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

Sep 2024

Project Reference Number

NIA2_NGET0076

Project Registration

Project Title

Thermal Analysis and Consequences of Thermosyphon Installations on Cable (TACTICS)

Project Reference Number

NIA2_NGET0076

Project Licensee(s)

National Grid Electricity Transmission

Project Start

November 2024

Project Duration

2 years and 7 months

Nominated Project Contact(s)

Hamid Shahrouzi

Project Budget

£674,000.00

Summary

This project aims to enhance cable circuit ampacity by investigating the potential of thermosyphon systems for improved heat transfer. Through a literature review, suitable thermosyphon working fluids and thermal modelling methodologies will be identified. An experimental apparatus will be designed to assess heat transfer in cable systems using thermosyphons, and simulations will validate the design. The project will also examine the impact of thermal aging on thermosyphon fluids and compare measured values with datasheet information. Recommendations will be provided to National Grid, including practical considerations and potential challenges for thermosyphon system installation.

Preceding Projects

NIA2_NGET0023 - Cable Alternative Cooling Technologies for Underground Systems (CACTUS)

Third Party Collaborators

University of Southampton

Nominated Contact Email Address(es)

box.NG.ETInnovation@nationalgrid.com

Problem Being Solved

Due to the projected doubling of electricity demand in 2050 compared to 2020, there is a need to either extend or uprate the grid infrastructure. Expanding the grid through cable tunnel extensions can be costly, and usually take a lot of time to take consent from different parties to run the project, making it crucial to find a solution to increase the ampacity of the existing cables. High voltage cables installed within tunnels are often thermally limited due to the limited heat dissipation through the surrounding air. This project builds upon the CACTUS project (code NIA2_NGET0023) and aims to design a passive cooling system for cable tunnels to address this challenge.

Method(s)

The ampacity of cable circuits is often limited by specific “hot spots” at critical locations. These can include joint bays, or shafts in the case of cable tunnels. This project aims to investigate the potential of thermosyphon systems, an established technology in gas pipelines and circuit breakers, to improve heat transfer in cable systems, potentially increasing the rating of cables circuits.
Thermosyphon systems are widely used on gas pipelines to keep ground frozen around buried supports to prevent mechanical damage that could arise due to natural thermal gradients. Their use in high voltage installations is largely focused on generator circuit breakers to improve heat dissipation. An advantage of thermosyphons is that they are a passive technology, with no operating noise or power requirements. This project will aim to look at using thermosyphons in cable systems, which has received very little research attention. Focus will be given to the installation requirements of thermosyphons, and the development of simulation tools to assess their potential impact, validating models against a laboratory test bed.
Thermosyphons have been employed to stabilise foundations since the 1960s, with the largest installation of ~120,000 units employed on the Trans-Alaska Pipeline in 1977. Thermosyphons have also seen application in cooling turbine rotor blades and solar heating systems. Thermosyphons transfer heat from a source to a coolant within a pipe. This coolant is a fluid with a low latent heat of vaporisation and consequently it evaporates. This vapour rises until it reaches a cooler region where it condenses and falls as a liquid on the surface back to the source. A key advantage of thermosyphons are that they are passive systems, requiring no external power supply and producing no audible noise.
A recently completed Network Innovation Allowance project “Cable Alternative Cooling Technologies for Underground Systems”, CACTUS, simulated the potential impact of installation thermosyphon systems within a cable tunnel shaft. The results indicated that significant heat dissipation was possible, with thermosyphon pipes installed on the cable surface transferring the majority of the heat produced by the cable. This would indicate a significant reduction in mutual heating between circuits, and a potential uprating of existing equipment.
The simulation results from CACTUS motivate the need for further work, including experimental investigations which can be used to validate the simulation methodology. The intention is to determine whether thermosyphons are a viable technology to cool localised hot spots in cable systems, such as those in tunnel shafts or joint bays.

