SP ENERGY NETWORKS

LV Engine

2017 Network Innovation Competition Proposal

Reviewed and approved by:

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  SP Energy Networks
- Ian Cameron, Head of Innovation
  UK Power Networks

Project Code/Version Number:
SPMEN02/V01

Section 1 Project Summary

1.1 Project Title	LV Engine
1.2 Project Explanation	LV Engine will carry out a globally innovative trial of Solid State Transformers (SSTs) within the distribution network at secondary substations (11kV/0.4kV) for the purpose of enhancing network flexibility and releasing additional capacity within our existing low voltage (LV) infrastructure and facilitating the increasing uptake of Low Carbon Technologies (LCTs).
1.3 Funding licensee	SP Manweb plc. supported by SP Distribution plc.
1.4 Project description	**Problem:** The UK electricity network is experiencing a significant change in the way electricity is generated and consumed due to the growing uptake of LCTs and the electrification of heat and transport resulting in: • A strain on the LV network leading to network operation out with voltage statutory limits and thermal capacity of network assets; • Inability to ensure cost effective network design due to uncertainty in uptake of LCTs; • An increasing demand for LVDC and the associated benefits. These developments mean that a conventional 'fit-and-forget' approach no longer represents value for money for UK electricity consumers. **Method:** LV Engine intends to carry out a network trial of SSTs within secondary substations and compare their effectiveness in supporting the LV network with conventional 11kV/0.4kV transformers. The outcomes of this trial will lead to technical guidance documents and methodologies to inform the optimal selection of secondary transformers and the functionality required at secondary substations given the local LV network characteristics and requirements. **Solution:** LV Engine will significantly enhance the flexibility and adaptability of LV networks to facilitate the uptake of LCTs whilst avoiding costly network reinforcement. LV Engine will enable the following: • Active operation of LV networks; • Better utilisation of existing network infrastructure; • Facilitate the integration of LCTs at LVAC & LVDC; • Support the DSO transition. **Benefits:** LV Engine will deliver savings to customers by enabling the uptake of LCTs within the 11kV & LV networks. The project will demonstrate how SSTs can be a more competitive alternative to conventional reinforcement, whilst stimulating a competitive market place for power electronics & SSTs within UK distribution networks. If successful, the roll out of the LV Engine solution at **GB level could represent a saving of £62m by 2030 & £528m by 2050**. Valuable learning will also be generated for future SST and LVDC projects.

1.5 Funding			
1.5.1 NIC Funding Request (£k)	7,290.06	*1.5.2* Network Licensee Compulsory Contribution (£k*)*	824.16
1.5.3 Network Licensee Extra Contribution (£k)	0.0	*1.5.4 External Funding – excluding from NICs (£k):*	53.69
1.5.5 Total Project Costs (£k)	8,295.28		
1.6 List of Project Partners, External Funders and Project Supporters (and value of contribution)	**Project Partners:** UK Power Networks will be project partner and member of our design authority board. Manufacturing partner(s) and a lead consultancy will be identified upon funding award through a competitive tendering process to ensure the project delivers value for money to UK electricity customers. **Academic Partners:** Extensive engagement has taken place with academic institutes to identify potential project partners. Academic partners who represent value for money will be selected during project set up. **Project Supporters:** Power Electronics UK, Glasgow City Council, ETH Zurich, Kiel University, Heriot Watt University, University of Strathclyde, WSP, BRE, PNDC, BSI, IEC, IET, Direct Current BV, Franklin Energy, Chargemaster.		

1.7 Timescale			
1.7.1 Project Start Date	January 2018	*1.7.2 Project End Date*	December 2022

1.8 Project Manager Contact Details			
1.8.1 Contact Name & Job Title	Anthony Donoghue, Innovation Engineer	*1.8.2 Email & Telephone Number*	adonoghue@spenergynetworks.co.uk +441416146904
1.8.3 Contact Address	Ochil House, Technology Ave, Blantyre, Glasgow G72 0HT		

1.9 Cross Sector Projects – N/A	
1.9.1 Funding requested the from the [Gas/Electricity] NIC (£k, please state which other competition)	N/A
1.9.2 Please confirm whether or not this [Gas/Electricity] NIC Project could proceed in the absence of funding being awarded for the other Project.	N/A

1.10 Technology Readiness Level (TRL)			
1.10.1 TRL at Project Start Date	5	*1.10.2 TRL at Project End Date*	8

Section 2 Project Description

2.1 Aims and objectives

LV Engine aims to add flexibility and release additional network capacity within LV networks by informing the design and selection of a cost effective intelligent secondary transformer solution. This enhances the adaptability of LV networks to enable the future uptake of LCTs. LV Engine will design and trial the first UK SST for deployment within secondary substations (11kV/0.4kV) and produce smart tools for the efficient reinforcement of future LV networks. SSTs will be trialled within five different schemes and their performance will be technically and financially compared with conventional reinforcement and transformers fitted with on-load tap changers (OLTC). This comparison will inform a series of technical and financial guidance documents for the selection of future LV network reinforcement solutions which deliver the best value for money for UK electricity customers.

SSTs provide multiple functionalities which can bring value to the LV network. However, LV Engine will focus and demonstrate the following preliminary smart SST functionalities under different network conditions:

1- Optimum real-time phase voltage regulation in LV networks;
2- Capacity sharing between secondary substations with complementary load profiles where spare capacity is available;
3- Fault level control to allow meshed LV network operation;
4- Provision of an LVDC supply for Electric Vehicle charging and LED street lighting.

The LV Engine solution enables the LV network to be scalable, flexible and adaptable to accommodate the uptake of LCT demand and generation. LV Engine has the following objectives:

1- Design and trial of the first UK grid connected SST for application within secondary substations;
2- Provide functional specifications and control strategies for deploying the smart functionalities which an SST can provide in different network conditions;
3- Compare the performance and functionalities of SSTs with those of conventional reinforcement and transformers fitted with OLTCs;
4- Provide technical guidance, policy documents, a cost benefit analysis methodology and tools for the intelligent selection of future secondary transformers to ensure the Business as Usual (BaU) adoption of SST technology;
5- Provide functional specifications of a fit-for-purpose network design to inform the provision of LVDC supplies to UK electricity customers from SSTs;
6- Demonstrate the protection of LV networks where power electronics are used;
7- Stimulate the SST market for future competitive production of this technology;
8- Provide performance data together with the control algorithms to universities for further academic research and development;
9- Up-skill internal staff on power electronics technologies and applications within distribution networks and the value it can bring;
10- Knowledge dissemination to UK DNOs and the UK power electronics industry to facilitate the replication of the LV Engine solution across GB;
11- Collaborate with our project partner, UK Power Networks, to develop a solution which can be adopted by all UK DNOs for BaU planning and operation of LV networks.

2.1.1 The Problems that need to be resolved

Colin Taylor, SPEN Director of Engineering Services: *"Projects like the New Thames Valley Vision have shown that the LV network is the part of the network that will be most stressed as LCT uptake increases. In addition to much improved LV network monitoring, we require new technologies and strategies to be made available to optimise use of capacity and facilitate a truly flexible energy system."*

The electricity network in the UK is experiencing significant changes in the way energy is generated and consumed due to the growing integration of LCTs. The UK government's intention to electrify the transportation and heating sectors will result in an increase in network demand despite improvements in energy efficiency. The growing connection of distributed generation (DG) is also causing an additional strain on the LV network. The conventional "fit-and-forget" approach to the design of our LV networks is no longer a cost effective solution to accommodate an increasing uptake in LCTs. Conventional network reinforcement does not represent value for money for our electricity customers for the following reasons:

Uncertainties in LCTs growth: The level and time horizon of the changes in demand and generation due to LCTs integration are difficult to predict as they depend on customer behaviour, technology maturity, costs of LCTs and also government policies. Figure 2-1[1] shows the range of possible growth in different LCTs (heat pumps, electric vehicles and solar panels) by 2040. Conventionally, LV networks are passive and designed for the worst demand and generation conditions. Considering a wide range of scenarios for LCTs growth, the conventional planning approach can result in prohibitively expensive and unnecessary LV network investment. Consequently, the LV network requires additional flexibility and adaptability to cope with this uncertainty in LCT growth.

