Notes on Completion: Please refer to the appropriate NIA Governance Document to assist in the completion of this form. The full completed submission should not exceed 6 pages in total.

NIA Project Registration and PEA Document

Date of Submission

Nov 2017

Project Reference Number

NIA_SPEN_0028

Project Registration

Project Title

Transition to low voltage DC distribution networks – Phase 1

Project Reference Number

NIA_SPEN_0028

Project Licensee(s)

SP Energy Networks Distribution

Project Start

March 2018

Project Duration

0 years and 10 months

Nominated Project Contact(s)

Anthony Donoghue

Project Budget

£142,000.00

Summary

It is well documented that the shift towards a low carbon society will result in a step change in how electricity is generated and consumed across distribution networks. In particular, the uptake of Low Carbon Technologies (LCTs) such as Electric Vehicles, Photovoltaics and Heat Pumps is reducing the available capacity within LV networks and creating a requirement for costly and time consuming network reinforcement. In fact, the potential UK network reinforcement caused by the uptake of Electric Vehicles alone has been estimated to reach £34bn - £48bn by 2040.

Furthermore, these LCTs are connected to an AC distribution network despite the fact that most consume and generate DC power. This creates the requirement for often low efficiency three stage converters between DC devices and the AC network, increasing both network demand and customer losses and equipment cost.

To overcome the challenges discussed above existing LV AC circuits could be converted to DC networks operation to release additional capacity within existing network infrastructure whilst significantly reducing customer losses. In theory, an LV DC distribution network could support longer LV feeders and reduce the number of secondary substations required to supply an area. This is due to improvements in transfer capacity caused by improved circuit voltage drop and increased cable thermal capacity. In addition to this, if the losses associated with EV charging were reduced by only 4% using a DC supply UK consumers could save up to £52m annually by 2040. For targeted applications LV DC network operations could deliver significant value to UK electricity consumers in the near future if innovation funding is invested into its development.

However, there are number of technical and commercial challenges which need to be addressed before LVDC can be fully adopted by UK DNOs as a business as usual (BaU) approach to facilitate the uptake of LCTs. Some of these challenges include:

- The impact on cable ageing when converting existing low voltage AC cables to LV DC at different voltage levels and cable types.
- The optimal LV DC voltage for distribution networks when considering both customers (reduced losses) and network requirements (increased transfer capacity).
- How an increased transfer capacity over distance could benefit and change network design practices i.e. longer LV feeders, less secondary substations, smaller cable etc.
- The H&S requirement for LV DC adoption both within the network and at the point of customer connection.

- The number of opportunities for UK DNOs to convert existing LV AC circuits to DC including a proven Cost Benefit Analysis (CBA) for different applications demonstrating the financial benefit.

The operational and maintenance requirements for existing LV AC circuits which have been converted to DC i.e. is the impact of a cable fault at DC any more or less severe?

Nominated Contact Email Address(es)

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Problem Being Solved

It is well documented that the shift towards a low carbon society will result in a step change in how electricity is generated and consumed across distribution networks. In particular, the uptake of Low Carbon Technologies (LCTs) such as Electric Vehicles, Photovoltaics and Heat Pumps is reducing the available capacity within LV networks and creating a requirement for costly and time consuming network reinforcement. In fact, the potential UK network reinforcement caused by the uptake of Electric Vehicles alone has been estimated to reach £34bn - £48bn by 2040.

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Method(s)

To address the problem listed above this project will carry out the following activities across two distinct Phases. Phase 1 will directly inform the requirements and refinement to the scope for **Phase 2 which will be registered separately** depending on the results and outcome of Phase 1.

