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 2018

Project Reference Number

NIA_SPEN_033

Project Registration

Project Title

CALISTA - Cable Asset Life by Integrating Statistical Failure Models

Project Reference Number

NIA_SPEN_033

Project Licensee(s)

SP Energy Networks Distribution

Project Start

September 2018

Project Duration

3 years and 10 months

Nominated Project Contact(s)

Andrew McDiarmid

Project Budget

£360,000.00

Summary

This Project will, through research, develop an analytical model to predict cable asset lifespan through analysis of the cable parameters.

Third Party Collaborators

Glasgow Caledonian University

Nominated Contact Email Address(es)

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Problem Being Solved

The Scottish Power Distribution (SPD) medium voltage network is an interconnected system comprised of wooden pole overhead lines and buried underground cables.

The installed cable types are largely dependent on the era of when they were deployed, and are typically either oil impregnated paper insulated cables including paper insulated lead sheath covered (PILC), which was the norm before 1980s; or cross-linked polyethylene insulated cables (XLPE). The expected design life of PILC cables is 60-80 years, with XLPE having a design life of some 35-40 years.

XLPE cables have become dominant since late 1980s due to their high reliability, low dielectric loss, lower cost and ease of installation.

At present, a good proportion of the SPD cables are approaching or beyond their operational design life. However, due to financial constraints, SPD is considering extending the service life of these important assets and identified management of the ageing assets as one of their main challenges.

Dialogue with SPD operational engineers along with liaison with sister companies in England and in Spain have indicated a significant number of cable failures.

Analysis of the failure events carried out within the group company only showed monthly distribution of cable failure events, with suspected moisture and partial discharge (PD) issues being the main cause of failure.

These reports lacked technical depth and failed to demonstrate convincing evidence to support the reasons behind the failures.

There is no supplementary evidence to show how the data is utilised to make useful forecast of cable life expectancies, which is essential for optimised and informed asset management decision makings.

Method(s)

A PhD student will be enlisted for a period of 3 years to undertake a research project to determine cable asset life by combining statistical and analytical models. The aim shall be to combine top-down and bottom-up approaches to forecast cable life, correlate this to asset age, asset operational history/environment and insulation condition measurement data.
Criteria Summary:

· Establish an analytical cable insulation loss-of-life or aging model via modelling of the failure mechanisms and carrying out PD measurement in selected circuits once every quarter.
· Develop a model to integrate statistical approaches and analytical loss-of-life model to analyse past failure events and help understand age-related insulation deterioration or degradation of cable assets under service conditions.
· Develop an asset management model to enable asset managers to evaluate the present condition and the remaining life of each individual cable circuit, based on the history of individual's operational stresses, historical failure data and/or condition monitoring results.
· Develop a methodology to enable asset managers to make optimised and informed decisions on the replacement of each of the cable assets individually, based on risk analysis which includes consideration of asset health and criticality.
· Develop a software package to facilitate implementation of all research outcomes.

In Addition to this, a feasibility study will be carried out for a cable fault location device which will use wireless charging techniques to locate cable faults.

Scope

The project shall include the following work packages (WP):
WP1:
Analysing routes to failures for PILC and XLPE cables, and acquiring essential data for the project.

Project success relies on real world data. The project will begin with analysis of routes to failures, and main influencing factors on life, for both PILC and XLPE cables, from which failure causes, failure mechanisms and failure modes will be clearly tabulated. Core to this will be utilities providing high quality data which will be readily applicable to the project, and to ensure quality inputs to the Weibull and PHM models. Data will include inventory and historical information for selected cable populations: failure/life data, operational/environmental stresses and condition monitoring results (ambient temperatures, moisture conditions, historical loading, PD, dielectric loss and insulation resistance etc.). Cable samples at different age groups, along with their historical operational and stress data will also be acquired from utilities for experimental investigation of aging vs. stresses.

WP2:
To carry out PD tests on a quarterly basis during the project life on 10 selected cable circuits and correlate the results against past failure events.

This will help to prove whether PD plays a key role in the elevated failure numbers in the spring and summer seasons as observed, and will serve as the basis for the modelling of insulation aging. The PD monitoring technique developed at GCU has been applied and proven in EDF Energy and will be used in the project.

WP3:
Developing the top-down, statistical tool and new knowledge on cable life/failure behaviour.

In order to achieve the best results when applying the Weibull and PHM models, work needs to be carried out to analyse the previous failure data and define clearly the concepts of component, equipment and systems, reparable and non-reparable systems within the context of cable populations. The Weibull model will be applied to model the trend of failure numbers and for evaluation of future failure rate with different replacement/refurbishment strategies. The PHM will be applied in conjunction with the Weibull model. The potential benefit of the approach is that it can allow covariates to be accommodated, providing different failure rate for the same cable group under different stress situations. In addition, efforts will be made within the WP to ensure quality of data, and managing inevitable weakness which means learning: how to deal with outliers, or onerous data points; how to deal with small and incomplete datasets (possible because the required data may not have been recorded in the past for some of the aged cable assets).