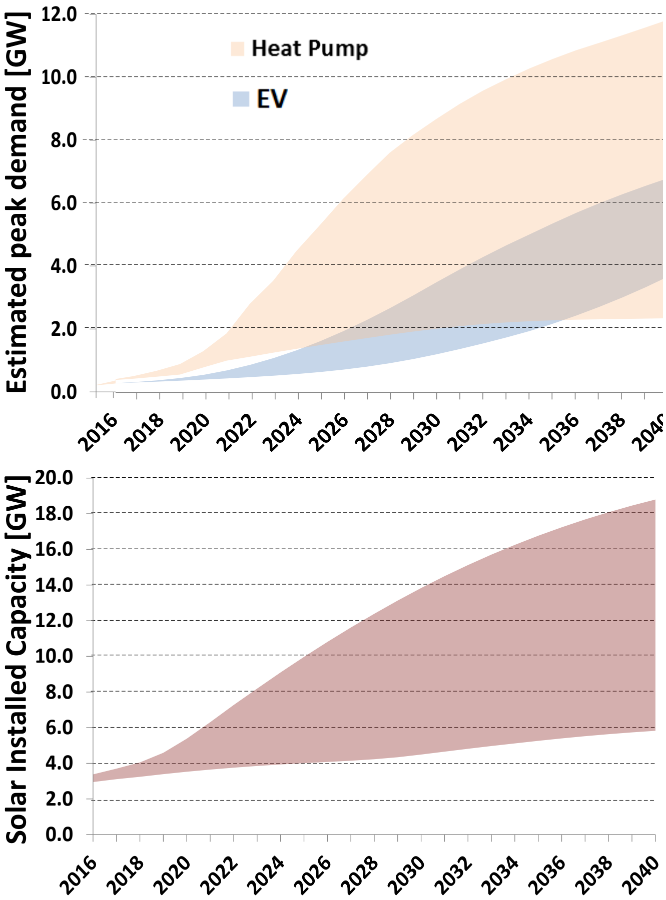

Figure 2-1: Range of possible growth in LCTs (a) range of estimated peak demand for EVs and Heat Pumps (b) range of estimated solar installed capacity

Increase in demand and LV DG connections: Although there are uncertainties in the levels of demand and DG growth, all future scenarios show an increase in LCT uptake. EVs are expected to grow significantly both in the total number of vehicles and the average size of EV charging points (increasing from 3.3kW in 2016 to 7.0kW by 2040). NG FES predicts that there will be 9.7 million EVs on the road by 2040. In addition, heat pumps are becoming the desirable option as the primary heat source for households and are projected to reach around 9.1m installation across GB by 2040.

The additional demand caused by EVs' and heat pumps' is very likely to coincide with the traditional winter peak demand doubling or even tripling the peak demand from each household. This could cause both significant voltage drops in the LV network and thermal stress on network assets. In addition, connection of G83 DG, mainly in the form of Photovoltaics (PVs), has been growing in LV networks and it is very likely that we will see more clustered connection of PVs in the future. This growing connection of PVs will cause overvoltage and reverse power flow issues in LV networks at off-peak times.

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[1] Data obtained from *National Grid Future Energy Scenarios (NG FES).*

The combination of additional LCT demand and generation may drastically increase the daily voltage variation on the LV network and result in a requirement for costly network reinforcement.

The conventional fit-and-forget operation philosophy is no longer a cost effective approach to maintain network voltage within the statuary limits. Figure 2-2 illustrates the daily voltage variation in LV networks when the uptake of LCT demand and generation increases.

It should be noted that within SPD & SPM licensee areas the LV network is already experiencing a strain due to unexpected load growth and the increasing penetration of LCTs, particularly photovoltaics (PV). Previous network innovation projects such as New Thames Valley Vision, LV Network Voltage Solutions have also demonstrated that LV networks in many areas will be unable to meet the demands of increased LCT adoption due to thermal and voltage issues. A summary of learning from other GB low carbon network fund projects addressing these issues is given in Appendix N.

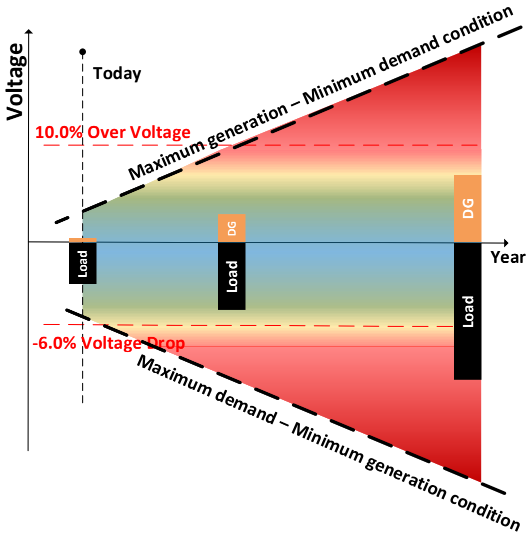

Figure 2-2: Illustration of LV network daily voltage variation range due to growth of LCT loads and generations. (+10% and -6% voltage statuary limits)

Increasing demand for the supply of DC power: Almost a third of household electricity demand is now from DC appliances[1]. This percentage will increase as LCTs such as EVs, HPs, and PVs become more popular in the future. DC demand is also increasing for the large commercial and industrial customers. A variety of research and innovation projects worldwide have already demonstrated the considerable benefits associated with a DC supply to electricity customers. A DC supply will allow DC generation and DC consumption to be offset against each other resulting in a reduction in the losses caused by device by device AC to DC conversion. Appendix K provides an overview of benefits of DC networks and the need case for DC supply. LV Engine intends to understand the value to DNOs and electricity consumers in providing a LVDC supply for EV charging and street lighting in commercial settings.

To overcome the aforementioned challenges, the traditional approach to LV network design and operation may no longer represent the best techno-economical option and an alternative approach must be found to deliver the LV network of the future. Secondary substations, as the bridge between LV and the rest of grid, can be intelligent hubs providing smart functionalities and the flexibility required for the operation of our future LV networks. Consequently, there is a need to develop a more informed secondary substation selection process to assess the levels of smart functions required by the specific LV network based upon its characteristics, thus ensuring the network is prepared for future uses and provides value for money for UK electricity customers.

2.1.2 The Method being trialled to solve the Problem

In order to develop a novel and informed approach to the selection of future secondary transformers, we propose trialling smart SSTs within secondary substations and comparing their effectiveness in supporting the LV network with that of conventional MV/LV transformers and those fitted with OLTCs. The outcomes of this trial will lead to

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[1] Demand DC: Adoption Paths for DC Power Distribution in Homes, ACEEE, 2016

technical guidance documents, policy documents and methodologies which will inform the optimal selection of the controllability required at secondary substations given the local and neighbouring LV networks requirements.

Our method includes designing, manufacturing, and trialling a fit-for-purpose SST. This represents the first UK grid application of SSTs for the purpose of enhancing LV network flexibility and facilitating a high penetration of LCTs. A general concept of the proposed method is illustrated in Figure 2-3. SSTs provide multiple functionalities which can be deployed for enhanced network operation, more efficient use of network assets and facilitating LCTs integration. SST functionalities include:

1- **Optimum LV phase voltage regulation:** The power electronic design of SSTs allows for smooth voltage regulation of individual phases at the LV busbar of a secondary substation in real-time. The overall voltage profile of an LV feeder can be optimised by intelligently adjusting the phase voltage in real-time at the secondary substation in response to monitored voltage data points along the length of each LV feeder.

