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NIA Annual Report
2018 – 2019

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Foreword

SP Energy Networks (SPEN) is committed to delivering the Distribution Network of the future in our two license areas (SP Distribution plc. and SP Manweb plc.) and is leading the industry across a number of areas with our wide and varied innovation portfolio. We have a continued drive, ambition and capability to be at the forefront of innovation in the best interests of our customers and wider stakeholders.

This is our fourth Network Innovation Allowance (NIA) Annual Distribution Report and is an overview of the projects we have initialised during the regulatory year 2018/2019 and an update on those projects reported during 2017/2018 that are still active.

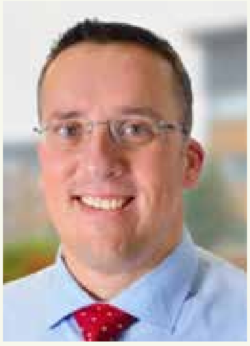
In addition to its function of supporting small scale innovation projects, NIA has also a designed role in fostering robust Network Innovation Competition (NIC) proposals. SPEN was delighted to have been successful with our 2018 NIC project submission "Charge". This project aims to engage with relevant stakeholders across network, transport, and planning to develop and trial electric vehicle (EV) charging solutions. The project will investigate the ability of smart control, storage, and active network management systems to provide lower connection and operational costs to customers. The project aims to develop a Distribution Network Operator led strategy to facilitate and accelerate the electrification of transport, and more specifically, the connection of charging infrastructure.

Project Charge will investigate several smart charging solutions which will enable easier and cheaper connection of high numbers of EV chargers to the electricity networks. The project will test EV technology and procedures in Liverpool, North Wales and parts of Cheshire and Shropshire that could then be rolled out across Great Britain.

Over the last six months we have taken the opportunity to review and enhance our internal processes for delivering innovation projects into business as usual. Through engaging with internal and external stakeholders and carrying out benchmarking against other companies' innovation processes, we have identified a number of improvement opportunities.

2019 has also marked the beginning of a drive to strengthen our culture of innovation; 2019 is SPEN's Year of Innovation! We recognise that our business is all about our people and are equipping, enabling and empowering them to be more innovative in their daily activities. To this end, we are creating opportunities for the wider business to engage in business focused challenges, raising up champions who can drive local innovation and driving initiatives to enable our people managers to be more innovative and deliver a better future quicker.

In support of our innovation ambitions, SPEN welcomes third parties to submit innovative ideas for potential NIA and NIC projects.



Colin Taylor
Director
Processes and Technology

Contents Page

Executive Summary

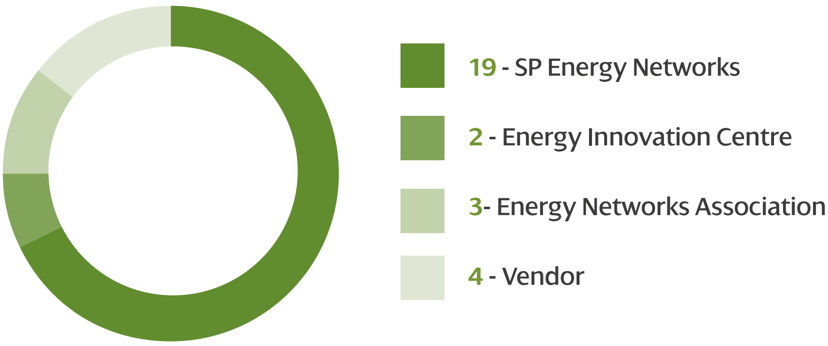
This Network Innovation Allowance Annual Distribution (NIA D) Report has been compiled in accordance with Ofgem's Electricity Network Innovation Allowance Governance Document which sets out the regulation, governance and administration of the Electricity NIA. This fourth NIA D Annual Report presents an overview of the projects we have initialised during the regulatory year 2018/2019 and an update on those projects reported during 2017/2018 which are still active.

We collaborate with other GB network companies to ensure that all customers benefit from customer funded innovation projects and, consequently, this report also provides details of NIA D projects, led by other DNOs in which we are a collaborating party.

Collaboration

As part of the overall strategy for our technology portfolio, SPEN aims to have a balanced mix of projects that originate from other sources and not just from within SPEN, as illustrated below.

Project Origin




SP ENERGY
NETWORKS

Introduction

We recognise the need to be innovative in order to get more out of our electricity distribution network and delivering value for money for customers.

Under the NIA, we are concentrating on a smaller number of higher value projects, with higher technology readiness levels that offer the prospect of earlier business benefits.

SPEN is committed to identify innovative performance improvements across all aspects of our business.

In ED1 there is increased need to ensure that innovation is embedded into all business function, as such the role of our Innovation Strategy Board is to ensure increased participation from all business functions and to allow innovation projects to be completed and integrated into Business as Usual (BaU). Our Think Big, Start Small, Scale Fast approach to innovation enables us to be at the forefront of innovative practice and is embodied in our guiding values. At SPEN we believe in the power of innovation to enhance all aspects of our business and improve our service for the benefit of both our internal stakeholders and customers.

SPEN recognise that consideration needs to be given to not only the RIIO-ED1 period and stakeholder's immediate needs, but also how we address the longer term issues which the Distribution network may face. This is being addressed through a balanced portfolio of innovation projects where we are considering some of the longer term issues which may involve technology and techniques at a lower technology readiness level as well as challenges to be faced over the next decade.

Estimated Timeframe to Adoption for Project Portfolio

2 | Progress Summary

During the reporting year 1st April 18 to 31st March 19 SPEN registered the following six NIA Distribution projects:

Project No.	Project Name	Project Start Date
NIA SPEN0031	Radiometric Arc Fault Location RAFL 2 http://www.smarternetworks.org/project/nia_spen_031	Apr-18
NIA SPEN0032	Transition to Dynamic Cable Rating http://www.smarternetworks.org/project/nia_spen_032	Apr-18
NIA SPEN0033	CALISTA - Cable Asset Life by Integrating Statistical Failure Models http://www.smarternetworks.org/project/nia_spen_033	Sep-18
NIA SPEN0034	Network Constraint Early Warning System (Phase 2) http://www.smarternetworks.org/project/nia_spen_034	Oct-18
NIA SPEN0036	A Holistic Intelligent Control System for Flexible Technologies http://www.smarternetworks.org/project/nia_spen_0036	Dec-18
NIA SPEN0037	Electric Vehicle Uptake Modelling (EV- Up) http://www.smarternetworks.org/project/nia_spen_0037	Feb-19

Active NIA Distribution projects, led by other Distribution Network Operators, which SPEN is collaborating on, are tabled below.

Project No.	Project Name	Project Start Date
NIA WPD 0008	Improvement Statistical Ratings for Distribution Overhead Lines www.smarternetworks.org/project/nia_wpd_008	Jul-15

During the reporting period SPEN has collaborated on four NIA projects that have been registered by other parties as follows:

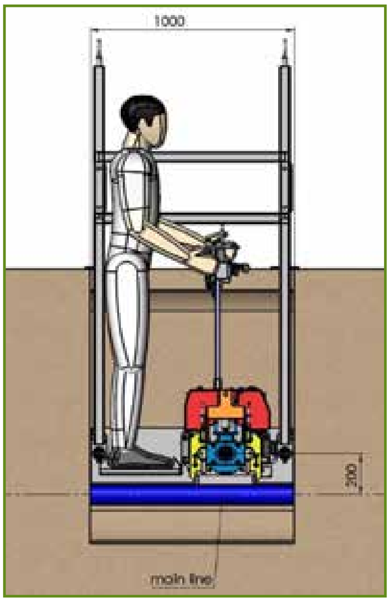
Project No.	Project Name	Project Lead
NIA WPD 0008	Improvement Statistical Ratings for OHL	Western Power Distribution
NIA SGN 0138	East Neuk – A Techno Economic Study into the Energy System	SGN
NIA SHET 0025	Zero Missing Phenomenon	Scottish and Southern Electricity Networks
NIA UKPN0047	HV Feeder Monitoring to Pre-Empt Faults	UK Power Networks

The following sections provide a short overview of each active NIA D project and summarises the progress made on them. Further details on SP Energy Networks Innovation activities can be found on SP Energy Networks's website (www.SP Energy Networksergynetworks.co.uk/pages/innovation.asp) and on the ENA Smarter Networks Portal (www.smarternetworks.org). Key learning associated with these projects is summarised in Section 6.

3 | NIA Projects Led By SPEN

3.1 | NIA SPEN0006 Mini Mole

Renewing and upgrading underground LV cables and service connections can be a costly and time consuming activity. The standard unit cost for this activity does not take into consideration different circumstances which can significantly increase costs and inconvenience to customers; such as increased excavation and reinstatements resulting from ornate or decorative paving. These types of excavations can be significantly more expensive and time consuming, removing limited resources from front line activities, and reducing efficiencies.

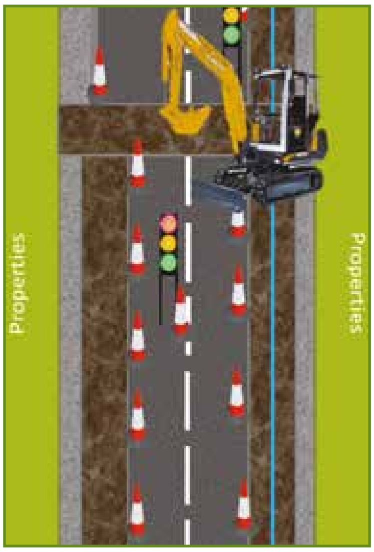


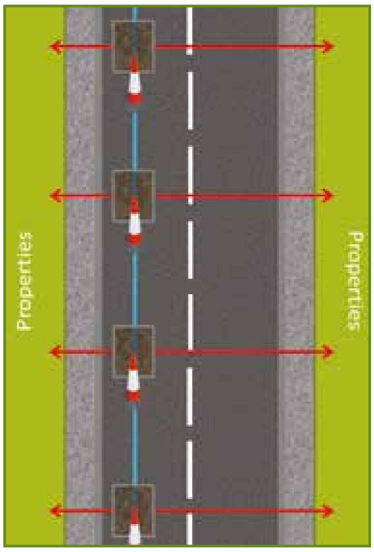
Although the merits of conventional open cut trenching are well known there is an intrinsic risk to home owners and members of the public. To develop an alternative solution to this problem SPEN has been working with R&D partner, Tracto-Technik (TT), to design an innovative trenchless technology system (Mini-Mole) which could be used as a viable alternative to traditional open cut trenching method currently utilised for LV cable applications. The R&D phase, completed during IFI Keyhole Trenchless Technologies, will be manufactured into a full scale working prototype and extensively trialled to establish the benefit of the technique over conventional excavation methods for a variety of typical jobs.

The pictures below illustrate the open trench work required in order to connect service cables.

This new method of inserting new/renewing existing services will help to prevent costly re-instatement of footways, which during excavation/reinstatement can render the footpath off limits to some pedestrians, as well as restricting access and egress from properties.

The Mini-Mole has been designed to fit a standard excavation required for jointing LV cables, removing the need to complete costly and time consuming road crossings. The Mini Mole method will greatly reduce the footprint of the work, reducing excavation and reinstatement costs, improving the working environment and lead to a reduction on standard traffic management costs. In addition, a reduction of exposure to manual handling risk using this innovative Mini Mole Trenchless Technology is anticipated.





The above diagram outlines the potential difference between the traditional method with road crossing and traffic management vs. the Mini Mole method with no open excavation road crossings and limited excavation requirements.

3.1.1 | NIA SPEN0006 Project Progress

Trials took place on different project types in the second half of 2018 these included LV service connections, a problematic service connection under a stream and installation of ducts for 11kV cables. The system was also demonstrated to internal staff and our cable laying framework contractors over a number of days at a training facility in Bathgate. We have now reached a stage gate review for the project to determine how best to progress.

3.2 | NIA SPEN0007 SUSCABLE 2

SUSCABLE 2 is the second phase of a project for the development of a new design of higher operating temperature, higher electrical stress power cable with respect to existing crosslinked polyethylene (XLPE) power cables. The objective of SUSCABLE 1 was to develop new power cable material technologies with reduced whole-life environmental impact, increased power system efficiency with enhanced sustainability (increased peak-load thermal tolerance and reduced cable manufacturing energy intensity) and increased security of supply in urban and environmentally sensitive areas. The outcome of SUSCABLE 1 was new polymer blends with high thermal stability materials with enhanced electrical performance, reduced production costs and improved whole life environmental performance.

The project sought to deliver a 35kV cable based on one group of the new materials based on polypropylene blends. The project also put in place the design and materials performance required for a 400kVAC cable based on the experience built up in making the MV cable.

First generation PVC insulation restricted cable ratings to 60 - 70°C, subsequent cross linked polyethylene (XLPE) prevented the plastic melting offered a continuous rating at 90°C while the new thermo plastics under consideration offer the prospect of an operating range of 120°C to 150°C. This increased operating head room will lead to improved cable thermal performance. The new materials also support higher electrical breakdown strength and lower electrical conductivity and do not require crosslinking reducing chemical contamination of the insulation system.

The objectives of the project were as follows:

- Design, develop and test a MV polypropylene (PP) blend cable, preferably 35kV, utilising existing cable accessory technologies that are compatible (or readily made compatible) with up to 150°C conductor emergency rating and 120°C continuous operating temperature
- Refine the PP blend materials to achieve the MV cable design, processing and cable production processes. The development efforts will also be used to specify material enhancements for EHV cable applications up to 400kV.
- Undertake cable manufacturing and testing with structured development to generate experience that will be of value in 400kV design, manufacture and testing.

- Undertake MV cable deployment and operational studies to define the best operating mode and value proposition for Network operators and other MV cable users including economics of deployment with incorporation of risk factors and environmental benefits assessment.
- Review material thermal properties, cable thermal performance and cable ratings to meet current international standards and develop an action plan to address any identified performance gaps

1. Morphology

Specific polymer morphology was targetted:

- Target morphology is a semicrystalline polymer with crystal domains including spherulites with merged boundaries as shown in Figure 1A in contrast to well defined boundaries that are electrically weak Figure 1B.
- Polymer blends with no evidence of phase separation

Evidence of more prominent spherulite boundaries with charging evidenced in the scanning electron microscope indicates a poor boundary condition which will have low electric strength. Phase separation and distinct spherulitic boundaries are an early indication of samples that will show poor electrical performance

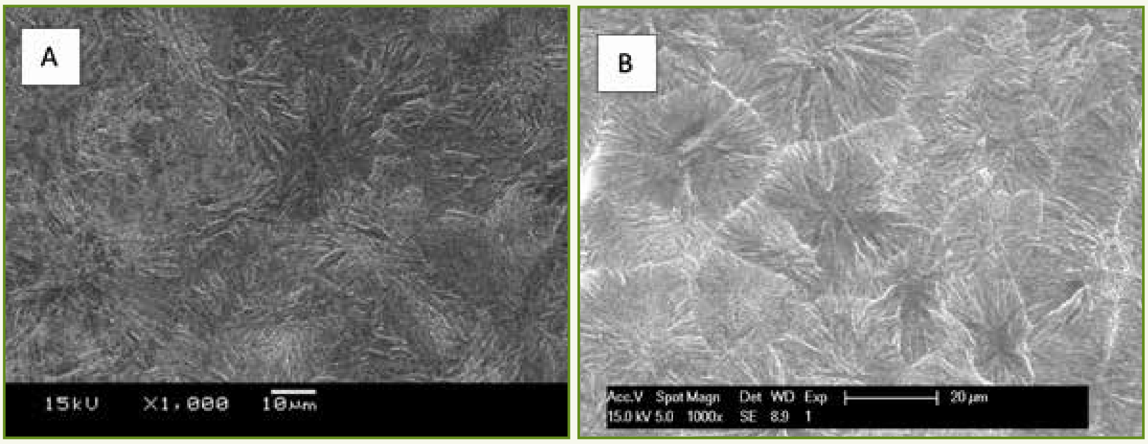


Figure 1

Electron micrographs showing A. a good blend, with no defined boarders between spherulites and no evidence of phase separation, B. a poor blend with sharp boundaries between spherulites and evidence of charging (brighter patches)

2. Performance of blends

The blends must perform electrically and mechanically to be used in both MV and HV power cables cables and a range of performance can be obtained dependent on the precise formulation used as shown in Figure 2 which also shows the performance for XLPE relative to the new blends.

