and implementability of the proposed alternative cooling methods are highly uncertain at the moment due to the fact that they are highly novel. The thermal and mechanical complications that these methods could impose on the cable system are yet to be thoroughly investigated. Without the NIA funding, these risks would never be mitigated and the potential benefits would never be realised.

This project has been approved by a senior member of staff

☑ Yes