Phase 1 will carry out **a** detailed review of LV DC network requirementsfrom a UK DNO point of viewand determine the optimal scope for Phase 2 as below based upon the latest learnings that are available from across the world. This includes:

- A literature review on latest technical and commercial learnings available for LV DC distribution networks from around the world. This will include protection requirements on both network and customer sides and the impact on existing network earthing.
- Desktop modelling of the expected capacity release and potential losses improvements that could be achieved by operating the existing LV AC circuits at DC under different applications using case studies of real network within SPD.
- Modelling of the transient and steady state performance of LV DC networks under fault conditions to inform protection requirements at different voltages and fed by different converter topologies.
- Developing technical specification requirements for LVDC DNO networks
- Developing technical specifications and laboratory test schedule for the cable testing planned within Phase 2.
- Market review of the available cable testing facilities that could be used within Phase 2 based upon requirements set out by the technical specification for LV cable testing at DC.

Phase 2 will carry out physical testing of existing LV AC cables of different types and sizes to determine the impact of converting circuits to DC for the purposes of increasing transfer capacity and reducing consumer losses. The results of the laboratory test will be compared with modelling activities conducted within Phase 1 and required adjustments to the model will be considered. This will inform DNOs on the practicalities of running a DC distribution network for applications such as rapid Electric Vehicle charging or supplying DC customers:

- Laboratory testing of typical 4-core and 3-core cables (new and existing) for operation under DC, using unipolar and bipolar cable configurations. This includes monitoring of partial discharge and cable temperature at different DC voltage levels and loading to determine:
  - The impact on cable health and rate of ageing when converted to DC operation.
  - The impact of a DC fault on the cable and surrounding area (informing operation and maintenance costs and damage level).
- Development of a CBA methodology for comparing the deployment of LV DC network vs traditional AC network design and reinforcement.
- Run the developed model and the CBA methodology on example networks (case studies) under several distinct applications to demonstrate the potential customer and network benefits.

Scope

Phase 1: 9 months and to include the following activities:

- **Literature review of existing and previous academic and practical projects in LV DC distributionfrom around the world**: The resulting document will contain current best practices and standards of LVDC networks that provide UK DNOs with the necessary background knowledge to develop LV DC networks. This document will also highlights any gaps in knowledge and testing that require further investigation. This will inform both the desktop modelling and technical specifications for testing of LV cables at DC. As a minimum the following content will be covered:
  - Protection requirements (relay, earthing etc.),
  - Potential network capacity increase over distance (assumptions and requirements)
  - Recommendations on DC voltage levels and associated operational risks and H&S issues
  - Customer requirements (voltage, equipment specifications, Health and Safety recommendations and risks)
  - LV DC networks configurations, comparison between bi-polar and uni-polar technologies, recommendations on suitability for UK distribution network application
  - Recommendations on LV DC metering technologies and potential commercial arrangements

- **Desktop modelling to demonstrate the performance of LV DC networks and their ability to improve network capacity and reduce losses:**
  - Evaluation of transfer capacity over distance for different cable types used by UK DNOs.
  - Fault transient behavior under DC operation considering different converter types and voltage levels and different earthing arrangements:

    DC faults profiles are significantly different from AC, and they can have different characteristics based on the following factors: the types of the converters providing DC and the local devices interfacing with the DC cables (e.g. LCTs); operating voltage levels; DC cable configurations and earthing arrangement; and used protection schemes and protection devices. With an LV DC network high transient discharging current with high rate of change can be experienced due the capacitive nature of LVDC followed by a steady state fault current without natural zero crossings. Such a profile will generate large thermal energy (larger Joules compared to AC) in the LV DC network which has to be absorbed and dissipated in the right time. In general this has to be done faster than in AC, to due to the aggression of DC arcs especially when a higher DC voltage is used compared to equivalent RMS AC. However, the level of such phenomena will depend on how the LVDC is designed and the type of protection is used. This task will investigate fault characteristics and potential fault levels of LV DC under different short circuit faulted conditions. This includes the simulation testing of faulted LV DC with different cable configurations, different converters interface (including converters without fault tolerance such as two-level VSC and converters with fault level capabilities such as full bridge MMC), and different earthing arrangements. The outcomes of the task will include:

    - Understanding the behavior of LV DC networks under different fault conditions
    - Identification of prospective fault levels under different LV DC and converter configurations, and this will help to identify the potential fault level management and protection requirements
    - Identification of the thermal energy generated during transient and steady state DC fault phases. This will feed to the Phase II testing for understanding how much energy is expected and passed in LVDC cables under different DC faulted conditions.
  - Time-domain analysis for different load profiles (24hrs) will be considered to demonstrate how losses/voltage profile/loading can be improved at DC when compared to existing AC operation.