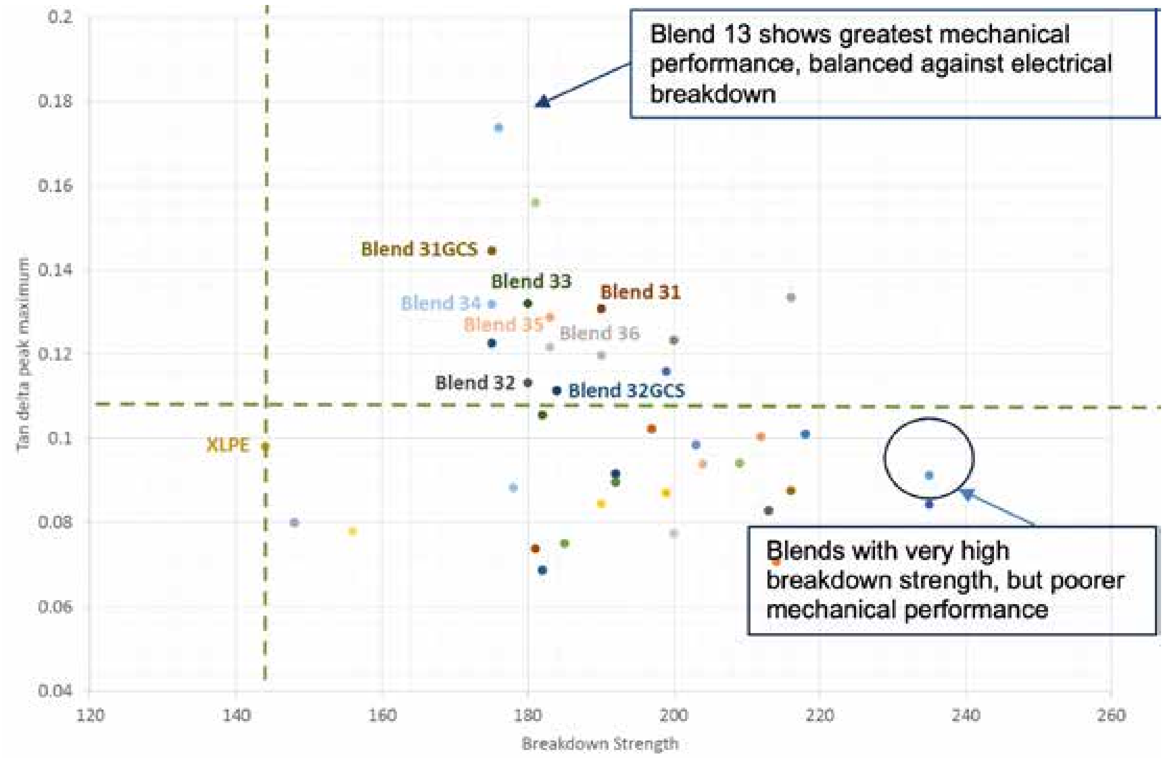


Figure 2 *Plot of breakdown strength vs tan delta peak maximum for all blends and XLPE. Dashed lines show the minimum position for both parameters, as achieved by XLPE. Candidate blends for upscaling selected from those towards the top right of the figure.*

3. Cable Manufacture and Performance

Both collaborating cable companies produced 20kV MVAC cables and one produced two prototypes following the need to refine the formulation to improve processability. Figure 3 illustrates the original PP-blend pellets and the resultant extruded cable.

Figure 3
Picture showing the pelletised blend granules which are translucent with the corresponding extruded MV cable. The aluminium conductor has an adjacent black inner semiconducting screen and there is an outer screen bounding the insulation layer – this layer appears dark grey because the cross section acts as a black reflector.

4. Cable ratings

Cable rating calculations for different conductor temperatures, for cables laid in free space were undertaken. Calculations were based on temperature dependent thermal conductivity data that was measured for the blends. The results suggest that at conductor temperatures of 140°C (cable rating 564A at 100% load), the sheath temperature will approach 100°C. This may require a change in sheath materials from high density polyethylene to an appropriate higher operating temperature material that can exhibit comparable mechanical performance to HDPE – this could be a PP-blend.

3.2.1 | NIA SPEN0007 Project Progress

The project began in June 2014 was completed in December 2018. In this period candidate PP-blend formulations were identified and extensively measured and both cable maker partners succeeding in making the first MV cables from the new bi-polymer and tri-polymer and eventually ter-polymer blends which were successfully formulated using materials sourced from multiple suppliers globally. The mapping of the new blends performance electrically, mechanically and thermally enabled the best candidates to be selected and volume scaled to tonnage level in advance of processing trials and cable manufacture by the cable manufacturers. New semiconductive screen compounds were also produced which have excellent compatibility with the new insulation materials.

Cable manufacturing revealed that while cable making was possible with the new materials, the melt flow behaviour could not support commercial high volume cable manufacture due to feed rate constraints affected by melt phase viscosity limitations. Further modifications were made to the blend formulations in Figure 2 to overcome this constraint and five new quaternary blends were produced and on evaluation a number of these satisfied the melt viscosity requirements and one was selected for volume upscaling to enable a second prototype cable to be produced and tested. This new cable was due to be manufactured and tested in 2018 by one of the two cable companies and unfortunately that company was acquired by a large global cable manufacturer and the cable was not produced before the project concluded

The cable extrusion trials started in October 2016 and were continued with the new quaternary blends into 2018 with associated assessment of short term performance before longer term testing begins. An example of the first MV cable produced to meet a common European standard design is shown in Figure 3 along with the polymer blend material used to produce it which was produced at 1 to 2 tonne level. The MV cable has satisfied the short term tests undertaken to date but it is planned that the long term tests will be undertaken on cable produced from the selected quaternary blend that will more closely match the materials will satisfy commercial production rates. The triple head extrusion equipment used to produce one of the two cables manufactured is shown in Figure 4.

Figure 4
Picture showing the triple head extruder used in General Cable Silec's cable manufacturing of the MV Suscable core. The cable core then passes through a water bath cooling zone 80m in length with no crosslinking stage.

Thermal modelling of underground deployed cable showed the need for higher operating temperature cable sheaths and materials have been selected to meet this requirement. This modelling was extended to cover HVAC as well as MVAC cables and both are considered to be manufacturable. Work was completed on the deployment options for both MV and HV cable designs Delays in obtaining the materials from suppliers created some knock-on delays to later tasks including extrusion trialling and cable making but the project plan was reset to accommodate this.

Extensive evaluation of the materials electrically and dielectrically including DC conduction and space charge measurements for HVAC and HVDC applications show that the materials are very well suited for both HV AC and DC application.

However, despite extension of the project timescales to enable the second prototype cable to be produced and put into longer term testing the failure to produce this cable is due to cable company acquisition which brought the project to an end.

In June 2018 a new patent application was filed detailing multi-component polymer blends for power cable applications and an IP management agreement was produced for the inventing parties to agree – this is ongoing at the time of completing the project. Despite this a number of non-participating cable companies have expressed an interest in manufacturing both a MVAC and an HVAC / HVDC cables based on Suscable 2 materials.

3.3 | NIA SPEN0008 Environmentally Acceptable Wood Pole Pre-treatment Alternatives to Creosote (APPEAL)

Project APPEAL was registered in March 2016; it is a collaborative project between SP Energy Networks, ENW, NPG and SSE and managed by the Energy Innovation Centre (EIC). This project aims to assess the performance of environmentally friendly alternatives to creosote for wood pole preservation. It is expected that the outcome of this project will influence UK DNO policies for the replacement of wooden poles.

The project consists of three stages with individual objectives:

Stage 1 – **Literature Review:** This stage will provide a comprehensive review of candidate replacements for creosote, enabling the DNO partners to select the solutions to take forward for testing.

Stage 2 - **Accelerated Testing:** This stage involves the creation of a 'fungal cellar facility' to provide a test environment to simulate >20 years of exposure to the elements for wood pole samples. This test bed will then be utilised to test several creosote alternatives side by side as well as wood pole samples treated with creosote.

Stage 3 - **Final Report:** This stage looks to collate and formally report on the key findings on the previous two stages and make recommendations based on the results obtained.

3.3.1 | NIA SPEN0008 Project Progress

The first uplift report was circulated that shows the visual/statistical analyses of the first set of timber stakes recovered from the Project APPEAL trial. The first set of stakes (128 out of a total 512) was recovered after 12 months exposure to the conditions of the trial. The trial is planned to proceed for a total of 48 months (Oct. 2017 – Oct. 2021) and allow 4 sets of stake recoveries.

The first stake samples recovered from the accelerated decay chamber were visually examined for any obvious decay before being processed prior to drying and being subjected to breaking tests to assess the impact of any decay on Modulus of Rupture (MOR). The determination of MOR was undertaken via a modification of the standard static bending test for small clear specimens of timber (BS 373 (1957)). Identically treated stakes that had been stored in a dry environment, and therefore not subjected to any decay processes, were included in these tests to give baseline MOR values for each sample type.

After the breaking tests were completed, untreated control stakes that had been encapsulated in the copper lined CAPTURA sleeve type were chemically tested to identify any copper migration to the untreated timber surface. After completion of all tests, all stake samples were treated as hazardous waste and disposed of appropriately.

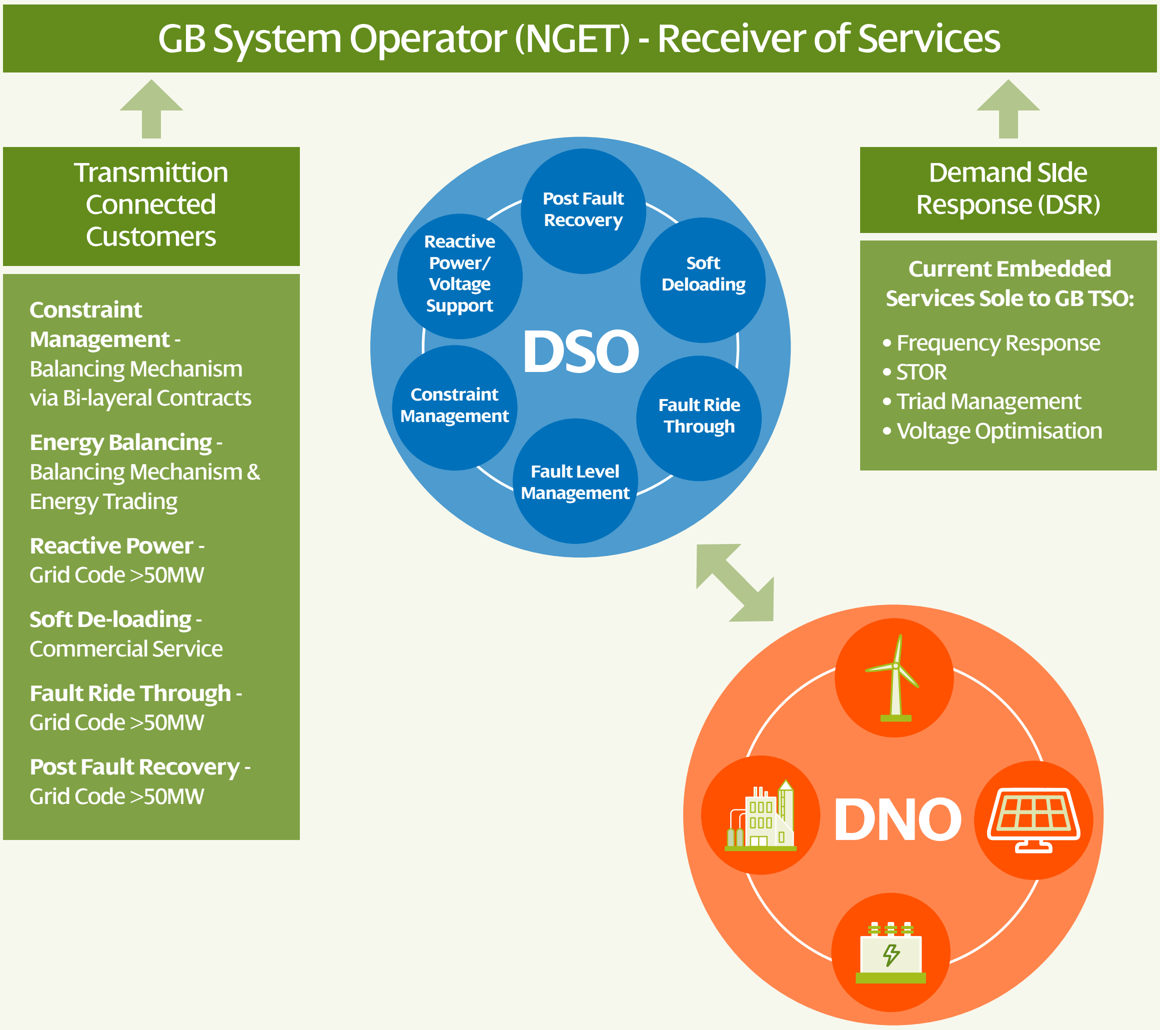
Wood Poles With Preservative Creosote

3.4 | NIA SPEN0010 EVOLUTION

It is acknowledged that our energy sector is transforming fast. With a strong energy policy focused to meet tight environmental objectives and reduce carbon emissions, the penetration of distributed generation is constantly increasing. New players are emerging in the electricity landscape: prosumers (producer/consumer), aggregators (who provide generation to National Grid) and distributed storage providers are examples of new participants that are starting to interact and use the networks in a more complex manner.

The role of the System Operator is to balance supply and demand as cost effectively as possible. Historically, this active role has been confined to National Grid; working with predictable demand levels and substantial large scale generation supplies such as nuclear and coal-fired power stations. The output from low-carbon technologies is far less predictable and the traditional DNO model means that SPEN cannot take a fully active role in balancing supply and demand. In recent years there has been significant discussion across the electricity industry globally about the development of a new entity known as a Distribution System Operator (DSO). The DSO will adopt the responsibility of local management of the network, bridging the gap between the current system operator and customers connected to the distribution network.

This transition to a DSO model is a major change coming to all DNOs and will only be made possible through the coordination of the UK electricity energy sector.



3.4.1 | NIA SPEN0010 Project Progress

During the regulatory year of 2018/19, Evolution played a critical role in fulfilling the two principle purposes of NIA, i.e.

- Facilitate and uplift the TRL of small scale innovation ideas, and
- Support the potential NIC proposals.

Our FUSION proposal received unconditional approval in October, 2018 under NIC. This is a good example of how NIA/NIC can supplement each other in de-risking the innovation. Evolution not only fostered, developed and provided the blueprint for the FUSION proposal prior to the 2017 NIC submission, it continued the safeguarding role during the transition period between December, 2017 and October, 2018 by enabling more studies and stakeholders engagement (including fellow DNO collaborations with EFFS (WPD) and Transition (SSEN), and Open Networks) to satisfy the conditions listed by the Regulator in December 2017.

3.5 | NIA SPEN0012 SINE Post

DNO business practices can, at present, require experts to undertake several manual activities which are time consuming and labour intensive.

Focusing on power quality monitoring, the scope of the project is to develop and demonstrate an expert system "SINE Post" for the more efficient location of overhead line faults, improved assessment of circuit breaker maintenance requirements and the improved assessment of power system harmonics, before and after DG/LCTs have connected to the distribution network. This system will overcome current business challenges due to limited numbers of experts and the labour-intensive time needed to carry out some power quality monitoring-related tasks at present.

SINE Post will demonstrate the automation of previously time consuming and labour-intensive tasks often undertaken by valuable experts. This will give design engineers, asset managers, control room staff and field staff within SPEN timely access to processed information, allowing them to make informed decisions more quickly. Ultimately, this will deliver performance benefits to SPEN's business (e.g. efficient data processing from multiple systems at scale) and its customers (responding to 11kV faults more quickly, enabling DG / LCT customers to connect to the network more quickly and cheaply).

SINE Post has the following objectives:

- Development and demonstration of an IT and hardware architecture (infrastructure and interfaces) that will allow data to be gathered from remote sites, processed efficiently and used, together with data from existing systems (such as GIS), to unlock business planning and operational efficiencies;
- Use data sets from multiple sources corroboratively to support planning and operational decisions;
- Trial various communications methods to assess their reliability, compliance and performance as enablers for gathering data into the expert system;
- Understand and document the effectiveness of developing and demonstrating SINE Post for 11kV fault location, CB maintenance decisions and harmonic analysis.