WP4:
Development of analytical models for both XLPE and PILC cables.

For XLPE cables, space charge has been recognised as an important factor that affects the electrical performance of the insulating materials. An analytical model will be developed to quantify the loss-of-life versus various stress factors. Comparing with the approaches published previously which demonstrated the ageing rate of XLPE insulation against thermal, electrical, and mechanical stresses, a novel approach will be taken to include space charge as a marker. Charge trapping and transport in PILC systems is less well defined, due to the variability of mobility of oil within the solid paper insulation component, and novel electro-chemical modelling will be required.

For PILC cables, even though PD and dielectric loss (tanδ) have been widely used as diagnostic tools, there are no well-established and physically sound criteria that define the probability of the next failure versus either PD or tanδ levels. A new approach is clearly needed to improve the diagnosis. During operation mass impregnated paper insulation often undergoes degradation due to thermal and electric stresses, resulting in reduced degree of polymerisation (DP) of the paper. The DP for new Kraft paper in PILC cable is around 1200, a DP of 200 leads to poor mechanical strength, leading to a final failure. Similar research has also been carried out for high voltage transformers where the DP shows a clear relationship with electrical performance of the Kraft paper insulation. In the present proposal the relationship between DP and the electrical performance of mass impregnated paper will be examined.

WP5:
To correlate the models resulting from WP3 and WP4 with utility data and propose a model for redefining cable insulation life under in-service conditions.

Expected outcomes from the exercise in WP3 include the characteristic life for various cables under different stress conditions. Then the analytical life model (WP4) will be applied to evaluate the insulation condition of individual cable circuits or segments and their historical working stresses, from which the overall failure rate is to be obtained. Correlation analysis will be carried out to analyse the results from WP3/WP4 and those failure data and condition monitoring data provided by industry. During the process, the parameters of the physics based life models will be identified. With the results of the work package, a model will be developed to enable the life expectancy of the cable population under in-service conditions to be redefined.

WP6:
Evaluation of the benefit of the proposed approach and the associated risks.

Monte-Carlo based simulation will be adopted, taking the characteristic life and failure distribution from the previous WPs. Estimation will be made in terms of the potential benefit by adopting the proposed approach against the current practice. Limitations and associated risks of the current and proposed practices will also be analysed.

To establish a credible benefit analysis of improved asset management, financial tools must be developed which have the confidence and support of the utilities. These tools must identify the real costs of additional activity and the costs and benefits of various levels of application.

WP7:
Propose a risk based asset management strategy for the asset managers to optimise their maintenance and replacement strategy based on the research results.

An improved asset management tool, using data representing operational stresses and condition monitoring results, will be developed, based on the aging/statistical models to be proposed from the project, and the criticality and financial model developed in WP6. Special attention will be paid to future trends as the cable population becomes increasingly aged, and loading patterns change. In particular, methods of early identification of increases in failure rates will be sought. The end of the technical life, the economic life and strategic life of the cables will be determined so that appropriate actions such as repair, refurbish and replace can be optimised. Investment balance, other investment opportunities and reliability constraints or operational risks will be considered.

WP8:
(Optional) to develop a software package to facilitate implementation of the research outcomes and to help SP to improve their cable asset management.

Objective(s)

(a) Establish an analytical cable insulation loss-of-life or aging model via developing analytical models for all failure and correlate the PD trend with past failure events.

(b) Developing a top-down approach, based on the Weibull model and Proportional Hazard Model (PHM), to allow systematic analysis of failure behaviour and to identify the main influencing factors on failure. The approach, based on historical life and failure data, will (i) formulate a methodology for systematic collection of cable failure, life and condition monitoring data, (ii) develop a method for dealing with small and incomplete datasets; and (iii) apply the PHM to generate knowledge on the effect of main influencing factors such as historical loading, climate conditions, frequency of circuit switching and installation methods on cable failures.

(c) Applying a bottom-up approach, based on physics-based analytical models which will quantify the aging mechanisms and the routes to failure of cable insulation, under various stressing conditions. The work will based on theoretical investigation and on-site partial discharge measurement results of the PILC cable circuits. It is supposed that the GCU research team will use their PD monitoring system to take PD measurements 4 times a year over the project life on selected circuits.