2- **Optimum active power sharing between neighbouring substations:** SSTs have the capability to control power flow due to the inclusion of power electronics. This allows an SST to load share with nearby traditional transformers in real time for the purposes of reducing the thermal strain at peak times. In conventional network design, secondary substations cannot be operated in parallel arrangements[1] due to uncontrolled power flows and issues with high fault levels. However, with SSTs we can overcome this limitation by providing power flow and fault contribution controllability functions, allowing safe parallel operation and the controlled sharing of thermal capacities among neighbouring substations.

3- **Voltage regulation at MV (11kV) network:** An SST offers independent voltage regulations at the LV and MV sides of SSTs. Reactive power support and local voltage regulation at MV can be deployed to improve the voltage profile along the MV network. This function can be complementary to the conventional Automatic Voltage Control (AVC) scheme at the upstream primary substations.

4- **Provision of a LVDC network:** Conversion of voltage from MV to LV by use of power electronics provides access to a DC voltage at the secondary substation. A DC connection can be made available to satisfy any local DC demand, renewable energy sources (RES), or energy storage without repeated rectification from AC to DC and the resulting network and customer losses. Running the LV network at DC can also increase the transfer capacity of the network allowing more EV load to connect to the network before costly reinforcement is required (Appendix K).

5- **Modular design and scalability:** The power electronic design and the use of high frequency transformers allow a modular and compact design of SSTs. This means SSTs can be uprated by adding additional "capacity blocks" rather than replacing the whole unit as with the conventional transformer upgrade approach.

LV Engine aims to provide a fit-for-purpose SST design and relevant control functions that can be repeated and adopted by UK DNOs. Nonetheless, we recognise that whilst SSTs can provide significant flexibilities to the LV network their deployment under different applications should be justified through a well-defined cost benefit analysis. Therefore, we will use the results of the LV Engine trial and its demonstration schemes (See section 2.1.3) to create policy documents, technical guidance and cost benefit analysis tools to justify the future selection of an SST against conventional transformers and those fitted with OLTCs during BaU network design.

[1] Except LV networks in some parts of SP Manweb which have been specifically designed for mesh operation

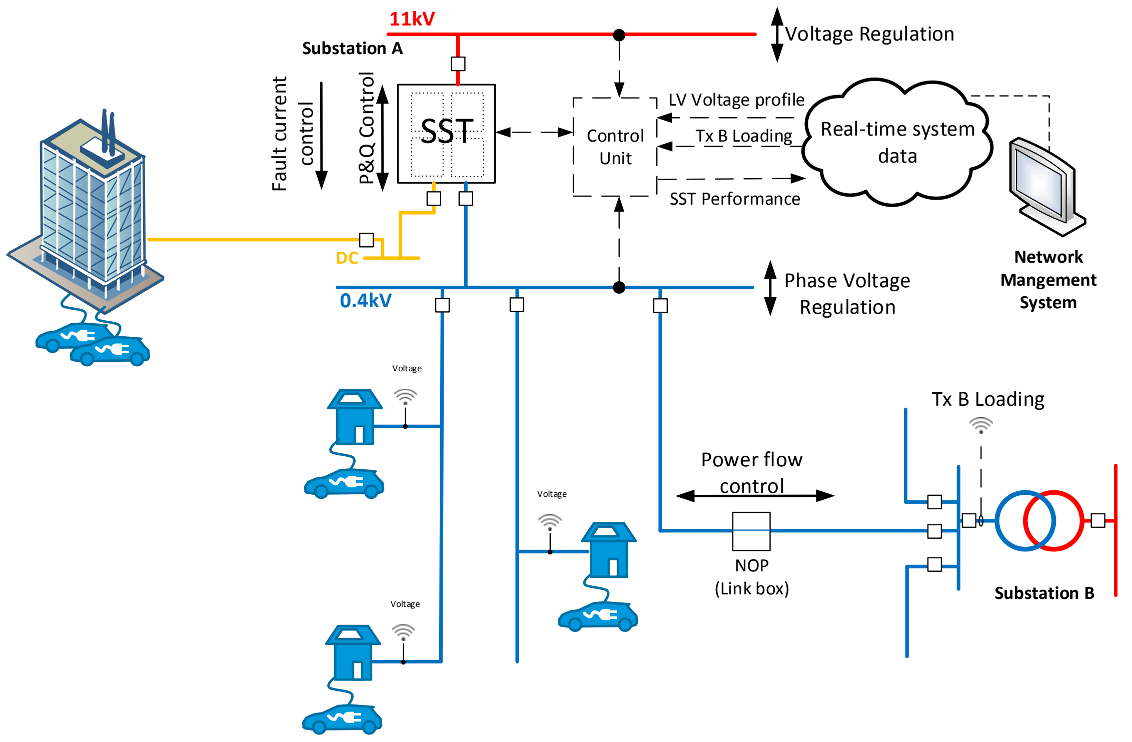
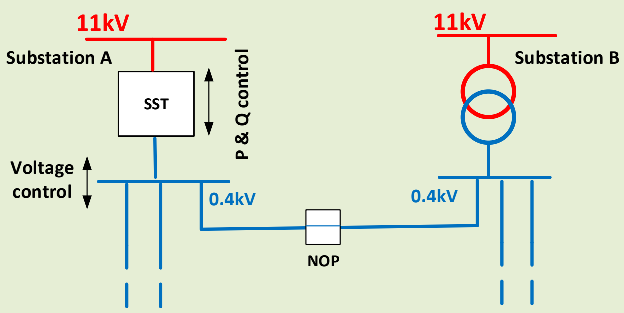


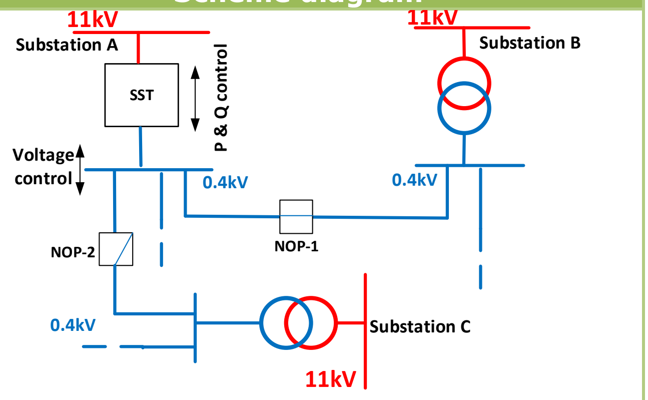
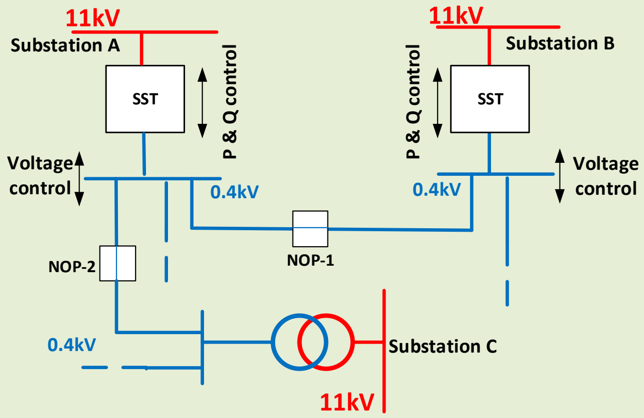
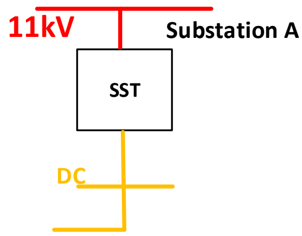
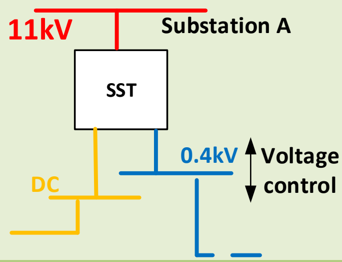
Figure 2-3: The high level functionalities of a SST considered in LV Engine's method

2.1.3 *The Development or Demonstration being undertaken*

We plan to demonstrate the SST performance in different schemes where different network issues or customer requirements need to be addressed. In order to provide an adequate level of technical and financial knowledge for applications of SSTs, five different schemes will be implemented within LV Engine.