3.5.1 | NIA SPEN0012 Project Progress

The project has now moved to implementation phase. SP Energy Networks Smart Data Integration Fabric (SDIF) contract is in the final stages of placement and a developer has been selected. A key milestone in the project is the development of the field gateway (Field Online) that allows external data connectivity. This has been trialled successfully and is moving to production.

There has been significant interest in the project and a series of use cases for implementation are under preparation.

It is anticipated that the first use case will be delivered this year.

3.6 | NIA SPEN0013 Interoperable LV Automation

Meshed LV networks are common place within SP Energy Networks (predominantly SP MANWEB), whilst these network provide greater utilisation of network assets and a more secure supply for customers they do have some associated issues:

Meshed LV networks require greater discipline and control to ensure the running arrangements are kept within the design and operational parameters

They typically operate at higher fault level than radial networks due to interconnection of multiple secondary transformers

HV automation schemes are reliant on the control of LV interconnections, the present approach to achieve this is through potentially costly network reconfigurations and subsequent control measures to ensure that the new running arrangements are maintained

LV Automation has the potential to provide a solution for the long term management of meshed networks, however, in order to do so there are a number of key requirements that need to be developed.

This project aims to develop and trial a prototype LV automation device for deployment on meshed networks. **The device will be designed to:**

- Autonomously and remotely un-mesh and re-mesh the network
- Provide customer service improvements through fault re-closing (designed for higher network fault level)
- Interoperate with HV automation schemes
- Provide real time visibility of the LV network configuration
- Fit all types of LV boards
- Keep deployment costs to a minimum with a targeted price per LV circuit board way of <£2,000

This is Stage 1 of an intended two stage NIA project, the first stage is to design, develop and trial a prototype LV automation solution. Stage 1 of the project only considers a limited field trial of 3 units. Should it be a success then Stage 2 will look to deploy the units on a larger scale.

3.6.1 | NIA SPEN0013 Project Progress

As of March 2019 Stage 1 of this project is complete, with a close down report to follow. The outputs of the project have been discussed internally within SPEN and with fellow UK DNOs, with a decision to progress to a Stage 2 pilot project expected to be made during 2019/20.

The decision to take this further will be based on

- Alignment with existing vendor contracts
- Suitability for networks operating at a higher than average fault level
- Appetite of the vendor to take the product to market

3.7 | NIA SPEN0014 Active Fault Level Management (AFLM)

The management of fault levels can be challenging and problematic. Fault level management is particularly challenging given the safety criticality implications as they can result in catastrophic equipment failure and represent a serious personnel and public safety risk. While conventional practice has been to establish system fault level design limits in line with accompanying plant specification, novel approaches that enable full utilisation of the existing headroom must be developed to facilitate a timely decarbonisation of the economy.

Due to unprecedented growth in distributed generation fault level headroom constraints are becoming increasingly challenging often requiring major reinforcement schemes. Fault levels can act as a barrier to the connection of renewable generation and have become a decisive factor in determining the financial viability of distributed generation connections.

There are distinct approaches to Fault Level Management, with variation in the means of management and operational characteristics. Each of the following approaches have a role in the proposed AFLM Toolbox:

Model: where power system modelling is used to support Fault Level Management, either as:

- An operational means of FLM;
- An input to FLM; or
- for FLM.

Monitor: where fault-level measurement methods either:

- Enable the verification of network modelling methods and assumptions; or
- Facilitate the online measurement of fault level for operational management purposes.

Mitigate: where various techniques for fault current limitation are taken in real-time through physical fault current limitation or via protection actions.

Manage: where control systems provide preventative avoidance of fault level infeed exceedance through control of demand and renewable generation to reduce fault level and create network headroom.

The project will aim to develop an AFLM Toolbox based upon the Manage approach, using elements of Model and Monitor, with opportunities to work in co-ordination with Mitigate techniques.

3.7.1 | NIA SPEN0014 Project Progress

The AFLM project is tasked with demonstrating an innovative solution to Fault Level Management by automatically controlling network equipment and customers in real time. This constrains network fault levels within equipment limits and will enable acceleration of flexible non-firm connections into fault level constrained areas of network. This project is at proof-of-concept, prior to a pilot stage.

Phase 1 of the project considered a toolbox of solutions for the development of active fault level management systems, including modelling, measurement, mitigation and management techniques. A range of networks were assessed with the toolbox of techniques, and cost benefit analyses were undertaken on the concept designs.

Phase 2 of the project has progressed a solution design with prototyping and laboratory based testing. This has refined the AFLM concept and use cases, including development of the AFLM specification, requirements, design principles, and high level commercial principles of access. Development of a prototype AFLM solution has been progressed. This prototype has undergone laboratory based testing.

An area of network (Warrington) has been selected to refine the solution. Long run tests, network and system studies and scalability assessments are presently being undertaken to provide a foundation for a production grade AFLM network trial in Phase 3 of the project.

3.8 | NIA SPEN0015 Real Time Fault Level Monitoring (RTFLM) – Stage 1

This project aims to develop and trial a novel Real Time Fault Level Monitoring (RTFLM) solution. The solution being developed to:

- Provide reliable and repeatable fault level measurements on-demand
- Be applied to LV --> 33kV networks
- Generate results through the application of an artificial LV disturbance to a transformer coupled to the busbar the fault level is required for
- Understand the impact the artificial disturbance has on the network
- Identify the optimum solution and potential business case following site trials
- One of the key benefits of this innovation is that the solution can be used to obtain Fault Level results continuously, in addition to "on demand".

3.8.1 | NIA SPEN0015 Project Progress

Two RTFLMs were delivered in October 2018, one installed at Station View Primary substation in Chester to obtain Fault Level on the interconnected 11kV ring serving the city centre. The RTFLM was connected to the network via high current LV connections to the LV bus bars serving the immediate locality and secondary wiring connections from the 11kV panel board Voltage Transformer (VT). The second RTFLM was taken to a substation within one of SPENs depots, with the intention this location would be used to assess the RTFLMs reliability over a prolonged period of time (unsupervised). Due to unforeseen complexities with the redevelopment of the site (not the RTFLM) these tests have not been undertaken and have now been superseded by the Station View trial.

At Station View the RTFLM has been operated supervised on several occasions for several hours at a time. During these tests the system has been predominantly operated with synthetic disturbances sufficient to generate reliable and consistent 11kV result, but it has also been run for short durations with the synthetic disturbances at 80% of their maximum power draw. These tests were undertaken to observe the flicker level that would be encountered if the RTFLM was used to generate 33kV results.

Early trials at Station View observed self-interference on the very high sensitivity voltage signals due to high (self-generated) currents in internal and external bus-bars. Subsequent modifications to the internal magnetic shielding and the inclusion of self-interference assessment mechanism mitigated this issue and allows for the future calibrating out of potential effects of long VT signal runs when operating at 33kV.

In trying to meet a number of conflicting requirements the RTFLM hardware design has proved robust for transport but overly complicated for maintenance. Some design improvements have been identified for future units.

Results on the Chester Ring were initially good for 90ms RMS Fault Level but poor for 10ms Peak. Voltage response to the disturbances on the interconnected network was found to be more complex than originally assumed, and the relatively selective processing was expanded to accommodate the extended network response.

With revised processing good results for both 10ms Peak and 90ms RMS Fault Level became available and the deliberate change in group running arrangements (5 transformers to 4 transformers) could be clearly seen in recorded results.

Connection of the second unit to develop reliability growth is now highly desirable.

3.9 | NIA SPEN0019 Operational Assessment of Composite Poles

Distribution Network Operators (DNOs) throughout the UK use the preservative Creosote to protect the wooden poles that are used for overhead line construction at all voltages from LV through to 132kV with over 25,000 new poles erected each year. Creosote is a harmful chemical. If it comes in to contact with the skin it can cause burns and it has carcinogenic properties. The use of Creosote comes under review every 5 years and there is already a ban in certain circumstances. Industry experts expect that the use of Creosote shall be allowed until 2023 but before this ban is enforced DNOs have to begin investigating alternatives and have a plan already in place if the ban goes ahead.

This project aims to investigate the feasibility of an alternative to wood poles. It will examine the use of composite poles for a network application involving both 11kV and LV applications, ensuring that best practice can be adopted whilst trialling and developing the different innovative working, design and climbing techniques required.

The project will have 3 stages:

- **Stage 1**: Offline assessment of materials and development of safe climbing methods
- **Stage 2**: Install poles (11kV and LV) on the SPEN Network
- **Stage 3**: Assessment/Audit of the results

3.9.1 | NIA SP Energy Networks0019 Project Progress

Stage 2

The trial was postponed due to a specific concern about the staying arrangement and the termination at the top of the pole to secure the stay. It was declared by the supplier that the "pole top wrap" for terminating the stay on a typical 11kV configuration could cause a crushing of the hollow composite pole. This is not the case with existing wood poles that are solid and not hollow.

The trial was therefore reduced in scope on the day of the installation but there was a second concern raised about the drilling accuracy and the steel inserts that must be used with the composite pole when inserting bolts through the pole. A satisfactory accuracy could not be achieved using conventional drilling practices and the installation was suspended.

Stage 3

There were a number of conclusions and learning outcomes from the trial. The two main areas that were identified were;

1. The existing stay terminations are not compatible with composite poles
2. The existing drilling practices are not compatible with composite poles.

The first point has been declared to the ENA Overhead Line Assessment Panel and they have agreed to commission a UK wide, ENA led, project to fully assess all the mechanical stresses and forces applied to overhead line structures and develop a construction specification for composite poles.

The second point has been assessed internally within SP Energy Networks and clear guidance will be issued in advance of any future installation of composite poles that states the drilling technique and equipment required. This second point is dependent on the conclusion of the ENA led project to fully understand the final agreed industry principles when constructing overhead lines on composite poles.

There has been no further work carried out on this NIA project due to the issues reported above in last year's report.

3.10 | NIA SP Energy Networks0020 Instrument for the identification of Live and Not Live HV and LV cables

It is vital when performing maintenance on cables that live cables close by are not interfered with, thus the need for a technology to detect them.

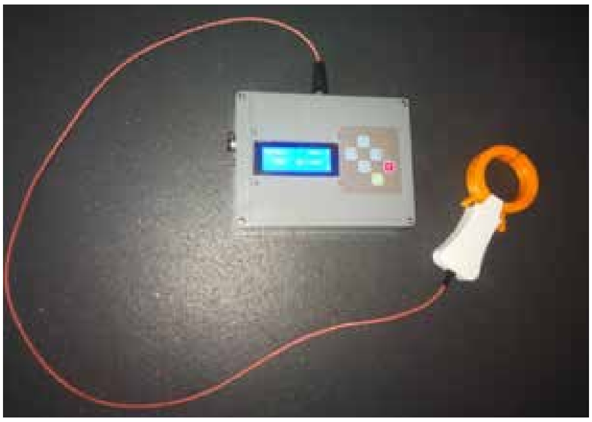
When carrying out maintenance on distribution cables, especially underground, there can be a large number of cables within a small region. With this project the safety of the workforce of the DNO should be drastically improved. Whilst those working in situations where live and not live cables are fully trained professionals, the underlying risk of working on the wrong cable is always present, hence the need for a new way of approaching these situations. It should be known at this time that this project will not eradicate the need and/or use of the tried and tested approach of cable spiking.

This project aims to utilize technologies which only in recent years have become available for use in environments such as those faced by the workforce in situations like this. In its development phase this project will trial a number of solutions, including but not limited to magnetic coupling using differential hall sensors and inductive coupling, and the measurement of the radio-frequency (RF) leakage levels.

At this time the prototype will be thoroughly tested to ensure that it is fit for purpose and able to meet the objectives of this project – to detect live or not live cable and thus determine whether or not the cable is running at HV or LV.

3.10.1 | NIA SPEN0020 Project Progress

With this project, we have continued to develop the algorithms driving the decisions of the identification device. This process has taken significantly longer than anticipated initially, due to the large amount of data which is required to adequately train the algorithms. This training requires large amount of data from all the main cable types – such as XLPE and PILC - for both 11kV and LV circuits. This must also include both Live and Not Live states, and with a variety of loads. These must also be carried out under field conditions to allow a wide range of cable conditions to be measured, allowing this to be factored into the algorithms.



An additional development is the development of a 33kV measuring head. This will allow the Live/Not Live state of 33kV cables to be assessed. This will require a similar process of training and data gathering to be carried out, but this process will be simpler due to the simpler nature of 33kV measurements; as 33kV cables are generally notably larger than 11kV cables, there is a much lower likelihood of these being mistaken for each other. In addition, even if these were conflated, live work is not carried out on either of these cable types.

3.11 | NIA SPEN0022 Weather Normalised Demand Analytics (WANDA)

Forecasts of electrical load are used by network operators to determine the volume, type and location of investments.

Load forecasts are based upon the power flows through substations and are adjusted for the embedded generation on the network. Currently, there is no regular adjustment made for the effect of weather upon demand in the local area served by each individual substation. This means that it is extremely difficult to separate out the effect of weather upon demand and the effect of other customer behaviour upon demand (e.g. energy efficiency measures, increases in the number of electric cars being charged, the closure of industrial premises, etc.)

This results in additional uncertainty when making investment decisions leading to under or over investment in individual network areas and therefore suboptimal outcomes for customers. Additionally, it leads to inconsistent regulatory reporting. An example would be a mild winter causing demand to drop and the load index metrics becoming artificially low for that year.

Weather patterns and customer behaviour are two key drivers in electricity demand. By undertaking this project, it will be possible to better understand how these have changed historically within a given licence area and will provide invaluable insights into future demand scenarios. It will also highlight their relative significance and current trends. This will allow asset managers to develop better and more targeted investment strategies. Furthermore, accurate demand models will provide more realistic data for investment risk and cost-benefit analysis and subsequently lead to better returns for customers.

A comprehensive understanding of the effect of weather upon demand is a key enabler for the transition to a DSO model.

The objectives of the collaboration are:

- Analyse historical demand data and calibration of normalisation models.
- Evaluation of the weather normalised demand model.
- Completion of uncertainty analysis against historical data.
- Analysis of demand trends – weather related vs customer behaviour.
- Creation of summary report and data files.
- Delivery of final presentation or paper at industry event/conference.

The study shall include all SPD primary substations across the central belt of Scotland covering both the west and east coast. The wide geographical area is to provide a broad range of input conditions for the machine learning algorithms to ensure applicability across the GB area.

The project shall be a desktop exercise using historic SCADA, generation and discretised weather data. Where available, the project shall use 10 years of hourly data. Each primary substation will be allocated a geographic polygon which represents the service area for the substation.

This data will be used to build and evaluate models which disaggregate electrical demand into load driven by weather conditions and load driven by other customer behaviour. Analysis of the underlying trends will be undertaken.

The output from the project will then be used in network planning and the completion of regulatory reports.

- An advanced numerical weather prediction model will be used to simulate hourly weather conditions.
- The location-specific weather data will be weighted by population density and aggregated across the areas served by each of SP Energy Network's primary substations.
- This will be used to calibrate a weather normalised demand model.
- An embedded generation module will be implemented within the demand function in order to reduce generation-related uncertainties.
- The demand model will be trained against recorded data for the period of analysis using advanced machine learning algorithms.
- A comparison of the demand model results vs historical data will provide a level of confidence in the predictions.
- The results will then be used to infer weather vs customer-behaviour trends over the period of analysis and predict future demand scenarios.

3.11.1 | NIA SPEN0022 Project Progress

The project is now complete.

Learnings from the intermediate stages of the project have been presented at:

- 4th Asset Management Forum (Amsterdam, December 2017)
- CIRED 2018 (Ljubljana, June 2018)
- Future of Utilities: Data Analytics and IoT (London, July 2018)
- LCNI 2018 (Telford, October 2018)

3.12 | NIA SPEN0023 Connected Worker Phase 1 - Field Data Automated Capture

The acquisition of field data to support and impact on decision making is imperative in this industry and that is recognised. However, due to the reliance on field staff to do this job, this generally comes with the consequences of accuracy and timeliness, as it is not something with which they are trained to do.

Through this project the business aims to find a new way to improve the quality, accuracy and timelessness of data collected by the field staff, whilst also reducing the burden on those staff simultaneously. As is the case with many innovation projects, the focus will be placed upon new technologies and applications of existing technology in order to improve data acquisition. Although at present field operatives enter some data via electronic devices, it is not yet widespread and in certain cases much of the manually collected data requires specific action by the field staff, especially when dealing with linear assets such as cables and overhead lines.