- **Development of technical specifications for the testing of LV cables at DC** This will include a review of the LV cable types that are prevalent across the UK distribution network so that the testing within Phase 2 is optimized. This includes developing plans for the type of testing required, test schedules, and testing facility technical capability requirements.

- **A market review of the available cable testing facilities** based upon the technical specifications for testing to identify the potential testing facilities which meet the testing capabilities requirement and can be invited for the procurement of the activities within Phase 2.

Phase 2 – Cable Testing and BaU Integration (to be registered separately)

The following describes the initial scope for Phase 2 prior to the refinements that will be made based on the learnings gathered from Phase 1.

Work Package 1: Cable Laboratory Testing (3 months)

- Laboratory testing of both 3-core and 4-core cable at increasing DC voltage levels and cable configurations (unipolar vs bipolar).
- The impact of DC on cable rate of ageing will be determined using partial discharge and cable temperature monitoring.
- The impact of cable failure will be tested to understand the HSE & O&M requirements for converted DC circuits.The energy released from DC fault is normally higher than in AC due to the high transient discharge currents and steady state fault currents without zero crossings. The test will provide understanding the impact of such phenomena which will give design engineers and district staff the confidence that circuits can be operated at DC without additional unmanageable risk.

Work Package 2: Reporting and BaU documentation (6 months)

- The development of case studies for network reinforcement and including a detailed CBA to demonstrate the financial benefit that would be realised using a DC reinforcement/design approach.

Recommendations for network applications which would benefit the most from the deployment of LV DC distribution.

Objective(s)

- Provide DNOs with a proven business case to demonstrate whether low voltage DC networks can be a financially and technically competitive alternative to costly conventional reinforcement and network design.
- Evaluate and understand the performance of existing low voltage cables under DC operation to provide adequate learnings for the technical and operational requirements of converting LV AC networks to DC operation.
- Provide a road map of potential applications that could benefit from low voltage DC supplies (rapid EV charging, street lighting) along with a detailed cost benefit analysis using relevant case studies.

Consumer Vulnerability Impact Assessment (RIIO-2 Projects Only)

n/a

Success Criteria

Assessment and quantification of the impact of DC voltages on existing AC cable.

Provision of technical guidance for converting LV AC circuits to LV DC operation.

Development of a clear business case demonstrating benefits of converting circuits to DC under different applications to avoid costly conventional network reinforcement.

Project Partners and External Funding

n/a

Potential for New Learning

Phase 1 – The technical requirements for DNOs to plan and operate LV DC networks. Demonstration of the benefits of LV DC and business case that can be realised if deployed as BaU under targeted applications.

Scale of Project

Phase 1 – 9 months to deliver scope described above.
Phase 2 - This phase of the project will test the impact of converting low voltage 3-core and 4-core cables that are prevalent across the UK distribution network from AC operation to DC operation at a test centre and provide documentation for the BaU adoption of the Method and the associated cost benefit analysis for future deployment.

Technology Readiness at Start

TRL3 Proof of Concept

Technology Readiness at End

TRL5 Pilot Scale

Geographical Area

NA

Revenue Allowed for the RIIO Settlement

None

Indicative Total NIA Project Expenditure

Phase 1 - £142,000

Project Eligibility Assessment Part 1

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

Requirement 1

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

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

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

n/a

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

n/a

Requirement 2 / 2b

Has the potential to deliver net benefits to consumers

Project must have the potential to deliver a Solution that delivers a net benefit to consumers of the Gas Transporter and/or Electricity Transmission or Electricity Distribution licensee, as the context requires. This could include delivering a Solution at a lower cost than the most efficient Method currently in use on the GB Gas Transportation System, the Gas Transporter's and/or Electricity Transmission or Electricity Distribution licensee's network, or wider benefits, such as social or environmental.