These demonstration schemes are designed to provide distinctive learning which can inform the adoption of SSTs as one of the BaU reinforcement options. Each scheme requires its own technical specification, control algorithms, communication techniques, and monitoring methodology. We will collate the learning from the five schemes to form a policy document and best operational practice guidance which also includes cost benefit analysis tools. This will inform a cost-effective and technically-sound selection of the intelligence required at a secondary substation given the characteristics of the specific LV network. One trial of each scheme will be considered and each scheme will be trialled in different parts of SPD and SPM where we can adequately demonstrate the functionalities of SSTs without risking supply to our network customers. An overview of each trial scheme is as follows:

Scheme description	Scheme diagram
Scheme 1 - This scheme aims to demonstrate the voltage control and capacity sharing functionalities of an SST. The Normally Open Point (NOP) between a conventional substation and the SST will be closed to create a solid interconnector between the two substations. The power flow control at SST with the NOP closed will allow a controlled exchange of power between LV networks supplied by Substation A and Substation B.	

Scheme description	Scheme diagram
Scheme 2 - This scheme provides further flexibility compared to Scheme 1. It aims to demonstrate the optimum LV voltage control and capacity sharing functionalities of SST with two neighbouring conventional transformers. In this scheme, SST will share the power with only one conventional transformer at a time which will be managed by the controlled remote switching of NOP-1 and NOP-2.	
Scheme 3 - This scheme provides a condition when two SSTs in neighbouring areas are operational. Scheme 3 aims to demonstrate the optimum LV voltage control and capacity sharing functionalities of two SSTs with one conventional transformer. In this scheme, the NOP between the three substations will be closed providing two solid interconnectors. The real-time power flow control at SSTs will provide a controlled power exchange among the LV networks supplied by substations A,B, and C.	
Scheme 4 - This scheme aims to demonstrate the DC supply capability of an SST. We are planning to supply a single customer with a LVDC supply. This scheme will demonstrate the requirements for design, installation and operation of an LVDC network using an SST.	
Scheme 5 - This scheme aims to demonstrate the hybrid AC/DC functionality of SST by supplying a DC customer along with other AC customers. This scheme will produce technical requirements for design, installation and operation of a hybrid LVDC/AC network.	

We have identified multiple candidate trial sites where the SSTs can alleviate the network issues (see Appendix M). However, during the project we will carry out a comprehensive trial site evaluation to identify the exact sites for trialling the SSTs and maximise the learning from each scheme. The methodology to select the candidate trial sites for each scheme is described in detailed within Appendix L.

2.1.4 The Solutions which will be enabled by solving the Problem

The methods proposed by LV Engine will significantly enhance the flexibility of the LV network and enable an active and adaptive LV network operation paradigm. Passive LV networks can no longer provide the best value for money for our customers in a low carbon energy system. LV Engine will demonstrate that the deployment of flexible and smart secondary substations can be a superior alternative to conventional reinforcement. The design, manufacturing and proof of technology of a SST will also create a competitive market reducing the SST cost while improving quality.

The LV Engine will enable the following solutions:

- **Active operation of LV networks -** An active and adaptive LV network operation scheme is required to accommodate the long-term and short-term uncertainties in LV customers' demand and generation; otherwise significant network reinforcement will be required to keep the network operational. LV Engine methodologies offer active real-time phase voltage regulation and capacity sharing capabilities which can be flexibly deployed to meet the customers' needs and grid requirements. LV Engine will also enable an adaptable network by providing a scalable secondary substation design.
- **Better utilisation of network assets –** The LV Engine method enables an alternative solution to conventional reinforcements, the cost of which may increase significantly during RIIO-ED2 due to growing LCTs integration. LV Engine will demonstrate how the use of SSTs can release network capacity within our existing infrastructure to reduce the requirement for this investment.
- **Facilitate integration of LCTs –** The UKs low carbon emission targets depend on the successful integration of LCTs within the LV network. However, the clustered integration of LCT demand and generation may be delayed due to network voltage and thermal issues. The LV Engine solution will facilitate the connections of LCTs by avoiding the lead time required for network upgrade through conventional reinforcements. Furthermore, an LVDC supply could act as an enabler for the faster and more cost effective integration of Electric Vehicle charging points into the LV network.
- **Support DSO operation transition –** LV Engine will provide the future Distribution System Operator (DSO) with tools and methodologies for real-time management of network constraints. That can delay the point at which a DSO will intervene or make requests customers to adjust their behaviour. In addition, managing network constraints can facilitate the access to market for energy aggregators and allow them to offer various services to our LV customers.

2.2 Technical description of Project

2.2.1 Solid State Transformer topology

There is considerable interest in the development of SSTs within academia and by manufacturers, who both see the potential for such devices within the power distribution networks of the future. Many topologies have been proposed for SSTs[1] and our initial engagement with manufacturers has also confirmed that there are a number of viable topologies which could be used to implement a SST. Appendix G provides some technical details of SST design. The key features of a SST can comprise of the following blocks:

- A converter from AC to DC which will be connected to the SP Energy Networks 11kV three-phase distribution supply;
- A DC stage, which can supply multiple output stages at both AC and DC voltages;
- A DC to DC converter, which can provide a desirable DC supply;
- A DC to AC converter, which can provide an AC (0.4kV) three-phase supply;

[1] Solid-State-Transformers: Key Components of Future Traction and Smart Grid Systems, IPEC 2014. Concepts, modelling, applications, advantages and challenges, Power Electronics for Grid Connected Renewable Energy Systems, 2015.

- A high/medium frequency transformer, which provides the required step-down in voltage of the SST and also ensures galvanic isolation between the Medium Voltage (11kV) and Low Voltage (0.4kV AC and DC) systems.

2.2.2 LV ENGINE is an innovation project

LV Engine is highly innovative and we are expecting significant learning to be generated in this project for a flexible and controllable LV network. The innovation aspects of LV Engine are fourfold:

- **SST manufacturing and design -** LV Engine will design, manufacture and trial the world's first grid connected SST (to our best knowledge). The TRL of SSTs for grid applications is considered to be 5, as numerous prototype devices have been through laboratory trials. There are still several technical and operational challenges for a SST grid application which require to be addressed before BaU adoption. LV Engine aims to enhance the SST TRL to 8.
- **Controllability in LV network -** The control algorithms and functionalities of the schemes considered within LV Engine including phase voltage control and capacity sharing are unique and innovative.
- **Trial of LVDC network -** LV Engine will trial an LVDC network for the purpose of supplying street lighting and EV charging points. This has not been trialled by any UK DNOs before. However, LVDC is a promising solution for connection of many LCTs. LV Engine will provide valuable learning and technical requirements for the future deployment of LVDC networks and allow DNOs to understand when and how it can reduce network reinforcement.
- **Methodology of future transformer selection -** A methodology for selecting the optimal transformer which considers the outcomes of the LV Engine schemes, conventional transformers and also transformers fitted with OLTC will provide the most technically capable and cost effective reinforcement solution.

2.3 LV ENGINE Work Packages

LV Engine is planned to be managed within seven work packages (WP). The separate work packages are designed to give focus to the major activities and developments required for the successful delivery of LV Engine.