However, there are technologies which are widely available – for example GPS, geo-fencing and barcoding – which could be used to improve the quality of data collected by our field staff in a more direct manner. For this project specifically, the data collected will relate to work on-site regarding underground assets that would be consumed and utilised by the Work Management System (SAP) or the Geospatial Management System (ERSI) to include both installed and decommissioned assets.

3.12.1 | NIA SPEN0023 Project Progress

Use cases for this project are being developed.

3.13 | NIA SPEN0024 Endbox G38 Level Detection Phase 2

Upon proving that the technology for project was in fact working successfully, and in order to ensure that this is suitable for use on the network, the testing boundaries must be increased, and as such Phase 2 aims to extend the trial of this technology across a wider range of voltages, and types and sizes of G38 apparatus across the network.

Upon the extension of this trial further across the network, this measurement technique will enabled to be validated, which is a vital step in preparation for integration of Business as Usual. This trial will involve testing this approach on a representative sample of switchgear across both licence areas, SP Distribution (SPD) and SP Manweb (SPM). Furthermore, within this trial, the methodology for the determination and classification of the status of endboxes will be developed. This should enable the objective of determining a method to classify the criticality of the endboxes, depending on the G38 levels within and whether the exposed conductors are fully covered and insulated.

3.12.1 | NIA SPEN0024 Project Progress

We have been carrying out a series of tests across our substations to use ultrasound monitoring to determine the level of G38 in the endboxes. This is an ongoing process, but this has raised a number of instances where the G38 level was close to being below a safe level, allowing for remedial action to be taken. These tests will be continuing across our districts, leading to work on how this detection can be taken through to being a business as usual monitoring technique.

One issue which has arisen through this project is the difficulty in identifying which pieces of equipment are filled with G38. This is due to the large number of assets across a wide geographic area, with few co-ordinated records. While it may be possible to correlate the installation dates and types of switchgear to determine where G38 assets will be present, this is difficult due to asset replacements or partial replacements. This has meant that local knowledge is relied upon, although this can mean that some assets are missed and are not monitored.

3.14 | NIA SPEN0025 Low Cost Fault Current Measurement of Wooden Poles

On the SPD and SPM networks, wooden poles are frequently used as the main infrastructure for power distribution. With this project, SP Energy Networks aim to solve two main problems which arise due to their usage.

The poles themselves have failure modes, meaning that under certain conditions they can become live – these conditions include rain or high levels of humidity. This creates a hazard to the workforce and to the public, which is not easy to find. A prime example of this is when the ceramic insulator fails, and the pole becomes the prime path to ground for the current when the moisture levels increase, and become a shock risk.

Another problem with the usage of wooden poles on the distribution network is that the insulators can become damaged over time: this can include cracks when the insulator is ceramic and electrical tracking paths in polymeric insulators. Furthermore, certain weather conditions also have the ability to damage the insulation which can result in flash overs, thus causing the protection systems to operate. These faults can be particularly hard to find as the insulation failure mechanism is weather dependent, hence finding a method to identify fault current passage through the poles is very useful as it would enable the area of inspection to be reduced.

This project will trial a card containing a low cost electrochemical cell device that is able to identify the fault current passage through the pole. This method takes advantage of the fact that impedance of the electrochemical cell is of a much smaller value that the section of wooden pole. As a result, the current will flow through the cell - as current takes the path of least resistance – causing a visible change in the cell, thus providing a semi-quantitative measure of the total current flow.

3.14.1 | NIA SPEN0025 Project Progress

Stage 1 (complete): Explored the device concept using a small electrochemical cell that integrates low-level leakage current and provides a visual 'fault' indication when the total current that has passed through the cell exceeds 24 mA.hr. This was successfully demonstrated at the end of Stage 1 meeting.

Stage 2 (complete): A looks-like works-like device was designed, and a number fabricated for testing and optimisation. A device that indicates a 'fault' should the current through it rise above a set threshold (1mA) for more than 24-48 hours in total has been demonstrated through laboratory experiments. Environmental tests have also been carried out to ensure the robustness of the selected chemistry.

Stage 3 (in progress): The device design has been refined to allow for low volume manufacture of 200 units. The design is reasonably representative of the final production device and suitable for field trials planned to start in 2019. The devices will be used by DNOs to test their suitability to detect faults through a combination of controlled tests and installation onto wooden power poles in the field.

3.15 | NIA SPEN0026 Linkbox Monitoring using Narrow Band IoT

Link boxes are an integral part of the electricity network, providing network protection and isolation in fault scenarios. They help to restore supply to customers quickly, and enable increased flexibility in heavily loaded areas of the LV network.

At present visual inspectors inspect these link boxes every 3 years to ensure the lids are accessible, secure and level. Furthermore, intrusive inspections take place at a range of frequencies every 1 to 3 years depending upon criticality. These inspections, however, are labour intensive as the currently rely on manual techniques, therefore the need for a new way of testing has arisen.

This project will aim to investigate the feasibility of making use of Narrow Band (NB) Internet of Things (IoT) communications and low cost sensors to automatically gather good quality data easily and cheaply from the link boxes. This new technology means that it is now possible to deploy monitoring and control solutions in areas where it was not previously possible due to insufficient cellular coverage, insufficient battery technologies and an uneconomical cost.

3.15.1 | NIA SPEN0026 Project Progress

Trials of both the Vodafone and Conners linkbox monitoring devices have proven that their respective communications techniques do work, and would be suitable for the link box monitoring application. In addition, the use of temperature monitoring has helped ensure that potential linkbox failures have been detected, allowing remedial action to be taken.

At this stage, we are looking to determine how we can transition this technology to being a business as usual solution, taking into account the telecommunications requirements, and the requirements for data hosting and processing, and ensuring that the benefits of the project are fully identified and tracked.

3.16 | NIA SPEN0028 Transition to low voltage DC distribution networks – Phase 1

Deliverable 1

It is concluded that in order to realise the potential values of LVDC and enable wider uptake of LCTs, there is an urgent need to accelerate the development of new electrical distribution standards, wiring regulations and grid codes that fit well within the LVDC technology requirements.

Deliverable 2

Fault transient contribution from shunt capacitors of existing LV cables energised by DC is insignificant and can be neglected in comparison with fault transient contributions from the LVDC converters filter capacitors.

The studies have identified the transient period of the applied faults as the period of the converters smoothing capacitors discharge (few milliseconds <5ms). During this period, transient fault currents with peaks almost equal to 227kA are experienced in the faulted LVDC networks. It is true that such energy will be dissipated very fast, but such additional thermal energy presence has never been experienced in existing LV cables under AC faults.

The dissipated transient energy in LVDC Zone 1 with

< 750Vdc (1500Vdc pole-to-pole) is 4 times higher than in LVDC Zone 2 with 375Vdc (750Vdc pole-to-pole) supply.

Using existing LVAC cables to form LVDC distribution networks, where high penetration of low carbon technologies exist, it must be recognised that additional energy will be dissipated during a DC fault event in a short period, potential causing "thermal shock" to existing cables.

Cable sections that are closer to converters (e.g. close to the main DC bus or EV chargers) are more likely to experience higher "thermal shocks" and may therefore degrade earlier under long-term DC operation. Further experimental testing is required to quantify the impact of the thermal shocks on the lifetime of LV cables used for DC.

Implementation of fault tolerant converters such as modular multi-level converters (MMC) can significantly eliminate the generation of thermal shocks in LVDC cables during DC fault transient period. This is of course in addition to other control functionalities which MMC can offer to the network in comparison to two-level voltage source converter.

Deliverable 3

Under DC conditions the ageing mechanisms are different as there is a single energisation and no cycling at the power frequency. In terms of DC ageing, this either consists of long term ageing above the intended voltage which overstresses the insulation or the voltage ripple has been shown to lead to premature failure of insulation systems. The electric field distribution under DC conditions is governed by the electrical conductivity of the insulation and realistic tests must take account of this fact.

A survey of commercial test facilities was conducted however it is apparent that such facilities provide testing for cable manufacturers and their customers, but do not mention offering testing relevant to DC operation regimes of different zones. These facilities could be considered for initial sample health assessment (for electrical and mechanical parameter measurements).

3.16.1 | NIA SPEN0028 Project Progress

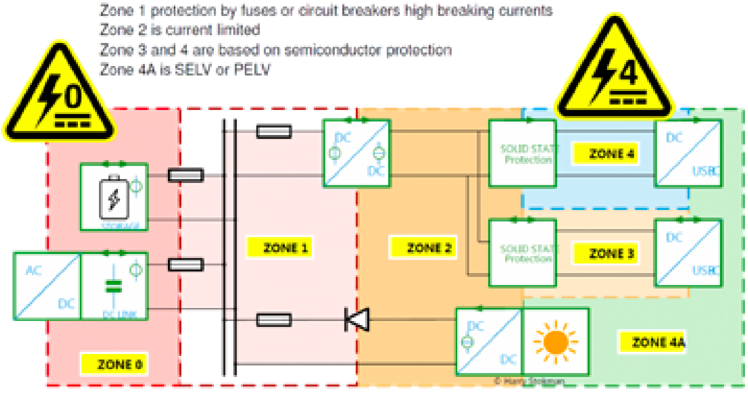
Phase 1 of this project has consisted of 3 deliverables, these have been completed and outlined below.

Deliverable 1: A review of developments in LVDC distribution networks for utility applications

Consisting of a review of the current practices in public LVDC distribution networks, outlining the key learning outcomes as reported by a number of trial projects that have been developed in Finland, Netherlands, South Korea, and China.

To address the complexity that emerges from embedding LVDC technologies in existing AC grids, this phase of research proposed a 'multi-architectural regime' approach. The approach classifies the embedded LVDC and the host AC distribution into the following four architectural zones.

- **Zone 1**: the highest LVDC voltage levels (i.e. 400Vdc to 750Vdc) exploiting power flow capacity potential in full. Zone 1 can act as a high power capacity corridor which enables longer power transmission distances and powering more loads in urban areas. It is also more suitable for replacing exiting ageing MVAC circuits in rural areas with long circuits and low sparsely loads.
- **Zone 2**: the highest DC voltage ranges that are set within DC safety limits as identified by the IEC 60479 (<400Vdc). Zone 2 can be an extension of Zone 1 or interfaced directly to exiting AC grid. It is also more appropriate example for urban applications when increased power capacity is not highly required and majority of loads are accessed by public.
- **Zone 3:** includes LVDC with the highest voltage ranges that have the same safety margins as in existing LV AC installations (<200Vdc). It is suitable for supplying most of the electric loads that can be supplied by today's LVAC distribution, and is more favourable for lower loads such as small buildings, street lightings, commercial offices, and etc.
- **Zone 4** :includes existing AC grid with well-known safety requirements and defined voltage level.



Safety zones	Source type	Protection type
DC-zone 0:	Unprotected sources with high short circuit currents (eg. batteries, synchronous machines, public distribution gris, and large PV systems)	Passive protection such as fuses and mechanical breakers are required
DC-zone 1:	Protected sources with high short circuit currents (e.g multiple protected sources from DC-zone 0)	Passive protection such as fuses and mechanical breakers can be used, and active protection devices are optional
DC-zone 2:	Protected sources with limited short circuit currents (e.g renewable sources <50A)	Current limited zone
DC-zone 3:	Electronic sources like PV or DC/DC converters or DC-zone 2 with limited short circuit currents	Electronic protection and RCD
DC-zone 4:	Unidirectional load with overcurrent. low SC currents	Electronic protection and RCD
DC-zone 4A:	Unidirectional loads, SELV or PELV	No protection is required

Safety zones/risk classes

A technical evaluation through simulation studies was undertaken for the fault transient response of an LVDC distribution network, and quantified prospective discharging fault let-through energy (FLTE) which can be discharged in the LVDC cables during the transient period of DC faults. Each zone was interfaced to the main AC grid through a two-level voltage converter with the LV cables modelled as detailed three-core cables and energised with DC. The simulation studies were conducted when the test networks were without EV chargers and when they had several distributed EV chargers (total load capacity 670kW).

Deliverable 3: Technical Specification for Testing of LV Cables at DC

This technical evaluation report considers the voltage requirements of zones 1, 2 & 3 and proposes appropriate tests and setups but additionally, the required setups to enact a fault on the cable under DC energisation was proposed.

3.17 | NIA SPEN0029 Secondary Telecommunications Phase 3 - Trial of Hybrid Telecoms

Transitioning from a DNO (Distribution Network Operator) to a DSO (Distribution System Operator) will require significantly increased real-time monitoring and control of remote electrical assets than is currently in place.

This will be of critical importance in order that the continued adoption of distributed renewable generation and electric vehicle utilization can be maximised without inadvertently destabilising the UK electricity grid or putting the security of supply at risk. The need for much improved monitoring and control in the future is well documented. There are six main criteria which must be satisfied and the current telecommunications solutions which are available to DNOs do not adequately do so. Furthermore, without a reliable and fit for purpose telecommunications network in place, it is not possible to capitalise on the possibilities that are presented by the 'Smart Grid', and this would also severely delay the DNO to DSO migration.

Previous work in this area (by SPEN, UKPN and WPD) has concluded that a single technology solution (which can cost effectively satisfy all of the technical and commercial criteria) is unlikely to be suitable. It is likely that a hybrid approach to the solution will be most cost effective and will 'future proof' the solution to the greatest extent possible. Similarly, arguments around the pros and cons of self-build vs third party solutions are not straightforward and the optimum is probably an intelligent combination of both.

3.17.1 | NIA SPEN0029 Project Progress

Progress has been slow due to difficulty obtaining spectrum in the UK for commercially available equipment. Some progress has been made on MNO public cloud offerings and narrowband radio, however a number of concerns exist with these around scalability, futureproofing and power autonomy.

Recently dialogue with the communications legislator indicates that they may be able to identify spectrum for trial purposes in an alternative band- feedback is expected in the third quarter of 2019.

3.18 | NIA SPEN0030 Zebedee Sectionaliser Device

When performing maintenance on the network it is vital that interruptions to supply to customers be kept to the absolute minimum.

The maintenance of sectionaliser smart links is a minor task which can have a major impact on supply for connected customers, particularly in rural areas. This device aims to reduce customer interruptions by providing a means to temporarily bypass the smart fuse which is undergoing a removal and replacement. This will be applied by using the same equipment as used to apply and remove smart links. It will consist of a conductor, surrounded by a spring, with a rigid, telescopic, insulated container and will have the relevant connectors to allow it to be attached using standard short or long stick apparatus.

3.18.1 | NIA SPEN0030 Project Progress

In the past year, we have made substantial progress with the Zebedee device. The Device is currently in its second prototype iteration; 20 of these devices are being manufactured to be trialled on the live network.

The device has undergone offline testing on sectionaliser equipment attached to standard wood poles. The device can be applied using standard fuse poles, but some training is required to ensure that the right connection can be made. The device's use has been proven on both types of sectionaliser equipment present on the SP Distribution and SP Manweb networks.

This device has also undergone laboratory testing at the PNDC to determine how it operates under maximum loading conditions (100 A for 2-3 hours) and under fault conditions. Under both scenarios, the device operated well, maintaining power flow with minimal impedance change in the former scenario, and being minimally damaged in the latter.

Zebedee Sectionaliser Device

3.19 | NIA SPEN0031 Radiometric Arc Fault Location RAFL 2

Transient faults on the overhead line distribution network can be difficult to locate and costly to repair and can have an adverse impact on customer service and quality of supply. Certain transient, intermittent faults are not easily detected through a line patrol, and can be onerous to narrow down using fault passage indicators on a network with numerous branches. When the circuit repeatedly trips, field staff manually reset and re-energise, but this does not address the root cause. These faults are frustrating to customers and staff and are time consuming and costly to locate.

This project builds on an earlier proof of concept project (NIA_SPEN005) which SPEN undertook to investigate the feasibility of a Radiometric Arc Fault Locator (RAFL) based on fixed hardware to detect transient faults. This project culminated in a field trial of the RAFL system which was permanently mounted to wooden poles supporting transformers on an 11 kV overhead line circuit.

Despite this circuit being chosen due to its historical poor performance, no faults were recorded during the trial period. Nevertheless, the trial demonstrated that the hardware was reliable and suited to the purpose of detecting impulsive radio frequency emissions from power system arcing.