Scope

The work will be divided into 6 work streams focused upon the achievement of objectives, with each producing a clear set of deliverables:
WS1. State of the art review
WS2. Experimental assessment of heat dissipation from thermosyphon systems
WS3. Simulation of heat transfer within thermosyphon systems
WS4. Assessment of Thermosyphon Fluid Properties
WS5. Recommendations to National Grid

Work Stream 1: State of the art review
There is a requirement to determine prior literature on thermosyphon thermal modelling and the identification of suitable fluids for HV applications. The University of Southampton has previously conducted work in this space, but it is from 2019 and was focused on circuit breaker applications. There is therefore a need to analyse more recent literature, and to appropriately consider historical work on thermosyphon applications in gas pipelines, which are a reasonable thermal analogue for cable systems.
Fluids will be analysed considering their environmental properties including ozone depletion, global warming potential and flammability. Other important properties include their operating temperature range, latent heat of evaporation and boiling point. As the thermosyphons will be placed outside of the cable sheath the dielectric properties of the fluid are less critical, provided that it is sufficiently insulating to prevent induced heating.

Work Stream 2: Experimental assessment of heat dissipation from thermosyphon systems
To demonstrate the potential cooling benefit of thermosyphon systems it is necessary to design and build a suitable test-bed in the laboratory. A number of temperature measurements will need to be made in order to demonstrate any potential cooling, but it is also important that they do not impact the fluid dynamics within the thermosyphon. At present it is intended to also use a high-speed camera to record the experiment. This intended to monitor the liquid film size on the external surfaces, and potentially the formation and motion of any bubbles within the system.
It is important that the experimental testing considers the need to orientate the heat source with respect to the thermosyphon in order to provide insight into systems where cables may be vertical (e.g. tunnel shafts/risers) and horizontal (e.g. buried). Consideration of thermal performance over a temperature range should also be undertaken. It is intended to consider up to three different fluids over a range of conditions.

Work Stream 3: Simulation of heat transfer within thermosyphon systems

Based on a review of prior literature in WS1, and experience gained as part of the CACTUS project, a thermal model of a thermosyphon will be constructed. The model will be validated against the experimental arrangement developed in WS2, but it is also intended to develop a “first pass” model to inform experiment design before validation.
It is envisaged that a two phase CFD model will be coupled to a thermal model within FEA software. In addition to the experimental arrangement, it is intended to develop models to demonstrate the impact of thermosyphons across a range of cable systems including cables in shafts, and traditional buried circuits. A further potential scenario is in joint bays. The University of Southampton has a range of extant models of National Grid cable circuits which can be altered to incorporate thermosyphons.

Work Stream 4: Assessment of Thermosyphon Fluid Properties
Given the length of cable systems design life it is imperative to confirm whether thermosyphon fluids are sufficiently stable such that their cooling performance is not impacted. A series of thermal ageing experiments and characterisation techniques will be undertaken to determine whether thermal properties (e.g. boiling point) or electrical properties, in particular conductivity, may degrade over time. This will also allow for a comparison of measured values against those of the supplied data sheet.

Work Stream 5: 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 thermosyphons. Using data from simulations it is intended to provide estimates of capital expenditure (excluding installation costs) that may be required to construct thermosyphon systems.
It is intended to collaborate with NGET staff in this workstream to ensure that the recommendations provided can be utilised by NGET swiftly, including the identification of any remaining unknowns or risks.

Objective(s)

The objective of this project is to develop and optimise a cooling system using thermosyphons for cable tunnels to enhance heat dissipation and increase the ampacity of installed cables. The aspects of this project are as follows:

- Model heat transfer in thermosyphons based on existing literature to inform simulations.
- Identify readily available candidate fluids for cable systems to conduct experiments.
- Determine achievable heat dissipation in a laboratory test bed as an indicator of cable system performance.
- Investigate how thermosyphon thermal performance depends on cable location and temperature range.
- Assess the accuracy of heat transfer models for thermosyphons.
- Analyse the impact of thermosyphons on cable ampacity.
- Evaluate potential degradation of thermosyphon fluids with age.
- Compare measured fluid material properties with datasheet values.
- Explore the retrofitting of thermosyphon systems in existing cable circuits.
- Assess implications for maintenance and health and safety during thermosyphon installation.
- Analyse the cost-benefit ratio of installing thermosyphons.