(d) Developing a systematic model which can combine the top-down and bottom-up approaches to forecast cable life for individual cable circuits under in-service conditions. Factors will include electrical, mechanical, thermal, environmental stresses including steady state and short term events (switching and lightning impulse, cable dig-up etc.). Effects of future load increase and changes in power quality will be considered.

(e) Based on the outcomes of the above research and with studies on the effect of maintenance on the insulation lifespan, an optimal integrated condition assessment, maintenance and replacement model will be developed.

(f) Development of software packages to implement the research results.

Consumer Vulnerability Impact Assessment (RIIO-2 Projects Only)

n/a

Success Criteria

Deliverables from the proposed research will include:
· a Weibull-PHM based methodology to identify and quantify influencing factors on cable life and failures, define focussed data collection from operational assets and influence policy makers.
· new knowledge on cable and cable joint failure behaviours under in-service conditions – providing underpinning technology for asset managers to make joint location/replacement decisions
· a model of insulation degradation against various stressing factors – which will, when combined with operational knowledge of their system, allow optimisation of material selection and product design
· a model for redefinition of cable insulation lifespan using operational history data and/or condition monitoring results, providing inputs for asset managers and policy makers
· a software package for asset managers to manage their cable asserts and plan optimal maintenance and replacement programme for the vast quantity of existing cable assets.

Project Partners and External Funding

Glasgow Caledonian University (GCU), with Prof. Chengke Zhou and Dr Ahmed Aboushady.

Potential for New Learning

This proposed research project will build on three areas of existing internationally recognised expertise: (i) academic knowledge of condition monitoring of power cables, gained from previous EPSRC funded projects EP/D048133 (£177k) and EP/G028397 (£560k) and four EDF Energy funded projects (£400k); (ii) world-leading research track record and facilities in insulation aging (CIGRE working group D1.39/C1.38 interaction) and, (iii) applying advanced forensic techniques and developing software packages containing data processing techniques to determine knowledge entrained in raw, field condition monitoring data.

Scale of Project

Project shall be broken down into the key sections over the 36 month period:
A – Literature review and data collection

B – Life/failure data analysis – reliability and failure trending

C – Analysis of aging mechanisms (physics based model + data mining and simulation)

D – Modelling of optimal maintenance and replacement programme

E – Development of software packages(statistical model)

F – PD Testing/ Report writing

G – Project meetings

Technology Readiness at Start

TRL3 Proof of Concept

Technology Readiness at End

TRL6 Large Scale

Geographical Area

SPD Locale

Revenue Allowed for the RIIO Settlement

NA

Indicative Total NIA Project Expenditure

£200,000

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:

n/a

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)

The key to improved assessment of plant integrity and successful extension of asset life thus lies in identifying, characterising and determining the rate of degradation of weak spots, before proactively repairing/replacing them. As a result, condition monitoring (PD, dielectric loss, distributed temperature, insulation resistance, oil leaks, etc.) and condition based maintenance (CBM) has been investigated around the world and promoted among utilities.
Although no cost benefit analysis has been conduct at present, potential savings are predicted to be in the £million level for the SP area.

Please provide a calculation of the expected benefits the Solution

NA

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

The proposed research shall develop a site by site data collection methodology combined with extensive data processing; refinement of cable and system modelling for enhanced asset lifespan utilising operational and condition monitoring parameters; and development of a cable asset software package.

Given the commonality of installed cable assets within the UK in general, the rationale of the proposal shall be applicable and transportable across the 14 licensed distribution network operators (DNOs) in the UK.

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

To be determined and understood as a result of research conclusions.

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 research outcome is expected to result in greater security of electrical supply to customers and significant cost savings for SP and the electrical supply industry. Knowledge generated by the project will be shared openly with other UK DNOs so that the learnings can be implemented widely after project closure.

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

Understanding and accurately modelling the aging process of cable assets under service conditions, predicting reliability and future failure rate, and identifying appropriate actions for acutely degraded individual assets or components.
Failing to evaluate the aging status and condition of individual assets will lead to increased operational risk and wasteful investment through premature replacement of assets that are aged, but still in good condition.

☑ Has the Potential to Develop Learning That Can be Applied by all Relevant Network Licensees

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.

The ENA portal has been reviewed to ensure the project does not replicate other NIA projects which have carried out the same learnings.

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

The project comprises academic research on new methodologies and techniques to determine cable asset life cycles using statistical and analytical models.

Relevant Foreground IPR

n/a

Data Access Details

n/a

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

No funding as been apportioned to the project activities under the current price control regime.

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 includes academic research principles not typically utilised as business as usual; therefore no funding apportioned under RIIO_ED1. Project shall be a low risk activity with potential high benefits for operational life activities of utility cabled assets.

This project has been approved by a senior member of staff

☑ Yes