The project will develop RAFL system hardware and software and expand on the NIA_SPEN005 project learning to develop a low cost, portable, battery powered version of the RAFL system field deployable unit that can be rapidly redeployed in service.

3.19.1 | NIA SPEN0031 Project Progress

Work commenced on the RALF2 project in July 2018. In the period to 31st March 2019, the following tasks have been successfully completed:

1.1 Liaison meetings with sponsoring utilities

1.2 Initial tests to investigate a) the distance over which arc-induced radio frequency transients can propagate and be adequately detected above the noise floor (range tests), and b) the differential timing accuracy of commercially available GPS units when operated over distances of several kms (timing tests).

1.3 Outline design of the RALF2 hardware unit.

The project team are working on the detailed hardware design, and the cloud server programming.

3.20 | NIA SPEN0033 CALISTA

CALISTA (Cable Asset Life by Integrating STAtistical failure models) is a three-strand project being run with Glasgow Caledonian University.

The first work package of CALISTA will develop an analytic model to predict cable asset lifespan through analysis of the cable parameters. This will allow the remaining lifespan of cable assets to be forecast, and allow an asset management tool to be developed to for asset managers to make informed decisions on the replacement of cable assets. This work will be carried out as a PhD study,

The second project strand will seek to support this study through monitoring the partial discharge in 33kV cables, particularly across trifurcating joints. This will also support work to monitor and manage failures in these joints.

The final strand of this project will look at using the techniques behind wireless charging to facilitate the location of cable faults. This will also be carried out as a PhD project.

3.20.1 | NIA SPEN0033 Project Progress

This project is currently in the start-up stage, with the PhD students due to begin work in July 2019. As such, there is little progress to be reported at this stage.

3.21 | NIA SPEN0034 NCEWS 2

Management of network access for the expected volumes of new and resultant increases in customer energy requirements continues to be the key theme for the Network Constraint Early Warning System phase 2 (NCEWS2) project. Continuing from the original NCEWS project key goals for the next phase are;

1.Develop data analytical support for key business process use cases,

a.Provision of a new IT supported innovation test platform called Network Analysis and View (NAVI).

b.Ongoing development of improved data visualisation, data gathering and API data export functionality.

c.Identification, training and logging of feedback on the platform from key business stakeholders.

d.Prioritisation and delivery of functionality identified through stakeholder engagement

e. Explore existing gaps in data analytical capability with initial investigation of HV network requirements.

2. Data science investigation of network constraint risk from the growing volumes of observable energy data supplied through Smart Meters (SM's) and LV network monitoring,

a. Initial use of SM data for constraint analysis through the use of underlying network impedance understanding and extrapolation of SM Voltage.

b. Connection constraint risk modelling through the combination of applied After Diversity Maximum Demand (ADMD) modelling data, improved through background property analysis along with the growing input of real observation data.

c. Use of observable energy data and underlying network asset data (impedance) to investigate data analytical techniques for network running and phase identification connectivity improvement.

Platform Evolution	EV and DER Management	Business Engagement	HV Analysis
• Platform Enhancements • Data Analytics • Data Improvement • SM Enablement • BAU Management	• LV/EV/DG Modelling • EV API Development • Data Analytics	• Stakeholder Engagement • BAU Implementation	• HV Development • Data Analytics • Leverage other Project Funding

NCEWS2 Revised Project Structure

3.21.1 | NIA SPEN0034 Project Progress

Particular focus within NCEWS2 is to develop the use of the NAVI platform to assist in the development of scenarios of growing Electric Vehicle (EV) penetration, and to integrate the platform data analytical functionality within other ongoing innovation projects in SPEN. Next step expectation is that this can then be developed through the platform functionality into LV network connection management tools. Key functionality of asset and connectivity data gathering and API export into other business project or BaU design analysis systems (Windebut and PSSE tools) will continue to be developed within the platform when use case benefit through stakeholder engagement can be established.

NAVI platform visualisation showing circuit connectivity, ADMD estimation and building understanding

To assist the development of this 'observed energy' risk analysis platform data science exploration of customer energy use estimation will also be explored through improved building type understanding and increasing visibility of LCT. Investigation of the application of improved LCT ADMDs, will provide the final risk analysis capability which will then be tested through stakeholder engagement with connection designers. It is expected that energy use estimation within the final observable energy systems will be an enduring requirement due to the perceived lack of full data availability. This will be through factors like data privacy, cost effective management of final data volumes and final levels and complexity of SM availability i.e. SM opt out, integration of commercial metering, introduction of SMETS2 export metering etc.

3.22 | NIA SPEN0036 A Holistic Intelligent Control System for Flexible Technologies

This project will investigate the potential use of a Holistic Intelligent Control System for the power network. There is a strong drive for DNOs to facilitate the ambitious UK government and Scottish Government target to ban all new petrol and diesel cars and vans by 2040 and 2032 respectively, and also relying on renewable energy resources for heat and transport. The way energy is consumed and generated are changing and customers are becoming an active player in the energy electricity system. Distribution networks are increasingly important to facilitate these changes in a most cost effective manner and provide the best value to customers. Providing active network operation and transition to a distribution system operator (DSO) arrangement are in the road maps of all the UK DNOs to accommodate the changes in electricity customers behaviour in line with the UK government Carbon Plan.There has been growing integration of flexible and smart solutions in electricity distribution networks to enhance the utilisation of network assets. In addition the growing controllable nodes and visibility in the distribution networks are the enablers for transition to DSO where network flexibility offers an adaptive system to customers' needs and facilitating the competition in energy market.

UK DNOs have been trialling different technologies that allow controlling network parameters such as voltages, power flow and network topologies in real-time e.g. Fun-LV, Active Response, LV Engine, Angle-DC and Equilibrium. Usually each flexible solution/technology requires its own controller which in principle aggregate the local and/or remote monitored data and uses an optimisation algorithm to determine the set points for the controllable devices. The control system architecture often consists of a Master and a number of slave controllers. Typically, the master controller uses regional input data, whereas slave controllers use data available locally.

There are similarities between these controller units in terms of their function, i.e. the control algorithms and the communication requirements. However, due to lack of a holistic smart control system, each flexible solution is currently independently designed, tested and taken through performance check for a period before it can be trusted for Business as Usual (BaU) adoption. **This can result in the following technical and commercial issues:**

- Incurring additional and unnecessary costs for a duplicate effort in designing the control systems for every solution
- Delaying the BaU adaption of the solution as the control system should go through a period of tests and refinement
- Incurring additional maintenance and training cost for operation staff as they have to deal with multiple systems provided by different vendors
- Sub-optimum network operation as each solution only limited to specific objectives, network area or voltage levels
- A proposed solution can be a DNO (DSO) owned Flexible Holistic Intelligent Control System (HICS) that:

Sets out the control signal hierarchy and overall network operation optimisation by considering the controllability and impact envelopes of controllable nodes and also the customers flexibility offer through aggregators

Can be flexibly adapted to coordinate different optimisation objectives, of controllable devices, to enhance network performance, reliability and also provide commercial signals to other network flexibility providers (e.g. aggregators). Some of the high level network operation objectives can be network losses, wide area voltage optimisations, maximum network headroom capacity etc.

Have the capability of machine learning or using artificial intelligence so it can be adaptive to network changes, robust against missing or real time data loss through loss of network communications and be functionally independent safely.

Provides a core control module which can flexibly and securely integrate the new technologies and interact with other DNO systems (data historian, Network Management System, Data integration platform etc.)

Provides a level of interoperability, allowing communication and integration with various network monitoring equipment offering a vendor agnostic solution

Is a DSO enabler and capable of providing market commercial signals and technical requirements associated with the DSO transition

Identifies the corresponding international standards and forums, including but not limited to CIGRE B4, C4 studying committee, IEC and SQSS, to inform and influence the ongoing discussion and standardisation when applicable.

It is envisaged that the HICS consists of the main (master) controllers providing overall coordinated network optimisation and local (slave) control units providing fail-safe function and set point adjustments based on local data. This project aims to identify the system architecture, optimisation algorithms HCIS and also trial of HICS within the distribution network demonstrating its performance at different voltage levels.

The objectives of the project are to:

- Identify the features required for a Holistic Intelligent Control system owned by a DNO (DSO) Technology Readiness Level at Start TRL 6 Technology Readiness Level at Completion TRL 8
- Analysis the evolving characteristic of distribution network with uptake of renewable generation, energy storage and EV
- Define the existing and future control technical requirements to future proof the controller functional design
- Scoping and specifying the control interfaces depending on the engineering and/or commercial relationship
- Review and Identify the common control algorithm to

3.21.1 | NIA SPEN0036 Project Progress

The project has only just started.

3.23 | NIA SPEN0037 Electric Vehicle Uptake Modelling (EV-Up)

The transition to electrified transport along with greater penetration of other Low Carbon Technologies such as heat pumps will put increasing pressure on the low voltage networks as demand increases in the future. To ensure that the network continues to provide the level of service required for customers there is an increasing need to improve forecasting to enable investment decisions to be made at the lowest overall cost, whilst minimising network risk. However, currently with immature electric vehicle (EV) market conditions and rapid technology change, accurate forecasting is extremely challenging and there is a need to model a range of adoption scenarios over an extended timeframe which increases this complexity.

Currently Network Operators have limited ability to accurately forecast where and when customers will transition to EVs and importantly how this will impact on the distribution networks. Improved forecasting is critical to ensure that our future networks meet customer expectations and can deliver the increased demand expected. In addition, this forecasting is also essential to ensure that investments are delivered on time, minimising the risk to the network, and ensuring value for money for customers.

EV-Up will allow Network Licencees to better understand the impact of EVs, and the ability of customers to transition to using EVs. EV-Up will contribute to the development of data sets to improve our understanding of customers' ability to transition to EVs based on off-street parking opportunity and customer demographics. This will enable improved understanding on the likely network areas which will see increased domestic demand and better inform future investment programmes. In addition, the dataset will complement existing work being carried out in other innovation projects such as NCEWS and Charge.

3.23.1 | NIA SPEN0037 Project Progress

The project has only just started.

3.24 | NIA SPEN1801 Distributed Ledger Technology-enabled Distribution System Operation (Phase 1)

This project will investigate the use of Distributed Ledger Technology (DLT) for smart contracts in Distribution Network Operation.

The DSO transition requires the implementation of efficient, neutral market platforms on the electricity networks, enabling a high penetration of distributed generation, flexible loads and energy storage. Co-ordinating these and balancing the network, will require new solutions. DLT, including block chain, is recognised as a revolutionary approach which is particularly suited to co-ordinating multiple entities in a network, allowing automated contract formation and settlement, and providing security and resilience.

DLT based smart contracts include rules for information exchange, contract formation and value transfer among multiple entities, based on a shared ledger which is easily validated. They could reduce the cost of establishing mutual trust between multiple DER owners and network operators who have agreed to behave in certain ways. DLT could also provide a means to manage electric vehicle charging and the integration of energy storage.

The proposed project will build upon the success of the pilot research activities funded by EPSRC HubNet ("Block chain based smart contracts for peer to peer energy trading using the GB smart metering system") and ENCORE ("Feasibility of applying Block chain and smart contracts technology to distribution grid management in the GB power system") from Cardiff University.

The project aims to create, test and quantify the performance of example agreement mechanisms encoded as DLT based smart contracts for distribution system operation. The project will define rules for interactions between neighbouring system operators (DNO or DSO). Then it will co-ordinate the actions of DERs on a distribution network within the same ownership. Alongside this, a use-case using actual network data will be developed to allow a DNO/DSO to best employ the defined smart contracts. Finally, the whole system will be implemented and demonstrated in software simulation environment, engaging with stakeholders in the supporting networks to raise the common level of understanding.

3.24.1 | SPEN1801 Project Progress

Distributed Ledger Technology-enabled Distribution System Operation (De-DSO) is a Network Innovation Allowance project representing an inclusive, collaborative and future proofing approach to understand the impact of the digital revolution. It is aiming to identify and address the challenges and opportunities involved in using Distributed Ledger Technology (DLT) applications to solve problems facing DNOs today and DSOs in the future. It was registered in December 2017 with a starting date of March 2018. The leading licensee is SP Energy Networks, partnered with SSEN and UKPN. The project duration is 48 months and is aiming to complete by March 2022.

2018/19 is the first year of the project. The project delivery has been on track thanks to the effective support from the Energy Innovation Centre.

The following activities have been undertaken:

Contract and agreements: SPEN, SSEN and UKPN agreed to work with Energy Innovation Centre and rely on their expertise and access to SMEs. The consortium further contracted Cardiff University as the academic partner based upon their track record on this topic and their initiatives in facilitating this proposal.

Workshops: Five workshops have been organised, representing the inclusive nature of this project. There were representatives from EIC, three Licensees and academic partner joined the workshops with relevant stakeholders (including international SME, suppliers).

Workshops	Purpose	Date	Location
Workshop 1	Horizon Scan of DLT technologies	19/10/18	EIC office, Ellesmere Port
Workshop 2	Mapping the Information Flows	30/11/18	Holiday Inn, Castle Street, Cardiff
Workshop 3-4 (Two combined)	Smart Contract Analysis	10-11/01/19	Scottish Power HQ, 320 St Vincent St, Glasgow G2 5AD
Workshop 5	Hardware and Security Implications	21/02/19	SSEN Southern HQ, 1 Forbury Place, Forbury Road, Reading, RG1 3JD

Reports Published: The consortium shared the reports with Open Networks under the ENA and all the DNOs regarding the landscape scanning. In addition, the project published the following reports:

Report	Name	Synopsis
Report 1	Horizon Scan	A general review of Distributed Ledger Technology, based on previous studies conducted by Cardiff University (EPSRC HubNet and ENCORE projects) and information gathered from external sources (including academic articles, open reports from industry, dissemination activities, and opinion from experts).
Report 2	Information Flows	A review of information processes within the GB power system at present and with a transition from DNO to DSO.
Report 3 & 4 (Combined into one)	Smart Contracts and Applications	A review of smart contract development and operation principles.
Report 5	Security and hardware	A review of security vulnerabilities and hardware related to DLT.

4 | Collaborative NIA Projects Led By Other Network Operators

During the reporting period SPEN has collaborated on four NIA projects that have been registered by other parties as follows:

Project No.	Project Name	Project Lead
NIA WPD 0008 Distribution	Improvement Statistical Ratings for OHL	Western Power
NIA SGN 0138	East Neuk – A Techno Economic Study into the Energy System	SGN
NIA SHET 0025	Zero Missing Phenomenon	Scottish and Southern Electricity Networks
NIA UKPN0047	HV Feeder Monitoring to Pre-Empt Faults	UK Power Networks

The following section provides a short overview of each active NIA D project on which SP Energy Networks is collaborating.

4.1 | NIA WPD 0008 Improvement Statistical Ratings for OHL

Distribution overhead line ratings are based on CEGB research work and further assumptions described in ENA ACE104 and ENA ER P27 published nearly 30 years ago. Recent work testing these assumptions have found some of them to be erroneous, with the result that existing distribution line ratings are now considered out of date. This means that load-related decisions to replace or reinforce lines are currently based on inaccurate ratings. DNOs, therefore, need a cost-effective, up-to-date and robust methodology for calculating and optimizing overhead line ratings.

A previous DNO collaborative project under the Innovation Funding Incentive established an overhead line test rig to monitor weather conditions and temperatures of different conductors at various current levels. Under this current project, the test rig will be operated continuously for 24 months, recording conductor temperatures and weather conditions. The data will be analysed and appropriate revisions of ENA ACE 104/ENA ER P27 will be made and a more sophisticated overhead line assessment software tool will be developed.

4.1.1 | NIA WPD 0008 Project Progress and Learning

This is a collaborative project involving all UK DNOs, with WPD acting as the main DNO Project Lead. This joint project was registered by WPD as the lead DNO and so details on project progress and project learning will be reported in the WPD 2018/19 Annual Report.

4.2 | NIA SGN 0138 EAST NEUK - A TECHNO ECONOMIC STUDY INTO THE ENERGY SYSTEM

This project will assess how an integrated hydrogen energy system in Fife will work and how it could function at a much larger scale for Scotland. Electricity from a variety of renewable sources are couples via the electricity network and an electrolyser to the gas network in the form of hydrogen. This in turn can be utilized directly in a vehicle refuelling station or at different offtake points from the gas network to supply domestic and commercial properties.