Please provide an estimate of the saving if the Problem is solved (RIIO-1 projects only)

As a research project Phase 1 will allow DNOs to understand the potential business case for LVDC distribution networks in more detail and will inform a more detailed business case for Phase 2 of the project. However, several studies have demonstrated the potential benefits associated with LVDC which gives confidence that the topic as a high potential to positively benefit UK electricity consumers if deployed in the future.

In brief, LVDC networks offer DNOs the opportunity to avoid costly reinforcement of the LV cable network by increasing the transfer capacity of existing assets. The cost to reinforce an LV feeder can vary between approximately £80,000-£330,000/km depending on the specific location and can take a long time to deliver with much disruption to the public. LV DC networks can also directly benefit customers by significantly reducing the losses associated with the repeated conversion between AC and DC powered devices and LCTs.

There are many potential applications where a DC supply could deliver savings but the precise cost saving will vary depending on the specific characteristics of each application. However, for the purpose of estimating the potential value for this Phase 1 Research NIA we have estimated that a DC converted secondary substation could save **approximately £123,000 per case** by avoiding the need to lay new LV cable and build additional secondary substations to satisfy the expected increase in LCT loading.

Furthermore, it is estimated that the uptake of EVs will result in the need to reinforce over 5000 additional circuits and 1000 substations across SPD by 2030 if alternative innovative solutions are not developed. LVDC circuits can provide additional capacity within the existing LV network for EV charging. It could also provide an opportunity to use the existing street lighting network to facilitate charging points whilst minimizing street furniture.

Additional Evidence of Potential Savings:

- The paper "Application of Low Voltage DC Distribution Systems – A Techoeconomical study" by Lappeenranta University of Technology in Finland has demonstrated a **cost saving of around £50,000** when designing a rural network at LVDC. This is not a reinforcement example, but demonstrates the economical comparison between a traditional 20/0.4 kV network design and a ± 750 VDC bipolar distribution system. A reinforcement example could demonstrate larger savings as the need to carry out cabling could be eliminated altogether as described above.

- The paper "An LVDC Distribution Concept" again demonstrates the costs savings for a newly built DC distribution network when compared to a traditional AC network. It shows a traditional cost of €328.25k for a 20/0.4kV network, compared with only €288.06k for a ± 750VDC distribution system, giving a **total cost saving of €37.19k**. Again, this application is different to the conversion of existing circuits to DC to avoid costly cable reinforcement altogether as described within this document.

Please provide a calculation of the expected benefits the Solution

Base Case: A congested secondary substation with four overloaded LV feeders caused by voltage and/or thermal issue.

The precise cost for conventional reinforcement varies case to case but may include the replacement of existing cables with larger size cables or shifting loading from one substation to a new secondary substation built close by. This total cost to deliver this can vary from £100k to £330k depending on the specific case. **Therefore, we have considered an average base case cost of £215,000.**

Method Case: Conversion of four LV feeders to DC and the cost of the associated equipment

The capacity for the connection of LCTs (particularly PV and EVs) can be released within the existing cables much quicker and with a lower cost by converting to DC. A conservative cost estimate to convert an LV AC circuit to DC is detailed below:

- Converter (AC/DC) at the beginning of the feeder (secondary substations): £4.0k to £8.0k , **Average £6.0k**
- Converter (DC/AC) at some of the customer's side: Assumed 15 customers per feeder, and £0.75k to £1.25k converter cost, **total average cost £15,000**
- Protection equipment at the secondary substation: £1.0k to £3.0k, **average £2.0K**

The above summates to a **Method Cost of £92,000** based upon four LV feeders.

Net Financial Savings = Base Case – Method Cost = £215,000- £92,000 = £123,000

This calculation does not include the following benefits / additional costs:

- The value of any improvement in customer losses.
- The capital cost reduction of EV charging points at DC instead of DC
- The time saving by not having to lay new cable or build new substations in a busy urban area (Approximately 9-12 months to plan and deliver a LV cable reinforcement job)
- The environmental and carbon benefits associated with not carrying out LV cabling in a densely populated area.