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 output will be important when assessing the success of the project:

Exploring and evaluating the design and construction of a functioning thermosiphon laboratory model that demonstrates reliable and consistent heat transfer performance to achieve effective heat dissipation.

Project Partners and External Funding

This project does not have any external funding.

Potential for New Learning

The potential new learnings from this project are:

- Gain a deeper understanding of heat transfer in thermosyphons and its application to cable systems.
- Identify suitable candidate fluids for cable systems that demonstrate effective heat dissipation properties.
- Determine achievable heat dissipation in a laboratory setting to gain insights into cable system performance.
- Assess the impact of thermosyphons on cable ampacity and their potential for increasing current-carrying capacity.
- Evaluate the feasibility, maintenance implications, and cost-benefit ratio of installing thermosyphons in cable systems.

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:

- Testing various candidate fluids: The project involves testing different types of candidate fluids to assess their effectiveness in heat transfer. These fluids, known for their desirable thermophysical properties, can be relatively expensive to procure and utilise in the experiments.
- Construction of a small-scale test bed: To analyse the thermal performance of the thermosiphon, a small-scale test bed needs to be built. This test bed requires specialised equipment, materials, and instrumentation, which contribute to the overall cost of the project.
- Research, development and data collection: The project involves extensive research efforts, development of new models, optimisation of the thermosiphon system design, and data collection and analysis.

Technology Readiness at Start

TRL3 Proof of Concept

Technology Readiness at End

TRL6 Large Scale

Geographical Area

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

Revenue Allowed for the RIIO Settlement

N/A

Indicative Total NIA Project Expenditure

£606,600

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 project has the potential to facilitate the energy system transition by reducing costs for capacity uplift in the underground transmission system and enhancing grid flexibility. The outcomes of this project will contribute to a more economically viable energy system because this technology offers the advantage of delivering more energy without the necessity of constructing new tunnels along the existing path.

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

A CBA has not been carried out due to the project is at low level TRL (3, Research). The implementation of thermosiphon technology provides the design team with an additional option to enhance the rating of power transmission lines while ensuring a higher level of fault tolerance. By improving heat dissipation capabilities, it enables higher power flow capacities without compromising system reliability. This technology offers the advantage of delivering more energy without the necessity of constructing new tunnels along the existing path.

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

The benefits calculation for this project is based on implementing this approach on one single circuit tunnel that could be immediately upgraded by adding another circuit and then equipped with thermosiphon technology. Thermosiphons can be installed in any double circuit tunnel to enhance the performance of the circuits, and therefore benefits and replication of this technique can be much wider.

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

A preliminary estimate for the cost of implementing thermosiphon technology in each cable tunnel shaft is approximately £2M. This estimation is rough and subject to change based on specific project requirements and other factors.

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

This project aims to demonstrate the feasibility of using thermosiphon systems for uprating cable tunnels. A successful project would allow the relevant licensees to make informed decisions regarding the adoption of this technology for their respective assets.

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.

Thermosiphon systems have been extensively employed in gas pipelines to maintain frozen ground around buried supports, preventing potential mechanical damage caused by natural thermal gradients. While their usage in high voltage installations has primarily centred around improving heat dissipation for generator circuit breakers, the application of thermosiphons for uprating cables is not reported anywhere in literature.

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

Thermosiphon systems have been extensively employed in gas pipelines to maintain frozen ground around buried supports, preventing potential mechanical damage caused by natural thermal gradients. While their usage in high voltage installations has primarily centred around improving heat dissipation for generator circuit breakers, the application of thermosiphons for uprating cables is not reported

anywhere in literature.

Relevant Foreground IPR

The foreground IPR will mainly be the model thermosiphon 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

Given the project current stage of development (TRL3), the project does not align with the typical routine operations and investments of the Network Licensee.

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

Using thermosiphons in cable tunnels carries certain risks that need to be carefully considered. These risks include challenges related to installation, compatibility with existing infrastructure, potential environmental factors affecting performance, and the risk of leakage or fluid contamination. This funding can help ensure the safe and effective utilisation of thermosiphons in cable tunnels, mitigating risks and maximising the benefits of this innovative technology.

This project has been approved by a senior member of staff

☑ Yes