The electrical network in this part of Fife has constraints and any increase to the amount of installed renewable generation capacity without upgrading the network would likely result in increased curtailment of output. Maximising utilisation of assets, revenue opportunities from multiple energy streams, and potentially other local economic benefits points to the consideration of combining gas, electricity and transport infrastructure in an optimal way.

4.2.1 | NIA SGN 0138 Project Progress and Learning

The project kicked off in February 2019 with supplier E4tech appointed to carry out the modelling and feasibility study. The recent commencement means there is no learning to date. Initial tasks carried out to date include literature review, model creation and sourcing network information. Completion of work and delivery of the findings and final report is due in the summer of 2019. Further details on the project will be reported in the SGN NIA 2018/19 Annual Report.

4.3 | NIA SHET 0025 ZERO MISSING PHENOMENOM

It is widely understood that when a short circuit occurs, the total current which flows consists of two components namely; an AC component which varies sinusoidally with time and a DC component which is non-periodic and decays exponentially at a rate determined by the time constant of the system. This system time constant is determined from the ratio of the system reactance to the system resistance (X/R). The higher the X/R ratio of a circuit, the higher the peak fault current and the longer the time it takes for the DC component to decay. For high system X/R ratios, it is possible that under low system fault level conditions the AC fault current component may not cross the axis due to the high DC current offset. This is known as the Zero Missing Phenomenon (ZMP).

The drop in system fault levels across the network, coupled with the use of shunt reactors for voltage management results in network topologies and conditions that are particularly susceptible to ZMP. AC circuit breaker design is reliant upon current zero crossing within rated time for successful interruption of current. It has however been shown on recent transmission designs that a circuit breaker on a circuit with a shunt reactor may have to interrupt fault currents with high and slowly decaying DC components that result in the ZMP, i.e. the current zero crossing not being realised within the rated time for the circuit breaker to clear the fault. This issue raises questions which require further investigation, such as:

- What are the transmission design characteristics that make circuit breakers susceptible to the ZMP?
- What is the likelihood that the circuit breaker will be faced with this situation?
- What are the likely consequences of the ZMP?
- If the circuit breaker successfully chops the current, what happens next?
- Can a switching strategy or some cost-effective mitigation be devised?

This project aims to address the questions above through detailed investigation of the phenomenon and its impacts followed by investigation and development of mitigation options.

4.3.1 NIA SHET 0025 ZERO MISSING PHENOMENOM

Since the project has only recently kicked off the project has not yet generated any significant learning. Once complete the project will provide new learning about:

- The ZMP DC current problem and any potential consequences and associated risks
- The capability of circuit breakers to interrupt the prospective fault current
- Mitigation options and strategies for this problem and their viability

The planning, training, operation and maintenance requirements of any viable mitigation options

Further details on the project will be reported in the SSEN NIA 2018/19 Annual Report.

4.4 | NIA UKPN 0047 HV Feeder Monitor to Pre-empt faults

When a fault occurs on the Network it has a large detrimental effect on consumers as it can cause outages or the need for temporary curtailment. This project will aim to investigate a method to detect faults before they result in an outage using Distribution Fault Anticipation (DFA) technology. The project aims to determine the reliability of DFA devices in capturing and identifying the type of anomaly which could lead to a fault on the UK network. This will also be trialled alongside a network analysis tool (ASPEN Distriview) and Fault Passage Indicators (FPIs) to monitor a selection of HV and 33kV feeders and expectantly identify the location of network issues before they manifest into faults.

As well as determining the functionality of the technologies by validating their outputs another aim will be to develop and validate the process from an operational perspective, which will respond to the DFA outputs and carry out necessary repairs to pre-empt faults.

4.4.1 | NIA UKPN0047 Project Progress and Learning

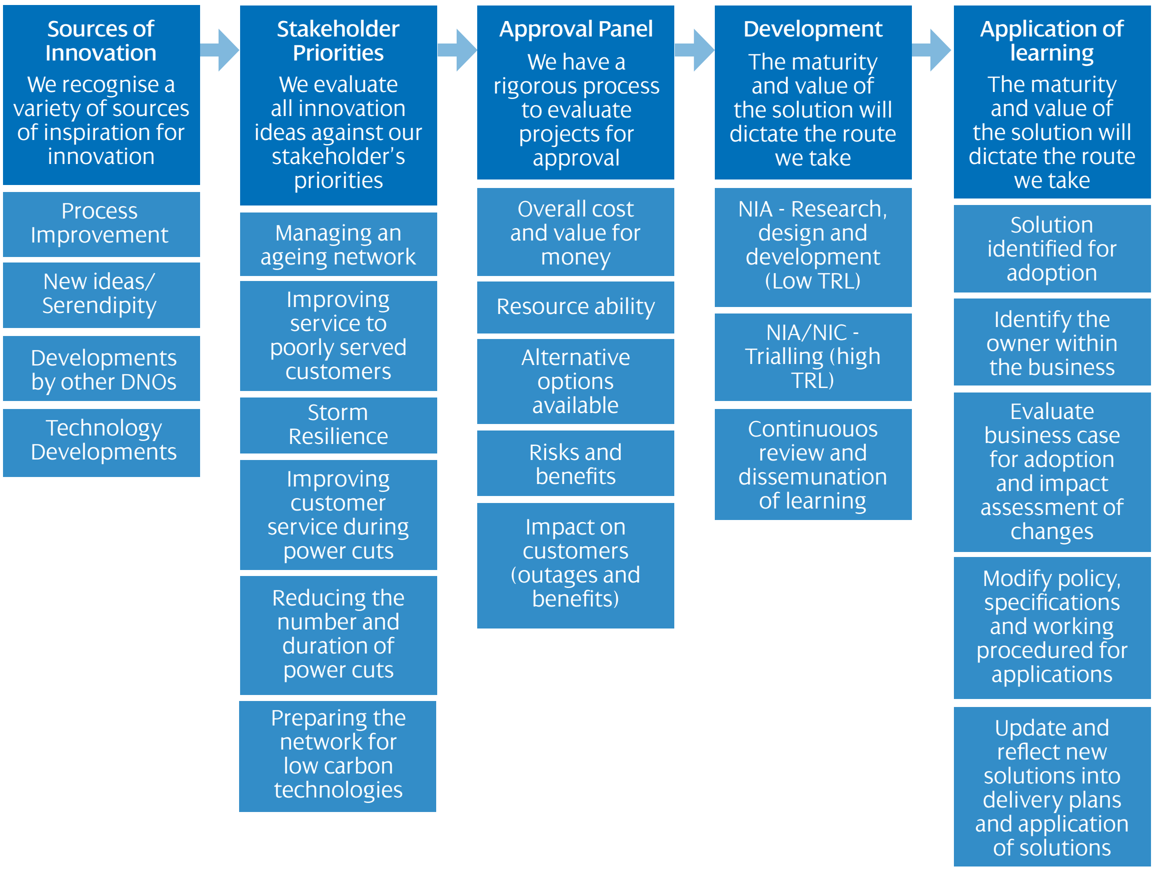
Since the project has only recently kicked off it has not yet generated any significant learning. The initial phase of testing to be undertaken at the Power Networks Demonstration Centre (PNDC), as a precursor to network trials, is in the planning phase and the required equipment to carry out the tests are in the process of procurement.

Further details on the project will be reported in the UKPN NIA 2018/19 Annual Report.

5 | NIA Activities Linked to SP Energy Networks Innovation Strategy

5.1 | From Inspiration to Solution

Our approach to innovation development (From Inspiration to Solution) is summarised in Figure 5 below which contains five steps:



The five key steps of our innovation process are:

1. Idea Generation: Ideas can come from a variety of sources. These sources can include technology developments by suppliers or academia and developments by other network companies and wider industry.

2. Evaluation: We use the priorities of our stakeholders as the main evaluation criteria for new projects. We will ensure that all new projects align with at least one of the areas listed in Figure 6 under Stakeholder Priorities. Operating our network safely, providing value for money and delivering excellent customer service are all implicit requirements in what we do.

3. Approval: Our R&D Approvals Panel reviews all technology innovation projects before they progress with NIA/ NIC funding. This is to ensure that the project aligns with our strategy, offers value for money, and is expected to deliver benefits that will justify the cost and risk. We also use the approval process to identify any other activity which has synergies to avoid any duplication, and identify resources from the wider business that may need to be involved.

4. Development and Delivery: A project manager and project team identified for each project to deliver the day-to-day project activities. Business champions are nominated to facilitate the integration of proposed, existing and completed project into BaU. Projects are monitored through their lifecycle and, in the event that anticipated benefits do not arise projects may be terminated. Technology readiness levels and project scale will be used to determine appropriate funding route, be it NIA, NIC or other funding steams such as research grants.

5. Application of Learning: Appropriate channels both internal and external will be used to disseminate learning from both successful and unsuccessful projects to a wider audience. We will also seek opportunities to learn from and collaborate, as appropriate, with other DNOs.

There is a need to ensure that innovation is embedded into all business function as such the role of the innovation board is to ensure increased participation from all business functions and to allow innovation projects to be completed and integrated into BaU.

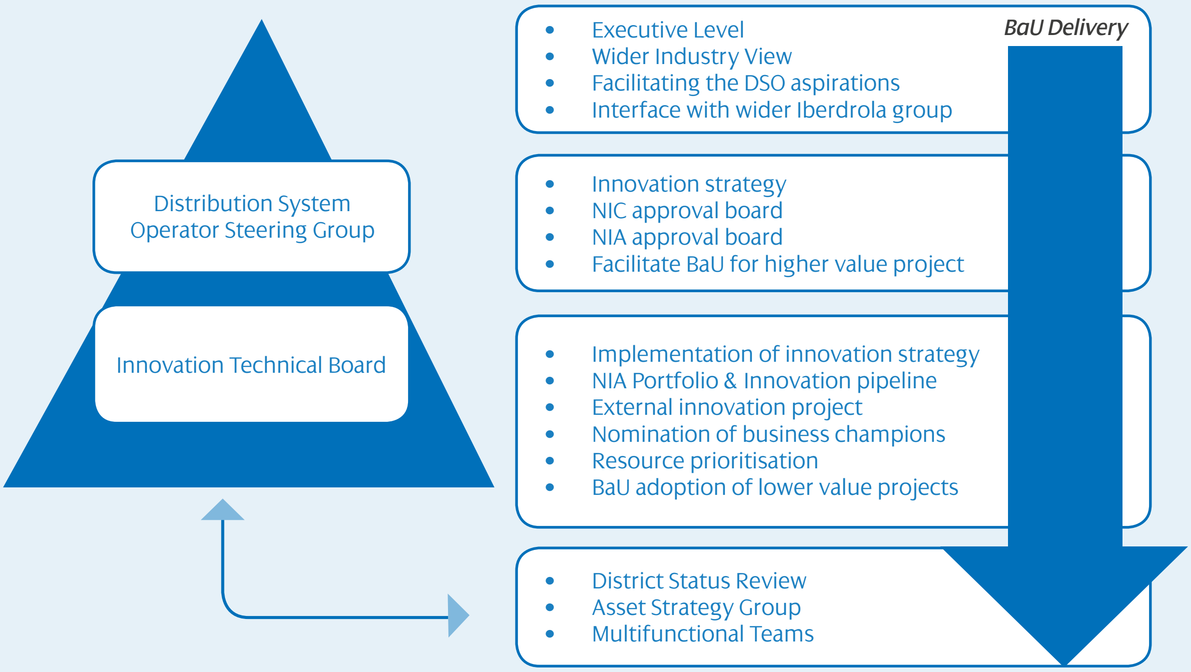


Figure 6 Innovation Governance Structure

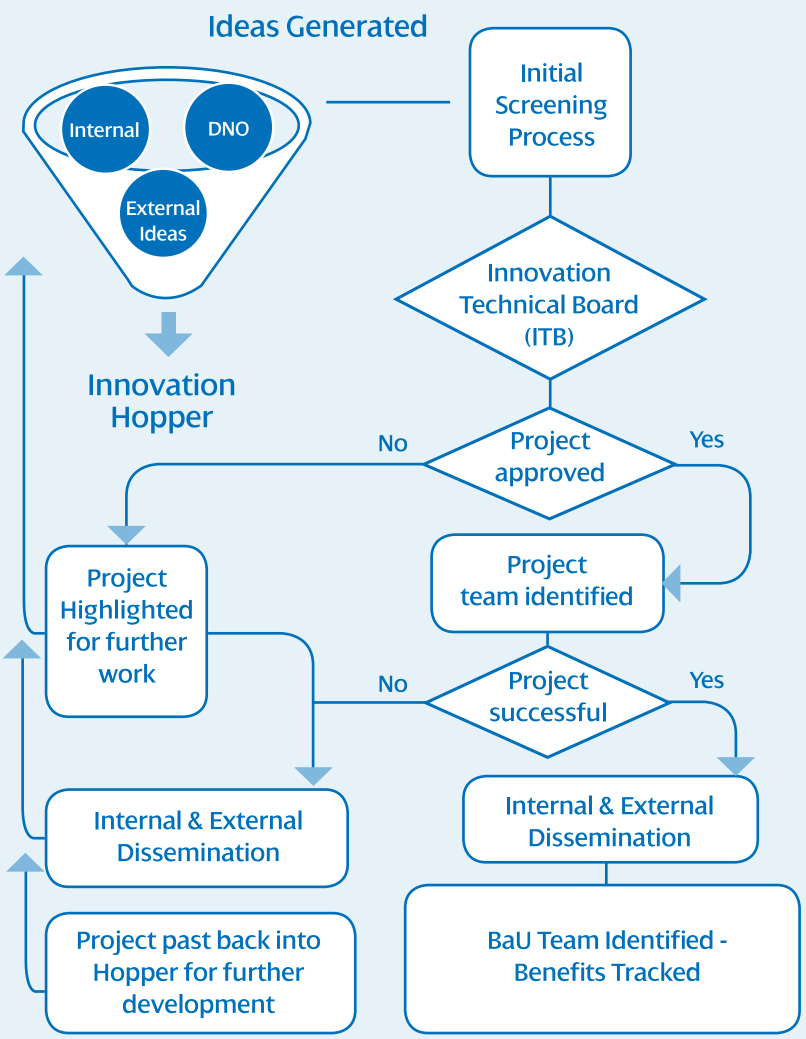
Our innovation governance structure and project approvals process Figures 5 and 6 respectively, helps to ensure the following:

Projects involve the Research, Development, or Demonstration of at least one of the following:

- A specific piece of new equipment
- A specific novel arrangement or application of existing equipment
- A specific novel operational practice directly related to the operation of the network
- A specific novel commercial arrangement

A Project must also meet all of the requirements

- Has the potential to develop learning that can be applied by all Relevant Network Licensees
- Has the potential to deliver net financial benefits to electricity Customers
- Does not lead to unnecessary duplication

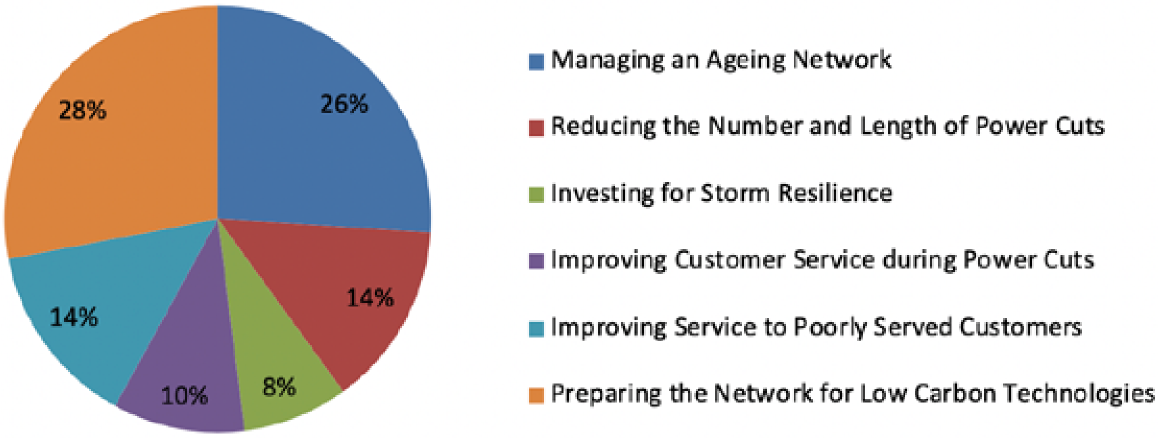


5.2 | SPEN NIA Project Mapping with Innovation Strategy

5.2.1 | Informed by Our Stakeholders

We are acutely aware that the funding we access through the various innovation mechanisms is sourced from our customers. In developing our Electricity Distribution Network Innovation Strategy 2018 we have not only ensured that our innovation activity is focused on areas which customers most value, but also that customers are willing to invest more in these particular areas in the short term, to allow the longer term benefits of innovation to be realised. Our Innovation Strategy uses the priorities identified through our stakeholder engagement process. **Of all the areas identified, stakeholder feedback identified the following specific priorities:**