Table 2-1: LV Engine work package description

WP 1 – Technical design	Duration: Mar 2018- Nov 2018
Objectives: Develop the detailed technical specifications which will be required for manufacturing and implementation of the LV Engine solution and identify trial sites.	
Description: The site selection methodology described in Appendix L will be modified where required and a fresh site selection will be carried out to identify the trial sites for each LV Engine scheme. The technical specifications of SSTs including control algorithms, operation ranges, component ratings, size and enclosure, and maintenance requirements will be developed in this WP. The technical specifications of SSTs will be developed based on each LV Engine's scheme operational requirements. The performance of SST in different network conditions and the specification of the control algorithms will be assessed through desktop simulation of the identified trial sites. We will engage with experts, academics, manufacturers and UK Power Networks prior to procurement to ensure that the developed technical specifications are fit-for-purpose and manufacturing risks and mitigation plans have been identified. Apart from SST, each trial scheme has its own requirements in terms of system architecture, monitoring equipment, protection schemes, communication technologies and detailed site preparation. We will develop the technical specification of each scheme and its components in this WP. The reliability of the scheme as a whole will be evaluated to ensure there is no impact on customers' security of supply. In addition, we will ensure that the operational performance of each scheme can be monitored remotely and all the	

field data is collected in a SP Energy Networks historian database for further performance analysis.

WP 2 – Partner selection and procurement — Duration: Sep 2018- Feb 2020

Objectives: Select the manufacturing partner through a competitive tendering process and also procure the equipment required for LV Engine schemes.

Description: This work package includes all the activities to procure LV Engine scheme equipment and conduct a competitive tendering for selecting partners for the SST design and manufacturing. We will build upon the manufacturing engagement conducted during proposal preparation and carry out further market research to identify leading manufacturers. We will develop detailed evaluation criteria specifically for LV Engine project based on its requirements and our experience from previous innovation projects to ensure we identify partners who maximise value for money.

WP 3 – Design & Manufacturing of SSTs — Duration: Feb 2019 - Dec 2020

Objectives: Design and **manufacture** a fit-for-purpose SST based on the technical requirements and functionalities developed in WP 1**.**

Description: This WP includes collaboration between SP Energy Networks and the manufacturing partner(s) to design and manufacture the SSTs required for each LV Engine scheme according to the technical specifications created within WP 1. The various design options and parameters will be optimised to deliver an SST which is fit-for-purpose for deployment within a distribution network and represents a balance between performance, reliability and cost. These design parameters include material choice, topology, number of redundant modules, control algorithms etc. This work package also includes various factory acceptance tests on the manufactured SSTs. The tests required will be determined within WP 1 and during the design stage in WP 3 to ensure a quality assured product is delivered for network trial. Furthermore, a detailed life cycle analysis will be carried out to assess the SST environmental impact.

WP 4 – Network Integration Testing — Duration: Oct 2019 - Aug 2020

Objectives: Test the functionalities and reliability of the manufactured SST in a network integration facility and obtain network integration certificate**.**

Description: In addition to the factory acceptance tests scheduled in WP 3 and in order to boost confidence in SST operation and reduce the risk of SST failure we will carry out network integration testing of the manufactured SST. This will be undertaken prior to the live trial within the real network. The purpose of this testing is to demonstrate the SST performance within a replica 11kV and LV network with mock customers' demand and generation behaviour. The detailed of test schedules and the test network conditions will be developed in WP 1 and WP 3. If we identify any issue in SST performance, the manufacturer will fix the issue on site or the SST will be shipped back to the factory for troubleshooting, diagnostics and any design refinement where required. As two distinct SST designs will be trialled within LV Engine, the tests will be carried out on both SST prototypes (hybrid AC/DC output and one with DC output only).

WP 5 – Live Network Trial — Duration: Nov 2019 - Oct 2022

Objectives: Install and commission the LV Engine schemes and monitor their performance.

Description: This WP includes all the activities required for the site preparation, installation, commissioning and performance monitoring of the SST schemes. The system architecture and communication solutions designed in WP 1 will be installed at the designated trial sites. Following the successful network integration testing within WP 4, Scheme 1 will be installed and commissioned after satisfying the required site acceptance tests. A staggered installation of each scheme will be implemented with one month between each installation. This will provide us with an opportunity to implement any refinements and lessons learnt from previous installations before the installation and commissioning of the remaining schemes.

It should be noted that in order to eliminate any adverse impact on the customers, the existing conventional transformers will be maintained in the secondary substations. The necessary switch over arrangement will be implemented to bring the conventional transformers back to service in case SSTs fail to operate. This work package will also include the installation of the voltage monitoring equipment within customer premises if required by each trial scheme.

After commissioning, we will collect the performance data under each scheme to evaluate the impact on the network and demonstrate the unlocked network capacity. Additional live tests such as forced power flow variation and voltage adjustments at LV and MV will be also carried to evaluate the performance of each scheme. These tests will aim to provide adequate evidence and data to inform WP 6 for developing a novel approach for transformer selection.

WP 6 - Development of novel approach for transformer selection	**Duration: Jun 2021- Nov 2022**
Objectives: Use the performance data from each scheme to develop documentation for the BaU adoption of SST and comparison with conventional solutions.	
Description: This work package aims to compare the performance of the LV Engine schemes with the performance of conventional transformers and on-load tap changers to provide a series of technical and financial guidance documents for BaU adoption of the solutions. We have already procured a number of OLTCs as part of our Accelerating Renewables Connection (ARC) project and intend to use the learnings available from these within LV Engine. We will use the data from these OLTCs to build a base case for comparison with the LV Engine schemes. A novel methodology for transformer selection and the best operational practices for each LV Engine scheme will be developed. This work package will provide our planning engineers and other UK DNOs with adequate knowledge and tools to confidently evaluate LV Engine schemes as one the solutions for future network reinforcement. Regular engagement with our planning and operation engineers will take place alongside our design authority, UK Power Networks, to ensure the documentation, staff training and internal dissemination are adequate for effective BaU adoption of the LV Engine methodology.	

WP 7 – Dissemination and knowledge sharing	**Duration: Mar 2018- Dec 2022**
Objectives: Disseminate lessons learnt and the techniques implemented in LV Engine to interested parties in particular UK DNOs, academics and UK Power Electronic industry.	
Description: Dissemination and knowledge sharing with internal and external stakeholders through workshops, webinars, LV Engine web pages and presentations. Knowledge dissemination will be in the core of our activities. Section 5 will provide details of our methodology for effective dissemination in WP 7.	

2.4 Changes Since Initial Screening Process (ISP)

Whilst creating this proposal we have engaged closely with a number of leading manufacturers to ascertain a funding request which will allow the project to be delivered as promised. This process has allowed us to put together a more accurate project cost estimate which is reflected in our total project cost increase from £6.9m to £8.295m.

Based upon the ISP feedback we received from Ofgem, we have recognised that innovation funding for OLTCs may not be appropriate. For this reason, the decision was made to not include any funding request for the deployment of OLTCs within our network. However, we intend to leverage the learning available from our previous innovation project ARC and carry out a study on the performance of five OLTCs that have already been purchased and are due to be installed within SPD.

Within the ISP a DC link was discussed as an approach for load sharing between secondary substations. However, we have since decided that an AC link between substations will provide the benefits of load sharing without the requirement to lay new DC cabling between substations. For this reason, we do not intend to lay a DC link between SSTs within the scope of this project.

Section 3 Project business case

3.1 Overview

The increasing uptake of LCTs is causing a strain on LV networks and driving the need for costly network reinforcement. However, these technologies are critical to achieve the UK Governments targets to reduce carbon emissions by 80% by 2050 whilst decarbonising the heat and transport sectors. Multiple studies, for example SSEPD's New Thames Valley Vision project, have indicated that a significant percentage of the LV network will require reinforcement due to the uptake of LCTs.