The additional OPEX associated with the power electronic converters.

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

It is estimated that the impact of Electric Vehicles alone could result in the reinforcement of 1000 substations and 5000 circuits across SPD by 2030.

Based upon 14 UK licensed areas this equates to 14000 substations and 70000 circuits across GB

Note: This does not consider the reinforcement caused by other LCT and non LCT load growth

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

To be determined and understood as a result of Phase 1 prior to Phase 2.

Requirement 3 / 1

Involve Research, Development or Demonstration

A RIIO-1 NIA Project must have the potential to have a Direct Impact on a Network Licensee's network or the operations of the System Operator and involve the Research, Development, or Demonstration of at least one of the following (please tick which applies):

☐ A specific piece of new (i.e. unproven in GB, or where a method has been trialled outside GB the Network Licensee must justify repeating it as part of a project) equipment (including control and communications system software).

☑ A specific novel arrangement or application of existing licensee equipment (including control and/or communications systems and/or software)

☑ A specific novel operational practice directly related to the operation of the Network Licensees system

☑ A specific novel commercial arrangement

RIIO-2 Projects

☐ A specific piece of new equipment (including monitoring, control and communications systems and software)

☐ A specific piece of new technology (including analysis and modelling systems or software), in relation to which the Method is unproven

☐ A new methodology (including the identification of specific new procedures or techniques used to identify, select, process, and analyse information)

☐ A specific novel arrangement or application of existing gas transportation, electricity transmission or electricity distribution equipment, technology or methodology

☐ A specific novel operational practice directly related to the operation of the GB Gas Transportation System, electricity transmission or electricity distribution

☐ A specific novel commercial arrangement

Specific Requirements 4 / 2a

Please explain how the learning that will be generated could be used by the relevant Network Licensees

The application of LVDC networks can be of value to all UK DNOs as all expect to be impacted by the same needs case driven by the uptake of Low Carbon Technologies (LCTs) particularly Electric Vehicles.

Knowledge generated by the project will be shared openly with other UK DNOs so that the learnings can be implemented widely after project closure.

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

This project will help to address the following challenges:

- **Faster, easier, accurate connection –** An LV DC supply could allow capacity for the connection of LCTs to be made available much quicker than conventional reinforcement that may include building new secondary substations and laying new LV cable.

- **Preparing the Network for Low Carbon Technologies (LCT) –**This project aims to lay the ground works for a more innovative and low cost method to facilitate the additional demand placed on the distribution network by LCTs, particularly Electric Vehicles.

- **Network Control, Flexibility and Communications –**This project will lead to more design options when reinforcing the distribution network leading to increase flexibility and network control by operating at DC and increasing network transfer capacity over distance .

- **Minimising the environmental impact of our activities and assets -** A DC network can reduce consumer losses and the associated carbon emissions and reduce the need for replacing cable due to LCT load growth which can be extremely carbon intensive, particularly in densely populated areas where local emissions can be harmful to health.

- **Modernisation of working practices –** This project will review how SPEN design policy and best practices would need to be updated to consider the deployment of LVDC circuits as an alternative to conventional reinforcement.

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

Is the default IPR position being applied?

☑ Yes

Project Eligibility Assessment Part 2

Not lead to unnecessary duplication

A Project must not lead to unnecessary duplication of any other Project, including but not limited to IFI, LCNF, NIA, NIC or SIF projects already registered, being carried out or completed.

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

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

Similarly, splitting the project into two separate phases allows the project to collate the latest learnings and apply them to Phase 2 to minimise project cost and maximise learnings.

If applicable, justify why you are undertaking a Project similar to those being carried out by any other Network Licensees.

n/a

Additional Governance And Document Upload

Please identify why the project is innovative and has not been tried before

n/a

Relevant Foreground IPR

n/a

Data Access Details

n/a

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

activities

n/a

Please identify why the project can only be undertaken with the support of the NIA, including reference to the specific risks(e.g. commercial, technical, operational or regulatory) associated with the project

n/a

This project has been approved by a senior member of staff

☑ Yes