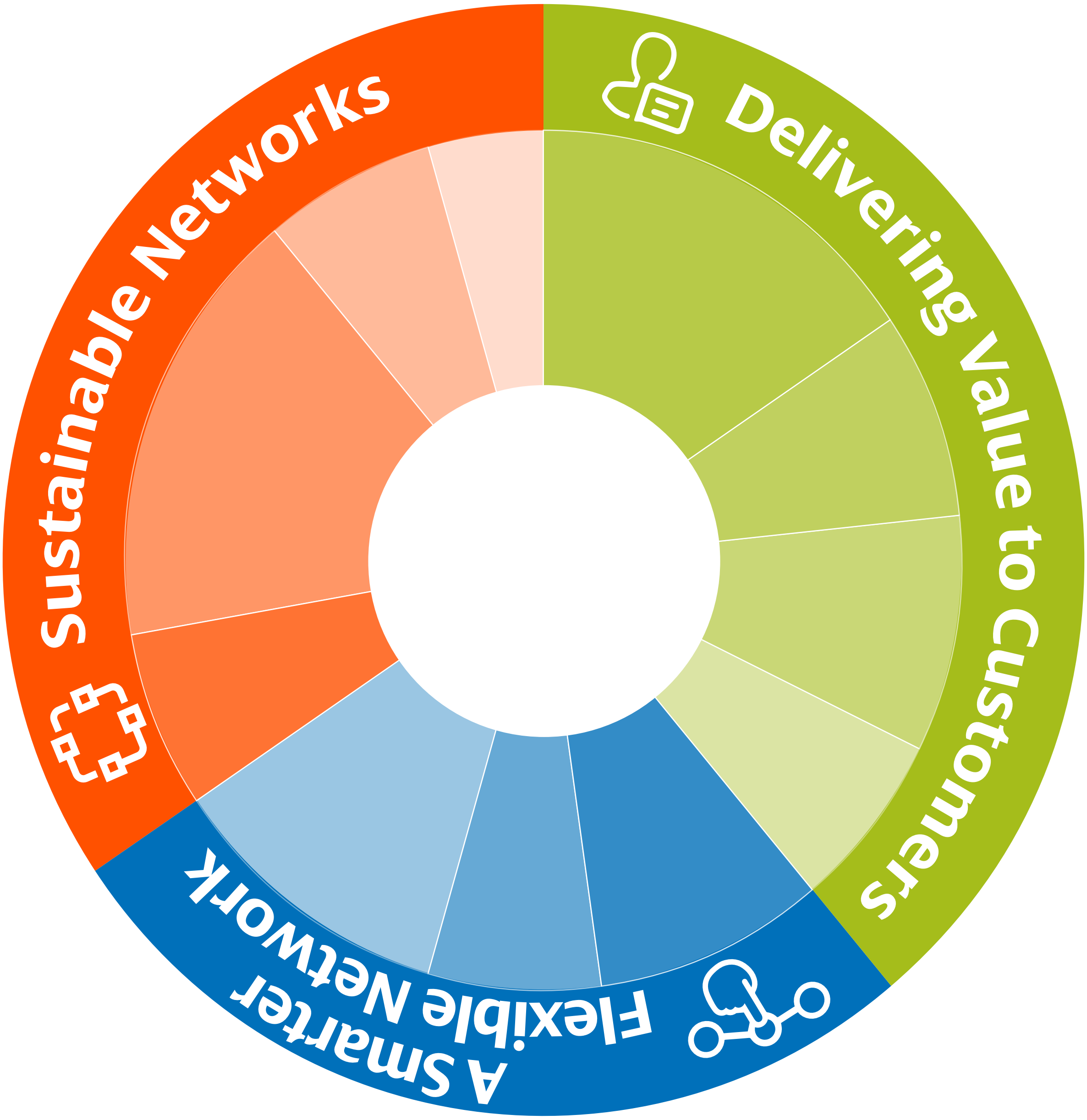
1. Managing an ageing network
2. Reducing the number and length of power cuts
3. Investing for storm resilience
4. Improving customer service during power cuts
5. Improving service to poorly served customers
6. Preparing the network for low carbon technologies



We have aligned our innovation strategy to these areas and will use this as a key feature of the selection process for new projects. These areas will be addressed within the context of a continued focus on health, safety and the environment.

In mapping our innovation projects onto the priority areas identified with our stakeholders, we took into account the following factors:

- Many of our innovation initiatives will fulfil more than one priority at a time
- Individual projects will be assessed relative to others in terms of the overall cost, effort, risk and benefit to customers and the network
- The learning from innovation projects will be an important input to the ongoing strategy
- What we learn from our innovation initiatives will have an impact on the overall innovation priorities. Where we have addressed a problem the priority may become less relevant, or if an initiative is unsuccessful that priority may require greater focus.



42% - Delivering Value to Customers

- 16% - Managing an Ageing Network
- 9% - Maximising the benefit of data
- 9% - Network Control & Managemen
- 8% - Reducing the number and length of power cuts

26% - A Smarter Flexible Network

- 8% - Managing an Ageing Network
- 7% - Network, Flexibility and Communications
- 11% - Preparing the network for Low Carbon Technologies (LCT)

32% - Delivering Value to Customers

- 6% - Minimising the Environmental Impact of Assets and Activities
- 14% - Modernisation of Work Practices and Business Systems
- 7% - Our People - Skills and Resources
- 5% - Socially Responsible Member of the Local Communities We Serve

5.2 | SP Energy Networks NIA Project Mapping with Innovation Strategy

No.	Project
01	NIA_SP Energy Networks 0006 Mini-mole
02	NIA_SP Energy Networks 0007 SUSCABLE 2
03	NIA_SP Energy Networks 0008 APPEAL
04	NIA_SP Energy Networks 0010 EVOLUTION
05	NIA_SP Energy Networks_0012 SINE Post
06	NIA_SP Energy Networks_0013 Interoperable LV Automation
07	NIA_SP Energy Networks_0014 Active Fault Level Management
08	NIA_SP Energy Networks_0015 Real Time Fault Level Monitoring
09	NIA_SP Energy Networks_0019 Operational Assessment of Wood Poles
10	NIA_SP Energy Networks 0020 Instrument for the identification of Live and Not Live HV and LV cables
11	NIA_SP Energy Networks 0022 Weather Normalised Demand Analytics (WANDA)
12	NIA_SP Energy Networks 0023 Connected Worker Phase 1 - Field Data Automated Capture
13	NIA_SP Energy Networks 0024 Endbox G38 Level Detection Phase 2
14	NIA_SP Energy Networks 0025 Low Cost Fault Current Measurement of Wooden Poles
15	NIA_SP Energy Networks 0026 Linkbox Monitoring using Narrow Band IoT
16	NIA_SP Energy Networks_0028 Transition to low voltage DC distribution networks – Phase 1
17	NIA_SP Energy Networks_0029 Secondary Telecommunications Phase 3 - Trial of Hybrid Telecoms
18	NIA_SP Energy Networks_0030 Zebedee Sectionaliser Device
19	NIA_SPEN_0031 Radiometric Arc Fault Location RAFL 2
20	NIA_SPEN_0033_CALISTA
21	NIA SPEN_0034 Network Constraint Early Warning Systems (NCEWS 2)
22	NIA_SPEN_0036 A Holistic Intelligent Control System for Flexible Technogies
23	NIA SPEN0037 Electric Vehicle Uptake Modelling (EV- Up)
24	NIA_SPEN_1801 Distributed Ledger Technology-enabled Distribution System Operation (Phase 1)

Delivering Value to Customers				A Smarter Flexible Network			Sustainable Networks			
Managing an Ageing Network	Maximising the Benefit of Data	Network Control & Management	Reducing the Number and Length of Power Cuts	Faster, Easier, Accurate Connections	Network Flexibility and Communications	Preparing the network for Low Carbon Technologies (LCT)	Minimising the Environmental Impact of Assets and Activities	Modernisation of Work Practices and Business Systems	Our People - Skills and Resources	Socially Responsible Member of the Local Communities We Serve
✓				✓		✓	✓	✓		
						✓	✓			
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6 | Areas of Significant New Learning

The following identifies area of learning on a project by project basis.

6.1 | Project Learning: NIA SPEN0006 Mini Mole

The mini mole has the capability to be more cost effective and environmental friendly than the conventional alternative in certain circumstances. It is, however, become apparent that changes to existing business processes would be required to implement it on a larger scale therefore we are undertaking a stage gate review of the project to decide how best to progress.

6.2 | Project Learning: NIA SPEN0007 SUSCABLE 2

The original primary objective for the materials development has been achieved and more, as further electrical and dielectric assessment of the materials and their ease of processing have shown the materials to be suitable for wide ranging MV and HV applications. This includes HVDC applications, in addition to HVAC, as the materials as sourced have higher purity than existing polyethylenes used to make conventional crosslinked polyethylene (XLPE) cables and their HVDC properties are very good and exceed those of XLPE.

The co-development of fully compatible semiconducting screen materials based on the same materials technology, essential for commercialisation of the new thermoplastic cables, will enable the cable to be produced and function up to the highest conductor temperatures expected for such designs – 140 to 150 ° C.

The new blends also avoid the use of crosslinking peroxide chemicals that further contaminate the insulation system in XLPE and which also impose the need for degassing to remove volatiles – both are avoided completely with the new polymer blends and this also requires lower cable manufacturing investment and reduces manufacturing risks particularly for HVAC and DC cables in the future. Avoiding crosslinking and degassing in cable making significantly reduces manufacturing time and energy, it reduces the level of capital investment required in new cable production facilities and de-risks the cable manufacture. The improved materials also provide cables with lower susceptibility to electrical ageing and are expected to increase service lifetime.

A significant area of learning has been the ability to formulate the insulating and semicon screen materials by using multiple sourcing of each component of the multi-component blends. This means that commercial supply is not limited to one of only three major global providers of so-called superclean polyethylene which limits sustainability options and economic competitiveness. Instead there are many suppliers of component materials and as the project has shown it is necessary for these components to be qualified and the compounding of these to produce to formulations in high volume will also need to be qualified. The basis for qualification has also been established by the project and quality control metrics can readily be defined and reduced to practice.

It is noted that the second objective of producing a MVAC cable core to support HVAC cable development has been achieved but not consolidated to the point of having a pre-commercial MVAC cable to commercialise. However, the experience gained shows that the production of a commercial MVAC cable is close and is likely to be achieved by other interested cable makers who have expressed an interest in producing the cable. The resultant cable core would then be available to support HVAC and HVDC cable development. A parallel development of the two HV cable technologies is the next step based on the multi-component polymer blend technology that has been filed as a patent by the research partners.

6.3 | Project Learning: NIA SPEN 0008 APPEAL

RV-PWR and Tanasote are not demonstrating any significant difference from the proven preservative creosote – none of the preservative treated timbers are showing any overt signs of significant decay either through visual observation or statistical analysis of MOR values. There is also clear evidence that both barrier products are being shown to protect the stakes. This is shown by the very evident signs of decay on untreated control stakes with no barrier which are entirely absent on control stakes with either barrier fitted. It is also pleasing to be able to confirm the supposition that migration of copper from the CAPTURA barrier inner sleeve to the underlying timber would occur.

The results of the visual examination of stakes removed from the soil bed clearly shows that the chamber is proceeding largely as expected with clear evidence of decay developing in untreated control stakes exposed to the soil bed. It is unfortunate that the progress of weathering and decay could not be definitively confirmed by MOR statistical analyses. This was perhaps not unexpected given the relatively small number of samples making up the respective populations in the soil bed and the known variability of timber in terms of strength. It is clear however that the trends are pointing in the right direction with mostly lower MOR values after 12 months exposure (especially for untreated controls).

6.4 | Project Learning: NIA SPEN0010 EVOLUTION

The studies carried out under Evolution during the reporting period provide the required clarity on the relationships regarding USEF (Universal Smart Energy Framework) and the 5 worlds identified under Open Networks[1]. It is important to provide such an evidence in a timely manner for customers, stakeholders and the Authority alike, to ensure that a balance has been maintained between an open/inclusive environment and avoidance of duplication during this dialogue, which in turn will influence the journey of DSO.

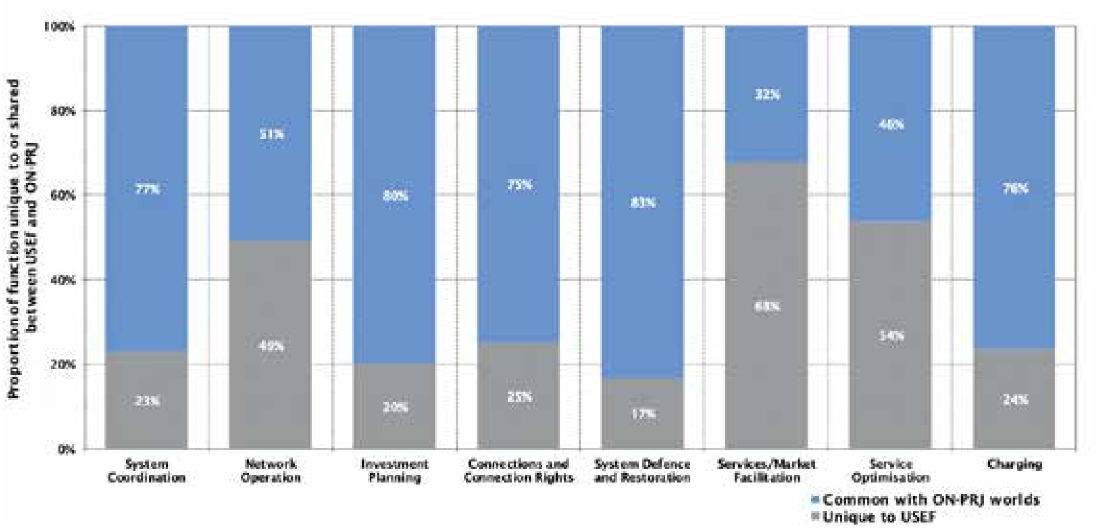


Figure 7 Proportion of links that are unique to the USEF model compared to what is shared with at least one ON-PRJ world

In the meantime, there were significant efforts made to ensure that the scope of the project could keep pace with technology advancement and new findings. It was noted that both the central government[2] and local authorities have a strong willingness to tackle the decarbonisation of heat systems.

While the original project proposal was focused on the electricity flexibility in a local system level, it was obvious that a holistic approach is now required to generate the maximum benefits for decarbonisation efforts at national level. From an engineering perspective, it is in the customer's interest to understand the potential impacts of electrification of the heat and transport system, and indeed, the active role that could be undertaken by those new vectors in the electricity network.