In addition, there is much uncertainty surrounding the scale, timing and locality of LCT uptake across the UK. For this reason, DNOs must be prepared for a variety of future scenarios and be equipped with the flexibility required to overcome the challenges they will present. Traditional LV reinforcement methodologies often include laying new cable and constructing new secondary substations to overcome voltage and thermal constraints associated with new LCT connections. This costly and lengthy approach to reinforcement may no longer represent value to UK electricity customers. It also causes significant disruption to the public when excavating and reinstating roads and pavements in active urban areas. A more innovative and cost effective approach is required.

LV Engine will uncover new and innovative approaches to unlock the capacity available within our existing LV infrastructure and facilitate the uptake of LCTs on the scale demanded by society, whilst providing the flexibility required due to the uncertainty surrounding the nature and timing of their uptake. If rolled out across GB, LV Engine has the potential to deliver capacity for the connection of low carbon technologies, provide environmental benefits and net financial benefits to customers as follows:

- The total financial benefit of **£62m by 2030** and **£528m by 2050**;
- Reduce CO_2 emissions by **418,307 tonnes by 2030** and **1,314,050 tonnes by 2050;**
- Reduce system losses and network reinforcement by facilitating a future LVDC supply for our LV customers.

Value for money for electricity customers is demonstrated by the **pay back of the full funding requested for LV Engine within 7 years** from the start of the project.

3.2 LV ENGINE is in line with SP Energy Networks' Innovation Strategy

SP Energy Networks believe innovation[1] is critical to deliver the energy networks of the future which can facilitate the changes in how the network is being used whilst providing value for money to our customers. The LV Engine proposal addresses one of the specific priorities of the SP Energy Networks' Innovation Strategy which is preparing the network for low carbon technologies. The trialling of cutting-edge technologies to bring a fresh approach to selecting fit-for-purpose secondary transformers is in accordance to the company's ethos of: "think big, start small, scale fast."

LV Engine matches one of SP Energy Network's three innovation areas, specifically Technology Innovation. The use of the SST is in accordance with the intention within this area to use new assets, whilst the development of the capability to share power flows between LV substations will make progress towards the objective to operate the network more dynamically.

LV Engine builds on the findings of previous network automation innovation projects whilst also exploring opportunities to reduce system losses with the provision of a LVDC supply.

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[1] https://www.SPEnergyNetworksergynetworks.co.uk/userfiles/file/201403SPEnergyNetworksInnovationStrategyMH.pdf

3.3 The LV Engine benefits

LV Engine proposes a new and innovative approach to LV network reinforcement that will provide additional network capacity at less cost and more quickly. The project will demonstrate how SSTs can release network capacity within our existing network infrastructure and lay the ground works for an adaptable and flexible LV network which includes a ground breaking low voltage DC supply to our customers.

Optimised & independent voltage control – LV Engine will provide automated and optimised voltage control of each phase thus overcoming constraints due to the limited voltage control in existing LV networks. Monitoring of voltage at strategic points along LV feeders will allow an SST to intelligently adjust voltage at the LV busbar to best support the voltage profile along the length of the feeders. Thus more LCT connections could be accommodated **on existing LV circuits** whilst maintaining voltages within statutory limits.

Automated load sharing between transformers – LV Engine will provide additional network capacity in existing networks by controlling power flow between transformers. Building upon the learning of UK Power Network's project "FUN LV", LV Engine will use an SST to allow multiple transformers to load share across LV feeders to defer or discard the requirement for reinforcement due to load growth.

DC Supplies – LV Engine inherently facilitates DC supplies which could be used to satisfy the increasing demand from DC devices. A significant increase in efficiency is realised by directly supplying these loads with DC and eliminating the repeated rectification between AC and DC. Strategically providing DC supplies will provide increasing benefits as DC demand is expected to grow; specifically electronic DC devices, lighting technologies which convert AC to DC and the demand from DC EV charging points are all forecasted to increase.

Phase Balancing – LV Engine offers increased capacity and reduction in losses by providing the ability to balance loading on the phases on the HV side of the SST, correcting any LV unbalance that would otherwise be transferred upstream.

3.4 LV Engine Business Case

3.4.1 Business Case methodology

A case study exploring the reinforcement necessary to accommodate LCT uptake has been used to quantify the LV Engine business case. Using this case study we have compared the Base Case reinforcement approach to that proposed by LV Engine as detailed in Appendix C.

For the financial analysis, Base Case and LV Engine method lifetime costs, comprising both Capex and Opex, were attained based upon the requirements of the case study. LV Engine cost estimates were based upon detailed guidance from manufacturers which allow for a reduction in unit price as production volumes and TRL continue to increase. Specifically, the method capex cost is £115.0k in 2023 falling to £62.0k by 2045 at which we assumed the capex cost remains unchanged in the following years. The Base Case capex cost of £149.0k is based upon SP Energy Network's unit cost manual and consultation with our design engineers drawing on extensive experience of implementing traditional reinforcement schemes.

Benefits corresponding to the roll out of LV Engine to SP Energy Network and GB were evaluated based on an estimate of the number of GMTs where LV Engine could be used to resolve voltage issues. In addition, we have factored in a generous market share to account for the uptake of other emerging smart solutions which may compete with the LV Engine methods.

To ensure that our financial analysis is both credible and transparent we have quantified the key functionalities and benefits associated with SSTs, specifically additional capacity due to voltage regulation and sharing between substations, because they can be reliably estimated based upon our current knowledge and understanding. Financial benefits associated with the provision of DC supplies are not included in the present business case due to a greater uncertainty regarding the number of applications and their timing.

3.4.2 Case study

The Case Study considers a typical 11kV/LV substation and network of four feeders shown in Figure 3-1. Reinforcement is necessary as the 500kVA transformer has become thermally overloaded and the maximum and minimum voltages at the end of the four LV feeders exceed the allowable limits due to increased uptake of LCTs, in particular the connection of LV generation and increases in LCT demand.

Figure 3-2 shows the LV Engine (Method) solution and Base Case (counterfactual) approach. With LV Engine the existing overloaded transformer is replaced with a new 500kVA SST which is now sufficient because the thermal overload is overcome by automating or closing the NOPs to allow load sharing with the neighbouring transformers. Furthermore, the intelligent phase voltage control provided by the SSTs maintains the voltage on each feeder within statutory limits.

The traditional reinforcement Base Case includes the replacement of the existing 500kVA transformer with a larger rated 800kVA transformer which is capable of satisfying the additional thermal loading due to LCT load growth. In addition, the counterfactual also includes the replacement of the tapered LV cabling on each feeder with a larger cable size that is capable of maintaining the voltage within statutory limits. Whilst this solution will facilitate LCT load growth it also comes at significant expense and disruption to customers due extensive costly excavation of public roads and pavements.

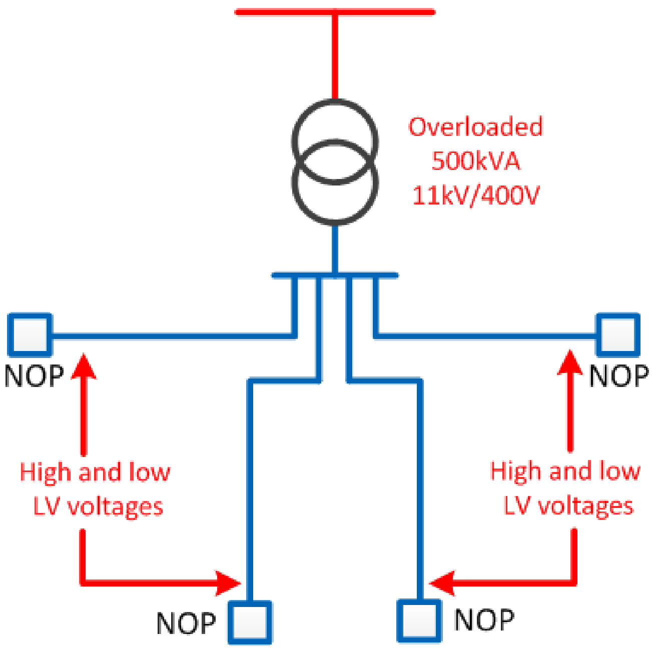


Figure 3-1: Problematic Case Study network

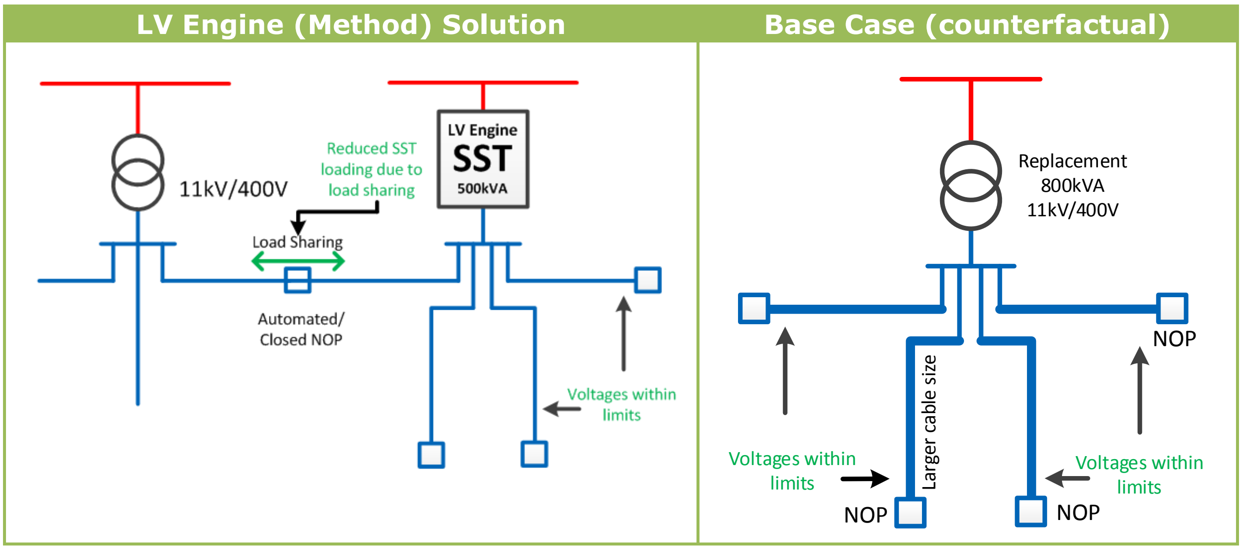
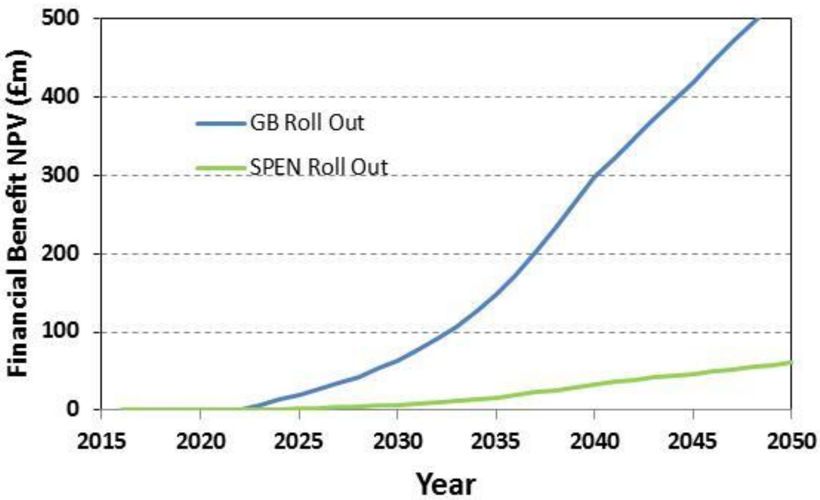


Figure 3-2: Case Study Reinforcement Solutions

3.5 Summary of financial benefits

LV Engine delivers financial benefit by delivering network capacity at a lower cost than traditional reinforcement. Figure 3-3 shows the NPV financial benefits of LV Engine when rolled out across SP Energy Network and GB based upon the methodology described within Appendix C.



Savings of £528m (NPV) are offered by the LV Engine solution by 2050 when extrapolating across GB.

Figure 3-3: NPV Financial Benefits of LV Engine

3.6 Unquantified financial benefits of the LV Engine solution

LV Engine's SSTs are also capable of providing the network with many other benefits that we have not directly quantified within our financial analysis. For this reason we have included specific deliverables within the projects work packages which will allow us to quantify the value of SSTs more accurately. These deliverables include:

- A detailed Cost Benefit Analysis (CBA) of the LV Engine schemes post trial.
- A CBA methodology and toolset for the BaU deployment of SSTs.

These documents will allow us to quantify and evaluate the following additional network benefits, which will be informed and extract learnings from both the network trial and the detailed SST designs that are developed during the project.

- Voltage support and reactive power contribution to the 11kV network.
- The value of a low voltage DC supply to electricity customers.

- Capacity increase of SST with modular "capacity banks"
- Power quality improvement by operating SST as an active harmonic filter.
- Value of any reduction in substation footprint.
- Peak shaving by exercising conservation voltage reduction.

3.7 Carbon benefits

Figure 3-4 shows the embedded carbon of the LV Engine solution alongside the alternative traditional reinforcement approach. The LV Engine method incurs significantly less embedded carbon than the traditional approach which requires the installation of more new assets. It also enables the earlier connection of LCTs by 15-18 weeks due to a quicker reinforcement time when compared to the counterfactual. The benefit of this has been quantified within the carbon benefit calculation as shown in Figure 3-5.

A contrary impact on carbon arises due to the increased network losses associated with the LV Engine solution relative to the counterfactual. In addition, SST losses are expected to be initially greater than the equivalent traditional transformer. A consequence of the increase in losses due to LV Engine is that operational carbon will be greater.

Figure 3-5 shows the overall (embedded and operational) carbon impact of LV Engine compared to the counterfactual evaluated using the methodology in Appendix C. It should be noted that the financial value of the additional losses is still much less than the cost of the avoided traditional reinforcement and that it has been reflected in the aforementioned financial analysis.

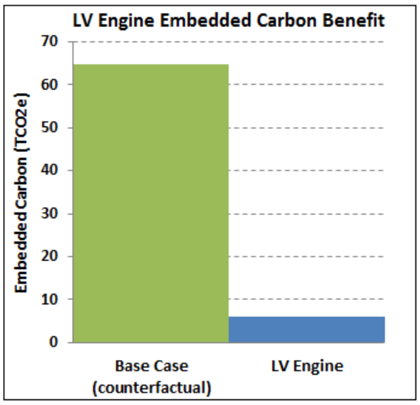


Figure 3-4: Embedded carbon comparison

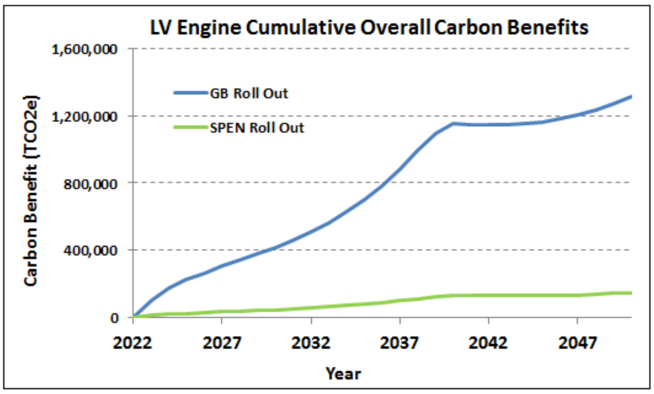


Figure 3-5: Cumulative carbon benefits

3.5 Project risks

A detailed risk register can be seen in Appendix E. The register is based upon the risks we have identified through discussion with a number of manufacturers, academics and internal stakeholders and our previous experience of delivering NIA and NIC projects.