Consequently, SP Energy Networks worked with Cala Homes (a national property developer) and installed monitoring devices to record the impact of Heat Pump installed in the new properties in West Scotland. This data is then analysised and compared with the LV feeder regarding harmonics (power quality) and ADMD (maximum demand). The initial findings suggest a promising impact:

Figure 7 LV substation where the monitoring devices were installed

[1]Worlds A-E, as set out under the Executive Summary of the Open Networks Consultation http://www.energynetworks.org/assets/files/14969_ENA_FutureWorlds_AW06_INT.pdf

[2]https://www.gov.uk/government/publications/heat-decarbonisation-overview-of-current-evidence-base

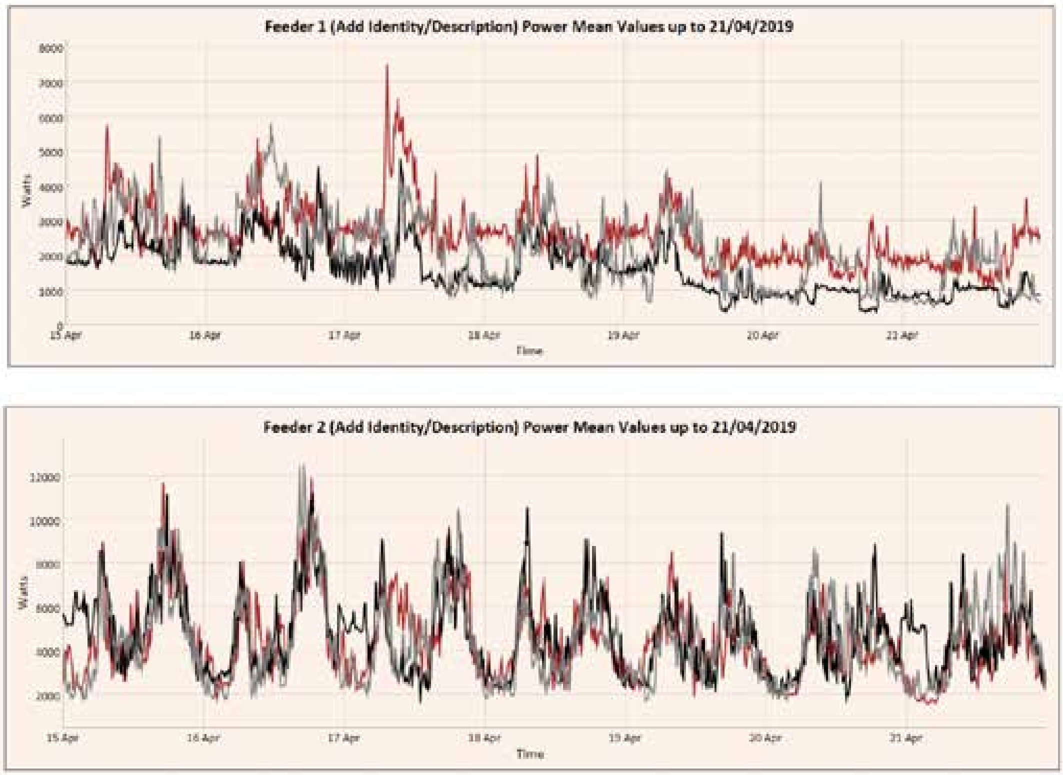


Figure 8 Installation of Heat pump at the new property might have positive impacts on ADMD

6.5 | Project Learning: NIA SPEN0012 SINE Post

A significant technical issue that has to be considered is Cyber security. The connectivity models have had to be revised to ensure that any device connected to our system has a proportionate and appropriate levels of cyber security.

6.6 | Project Learning: NIA SPEN0013 Interoperable LV Automation

This project has proven that sophisticated highly functional LV automation can made

• Cheaper than existing market leading products.

• Further development required to get to market.

• Wide range of functions.

• Reclose functionality supported limited by combination with fuse.

• Infinitely variable number of reclose attempts (typically greater than 3).

• Adjustable close-open to assist cable insulation restoration performance (particularly valuable for wet cable faults).

• iLVCB pPassed tests at KEMA Prague 2018.

• MVP specification for LV Automation generated.

• Low cost opens door for wider deployment than existing market products. Initial pilot volumes do, but not offer sufficiently low unit prices for enough for widespread fit and forget approach at this early stage. However as the market place matures indications are that significant price reductions are possible.

6.7 | Project Learning: NIA SPEN0014 Active Fault Level Management (AFLM)

Phase 2 of the project has refined the concept design for an AFLM system. The project has developed the specification, requirements, design principles and high level commercial principles of access for the AFLM system. These provide key learning and insights on the AFLM design and how it can be applied.

6.8 | Project Learning: NIA SPEN0015 Real Time Fault Level Monitoring (RTFLM) – Stage 1

The complexities of the Chester interconnected network have proved to be a challenge, but results have shown that the RTFLM system is able to deliver good quality 11kV fault level results using the LV injection system.

The noise performance with the original design power is in line with expectation.

For obtaining Fault Level on the target 11kV Station View bus (in the region of 250MVA), Flicker at the LV injection point is significant as expected, but not significant at 11kV. Other than LV Flicker no adverse effects have been observed on the network, neither have any effects on substation hardware (500kVA transformer, relays) etc. been observed.

Modelling has also shown that two-transformer excitation should also work for 33kV, allowing Fault Level at 33kV to be obtained without a dedicated 33kV to LV transformer. The 33kV connection is achieved by employing the in-situ 33kV/11kV transformer and a dedicated 11kV/LV transformer. Flicker at 11kV should be insignificant and Fault Level results should be tolerant to loading at 11kV (and LV).

6.9 | Project Learning: NIA SPEN0019 Operational Assessment of Composite Poles

The ENA CEP012 project is progressing to develop a methodology and ultimately the specification for "engineered poles".

The issues encountered with stay attachment and drilling practices have not been overcome to date.

6.10 | Project Learning: NIA SPEN0020 Instrument for the identification of Live and Not Live HV and LV cables

The main lessons learned from this project relate to the development of a device such as this from a low TRL level; it is clear that a large pool of data must be used to ensure that the device can operate successfully. In particular, as the data required by this device is not regularly gathered or held within the business, the gathering of this data must be considered as a key process, and may take a long period within the development process.

6.11 | Project Learning: NIA SPEN0022 Weather Normalised Demand Analytics (WANDA)

The project demonstrated that the weather has a strong influence on electricity demand at a local level and that there is a large degree of local variability that cannot be quantified by a system level correcting. It investigated the historical trends in customer behaviour at individual substations by correcting the varying annual peak demand to account for the effect of variable weather conditions.

Key findings of the project are as follows:

- Weather is masking underlying demand trends
- There is a clear relationship between demand and multiple weather variables including effective temperature, global horizontal irradiance and the cooling power of the wind.
- The effect of weather conditions at local substations will be different due to a combination of customer sensitivity to weather and local climate effects.
- The variability of weather driven demand at a local level is significant.

Understanding demand at this level of granularity is a key enabler for DSO and microgrids. It provides tools to improve the targeting of investment, provides earlier warning of shifts in demand and provides a platform to run scenarios upon.

6.12 | Project Learning: NIA SPEN0023 Connected Worker Phase 1 - Field Data Automated Capture

This project is only at an early stage and consequently project learning will be reported in the next annual report

6.13 | Project Learning: NIA SPEN0024 Endbox G38 Level Detection Phase 2

The main lesson learned from this project has been the proof of the non-destructive monitoring being an effective tool for measuring level of G38 within endboxes and similar equipment. Development of this into a business as usual solution is more difficult however, considering that this is a task and operation which is far removed from the majority of work which is currently carried out within operations. As such, there must be a large amount of consideration given to how effective training can be established and given to people with sufficiently developed skillsets in order to make effective and safe use of this monitoring technique.

6.14 | Project Learning: NIA SPEN0025 Low Cost Fault Current Measurement of Wooden Poles

Testing of the stage 2 device has led to important design changes that will help prevent the occurrence of false positives caused by factors such as normally present low-level leakage pole currents and environmental factors (temperature and UV). Input from network operators on device mounting and installation has also been considered in the stage 3 device design to help ensure easy and reliable deployment.

Stage 3 devices will soon be available for testing by the network operators. This will enable the operators to gain confidence in the device's ability to detect and indicate fault currents through controlled tests in training facilities, and suitability of the device in the field when subject to the elements. It will also allow the operators to identify areas for device improvement, whether that be to do with installation or changing of the threshold at which the device detects fault currents.

6.15 | Project Learning: NIA SP Energy Networks 0026 Linkbox Monitoring using Narrow Band IoT

One of the main lessons to be taken from this project has been the measurements which have proven useful in monitoring linkbox condition. Temperature is the key metric here, with a significant rise in linkbox heat being a key indicator of imminent linkbox failure. Further to this, only one sensor is required for this; the Vodafone system had two sensors to measure temperature in different parts of the linkbox, but no significant differential was found between the sensors.

There is additional learning to be taken from the communications aspect of this project; both the Vodafone NB-IoT communications and conventional multi-network Sim-based communications were proven to give good coverage over the trial area. These also provided good underground coverage, with few instances of coverage being lost after being installed underground. This has positive lessons for communications in similar circumstances, such as communications for underground substations.

6.16 | Project Learning: NIA SPEN0028 Transition to low voltage DC distribution networks – Phase 1

Deliverable 1

It is concluded that in order to realise the potential values of LVDC and enable wider uptake of LCTs, there is an urgent need to accelerate the development of new electrical distribution standards, wiring regulations and grid codes that fit well within the LVDC technology requirements.

Deliverable 2

Fault transient contribution from shunt capacitors of existing LV cables energised by DC is insignificant and can be neglected in comparison with fault transient contributions from the LVDC converters filter capacitors.

The studies have identified the transient period of the applied faults as the period of the converters smoothing capacitors discharge (few milliseconds <5ms). During this period, transient fault currents with peaks almost equal to 227kA are experienced in the faulted LVDC networks. It is true that such energy will be dissipated very fast, but such additional thermal energy presence has never been experienced in existing LV cables under AC faults.

The dissipated transient energy in LVDC Zone 1 with < 750Vdc (1500Vdc pole-to-pole) is 4 times higher than in LVDC Zone 2 with 375Vdc (750Vdc pole-to-pole) supply.

Using existing LVAC cables to form LVDC distribution networks, where high penetration of low carbon technologies exist, it must be recognised that additional energy will be dissipated during a DC fault event in a short period, potential causing "thermal shock" to existing cables.

Cable sections that are closer to converters (e.g. close to the main DC bus or EV chargers) are more likely to experience higher "thermal shocks" and may therefore degrade earlier under long-term DC operation. Further experimental testing is required to quantify the impact of the thermal shocks on the lifetime of LV cables used for DC.

Implementation of fault tolerant converters such as modular multi-level converters (MMC) can significantly eliminate the generation of thermal shocks in LVDC cables during DC fault transient period. This is of course in addition to other control functionalities which MMC can offer to the network in comparison to two-level voltage source converter.

Deliverable 3

Under DC conditions the ageing mechanisms are different as there is a single energisation and no cycling at the power frequency. In terms of DC ageing, this either consists of long term ageing above the intended voltage which overstress the insulation or the voltage ripple has been shown to lead to premature failure of insulation systems.

The electric field distribution under DC conditions is governed by the electrical conductivity of the insulation and realistic tests must take account of this fact.

A survey of commercial test facilities was conducted however it is apparent that such facilities provide testing for cable manufacturers and their customers, but do not mention offering testing relevant to DC operation regimes of different zones. These facilities could be considered for initial sample health assessment (for electrical and mechanical parameter measurements).

6.17 | Project Learning: NIA SP Energy Networks 0029 Secondary Telecommunications Phase 3 - Trial of Hybrid Telecoms

A number of valuable insights have been made during the initial phases of the project:-

i) Inability of some services such as NB-IoT to support protocols such as TCP traffic

ii) The significant impact which factoring cyber-security over the life of the product (ie to 2030+) has on the solution

iii) The importance of vendor selection and clear understanding of costs as demonstrated and experienced in current public sector contracts and circulars (ie Huawei and ESN overspend)

6.18 | Project Learning: NIA SP Energy Networks 0030 Zebedee Sectionaliser Device

As this project is creating a device to facilitate online sectionaliser maintenance, there are few lessons to be taken from the development process. However, it can certainly be observed that there is potential for development of new use cases for the device – such as preventing ferroresonance – which were not initially considered. This was discovered through business engagement wider than just the user base. As such, it is clear that restricting engagement when developing new devices could restrict effective development of the device, and prevent making full use of the device's potential.

6.19 | Project Learning: NIA SP Energy Networks 0031 Radiometric Arc Fault Location RAFL 2

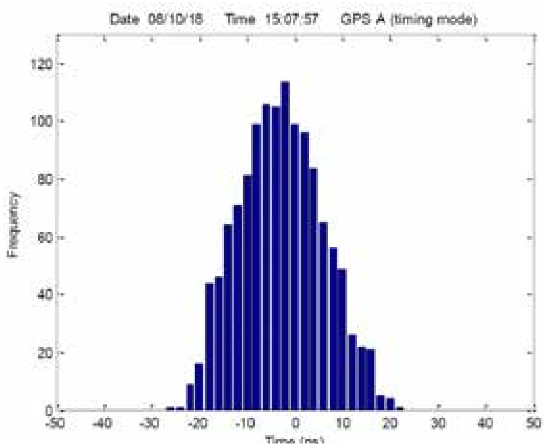
The significant learning from this project arises from the range and timing tests.

The range tests used the Power Networks Demonstration Centre (PNDC) to operate an 11 kV air break switch to energise an uncharged 40 m section of overhead line to simulate the initial stages of an arcing fault. Vehicle-mounted radio frequency receiving equipment (see Figure 1) was progressively moved further away from the PNDC to assess the maximum distance over which the switching operation could be received. The tests established that using narrowband receiving equipment the operation could be received at distances in excess of 5 km. This was a good outcome, given that genuine arc faults are anticipated to generate radio frequency signals significantly larger than the PNDC switching tests.

Figure 9 Mobile radio frequency receiving equipment used to detect arc-induced radio frequency signals

The timing tests aimed to establish the practically-realisable timing accuracy of commercially available GPS units from three manufacturers. This was achieved using an identical pair of GPS equipment, one of each pair being located at either end of an unused optical fibre running a distance of 2.1 km between a windfarm and a substation. The timing pulse (1PPS) from the substation GPS unit was transferred, via the fibre, to recording equipment located at the wind farm which measured the timing pulses from both GPS units. By compensating for the fibre delay, the timing accuracy of the two GPS units could be determined. This test was repeated with 3 pairs of GPS units from 3 separate manufacturers. The tests established that the combined accuracy of the best performing GPS device was 30 ns when operated over distances anticipated for the deployment of the RALF units – see typical result in Figure 2 for 1500 separate measurements. This accuracy corresponds to a location error of 9 m (if the fault lies midway between 2 RALF units) which is a satisfactory outcome for the project. The best performing GPS unit identified from these tests is now being incorporated into the hardware design of the RALF unit.

Figure 10 Typical timing accuracy histogram from best performing GPS unit



6.20 | Project Learning: NIA SPEN0033 CALISTA

As this project is still in a very early stage, there is no learning to be reported at this point in time.

6.20 | Project Learning: NIA SPEN0034Network Constraint Early Warning Systems (NCEWS 2)

Due to the slower than anticipated rollout of SMETS2 meters in the UK some of the connectivity improvement Data Analytical techniques that the project wished to explore have had to be delayed. But it is still recognised that the growing requirement for verification and near real time connectivity understanding, including phase identification, will continue to be a major requirement within this project to maximise benefit of LV data analytics going forward.

6.22 | Project Learning: NIA SPEN0036 A Holistic Intelligent Control System for Flexible Technogies

The project has only just started consequently there is no key learning to report at present.

6.23 | Project Learning: NIA SPEN0037 Electric Vehicle Uptake Modelling (EV-Up)

The project has only just started on consequently there is no key learning to report at present.

6.24 | Project Learning: NIA SPEN1801 Distributed Ledger Technology-enabled Distribution System Operation (Phase 1)

The project so far identified a number of potential benefits for electricity network users, including:

- Increased openness of the rules for interaction related to electricity network operation compared to traditional approaches. DLT allows the transactions to be made public in a way that cannot easily be tampered with, as compared to a third party controlled database and website, facilitating the independent verification of the outcome of transactions.
- Cost savings arising from the automation of contract performance, including transactions between businesses and between network users. Automation of contracts (smart contracts) using DLT means that the future performance of contracts can be trusted and that, dependent on the application, there is a reduced cost associated with monitoring and enforcement of agreements. Furthermore, where there is requirement for public scrutiny of contract processes, DLT allows for relatively tamper-resistant, low-cost and high resolution independent verification, compared to a manual process (e.g. scrutiny committees) or the use of a third-party database.
- Stimulation of regulatory renewal, particularly with regard to trustworthy instantiation of economic rules between multiple parties. For example, considering the whole system as an information network consisting of regulated monopolies, DLT offers new ways for regulators to define and implement rules for interaction between the monopolies so that the transaction information can be openly, and independently, verified by stakeholders.

Market facilitation	Generation	Transmission	Distribution	Trading	Metering	Other
Wholesale energy market	●	●	●	●	●	
Retail energy market				●	●	●
P2P enegry trading			●	●	●	●
Network operation						
Network management and security		●	●			
Flexibility services & demand response			●	●	●	●
EV charging & operation			●	●	●	
Network operation						
Data collection & management	●	●	●	●		
Security	●	●	●	●	●	
Network operation						
Renewable certificate handling	●			●		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