Section 4 Benefits, Timeliness, and Partners

4.1 Accelerates the development of a low carbon energy sector and/or delivers environmental benefits whilst having the potential to deliver net financial benefits to future and existing customers

LV Engine aims to facilitate the adoption of LCTs by providing flexibility and controllability in the LV & MV networks. Passive distribution networks are no longer always cost effective solutions to accommodate the uncertainty in the generation and the demand profiles of our customers. LV Engine will trial cutting-edge technologies to provide a novel approach for selecting fit-for-purpose secondary transformers. The outcomes of this project can be a model for operation and planning of our future distribution networks.

Impact on low carbon energy sector and environmental benefits:

As described in Section 3, the LV Engine solution and the counterfactual reinforcement approach both release adequate additional network capacity to facilitate the future uptake of LCTs. We have assigned a carbon reduction value to the LV Engine solution in the form of avoided civil works associated with cable installation and a faster connection of LCTs. Table 4-1 shows the carbon reduction we expect between 2030-2050 based upon the number of deployment opportunities we have projected.

Table 4-1: LV Engine carbon savings due to avoided civil works

Scale	2030	2040	2050
SPEN Rollout (kt.CO_2)	46.99	129.88	147.61
GB Rollout (kt.CO_2)	418.31	1,156.21	1,314.05

The outcomes of LV Engine can also contribute to our low carbon energy sector by:

1. Expediting the connection of renewables e.g. PV uptake is often limited due to voltage issues without costly LV network reinforcement;
2. Reducing the curtailment of the renewables connected to the MV and LV network due to temporary voltage issues;
3. Providing voltage support to the 11kV network to improve the point of connection of 11kV LCT developments. Improving the voltage profile along the length of an 11kV feeder may reduce the need for costly overhead lines if a connection at the primary substation is required, thus improving the financial feasibility of 11kV LCT projects;
4. Providing local reactive power compensation and reducing the overall network losses which will ultimately reduce carbon emissions;
5. Expediting the connection of electric vehicles and other LCTs which may benefit from a LVDC connection;
6. Reducing network losses by providing an LVDC supply to allow DC distributed generation and consumption to be coordinated without the need for repeated conversion between AC & DC. A reduction in losses will increase the kWh exported by LCT generation and directly improve the financial feasibility of LCT projects particularly as feed in tariffs are reduced;
7. Reduced fire risk due to possible use of dry type transformers providing additional flexibility in site location particularly within environmentally sensitive areas.

Financial benefits to customers:

Conventionally, distribution networks are passive and they are designed for the worst demand and generation conditions. This approach is becoming a prohibitively expensive approach to network design and reinforcement and may limit the future uptake of LCTs.

LV Engine will deliver a fit-for-purpose SST and an improved methodology for the economic design and planning of our LV network to facilitate the uptake of LCTs whilst significantly reducing the costly reinforcement it causes. **LV Engine will deliver £528m in avoided network reinforcement across GB by 2050** as per Table 4-2.

Table 4-2: Summary of the financial benefits of LV Engine between 2030 and 2050

Scale	2030	2040	2050
SPEN Rollout (NPV)	£6.98m	£32.63m	£59.27m
GB Rollout (NPV)	£62.11m	£290.48m	£527.61m

In addition, we expect LV Engine will provide the following additional financial benefits that have not been quantified at this stage:

1. **Reduction in network charging costs -** LV Engine will reduce the network charging costs imposed on our customers by avoiding and deferring the costly network reinforcement required in both the LV and MV networks due to the uptake of LCTs.
2. **Facilitate access to low cost energy -** LV Engine will act as an enabler of PV connections for the purposes of addressing fuel poverty and facilitating access to cheaper energy. There are multiple examples within SP Energy Networks where local housing associations and councils have been limited in their ability to install rooftop PV due to the inability of the network to regulate voltage effectively. LV Engine will remove this constraint and allow a much higher penetration of PV within the LV network to allow organisations to combat fuel poverty and reduce customer bills.
3. **Providing scalability to secondary substations -** The modular nature of SST technology will allow the capacity of an SST to be increased at limited cost and disruption to customers by adding additional "capacity blocks" when demand increases. This will allow capacity upgrades close to the actual requirement rather than replacing an overloaded transformer with a higher rated and under-utilised unit.
4. **Enabling the transition to DSO** by removing LV network constraints and increasing the flexibility and adaptability of the LV network. This will provide a future DSO with the tools it requires to intelligently operate the distribution network efficiently and delay the point at which the DSO is required to interact with customers to remove local constraints. A flexible distribution network will also provide aggregators with access to the LV network and enable them to offer services to LV customers. This will increase competition in the energy supply industry and allow customers to choose low carbon energy sources if desired. Furthermore, if rolled out SSTs have the potential to offer voltage control to the 11kV network as a service to the future DSO. For these reasons we believe LV Engine is complementary to SP Energy Networks NIC proposal "Fusion" and both are in line with SP Energy Networks' innovation strategy.
5. **Delivering a fit-for-purpose SST design -** LV Engine will produce a cost competitive SST design for deployment within distribution networks which can be adopted by other UK DNOs quickly to facilitate the uptake of the technology into BaU practices.

4.2 LV Engine provides value for money to electricity distribution and transmission customers

A breakdown of the project costs against each participant and work package can be seen in Figure 4-1 & Figure 4-2. The total project cost summates to £8,295.28k. This has been created based upon detailed conversation with a number of manufacturers, potential project partners and experience working on other successful SP Energy Networks innovation projects.

[redacted]

Figure 4-1: A breakdown of project costs by work package

[redacted]

Figure 4-2: A breakdown of project costs by participant

In addition, Table 4-3 shows a detailed breakdown labour cost of project.

Table 4-3: LV Engine detailed labour cost breakdown

Work Package	Project Participant	Rate (£)	FTE (days)	Man-hours cost (£k)	Total* (£k)
Project Set Up	SP Energy Networks	[redacted]	[redacted]	[redacted]	[redacted]
WP 1	SP Energy Networks	[redacted]	[redacted]	[redacted]	[redacted]
	UK Power Networks	[redacted]	[redacted]	[redacted]	[redacted]
	Technical Consultant	[redacted]	[redacted]	[redacted]	[redacted]
	Academic Advisor	[redacted]	[redacted]	[redacted]	[redacted]
WP 2	SP Energy Networks	[redacted]	[redacted]	[redacted]	[redacted]
	UK Power Networks	[redacted]	[redacted]	[redacted]	[redacted]
	Technical Consultant	[redacted]	[redacted]	[redacted]	[redacted]
	Academic Advisor	[redacted]	[redacted]	[redacted]	[redacted]
WP 3	SP Energy Networks	[redacted]	[redacted]	[redacted]	[redacted]
	UK Power Networks	[redacted]	[redacted]	[redacted]	[redacted]
	Technical Consultant	[redacted]	[redacted]	[redacted]	[redacted]
	Academic Advisor	[redacted]	[redacted]	[redacted]	[redacted]
WP 4	SP Energy Networks	[redacted]	[redacted]	[redacted]	[redacted]
	UK Power Networks	[redacted]	[redacted]	[redacted]	[redacted]
	Technical Consultant	[redacted]	[redacted]	[redacted]	[redacted]
	Academic Advisor	[redacted]	[redacted]	[redacted]	[redacted]
WP 5	SP Energy Networks	[redacted]	[redacted]	[redacted]	[redacted]
	UK Power Networks	[redacted]	[redacted]	[redacted]	[redacted]
	Technical Consultant	[redacted]	[redacted]	[redacted]	[redacted]
WP 6	SP Energy Networks	[redacted]	[redacted]	[redacted]	[redacted]
	UK Power Networks	[redacted]	[redacted]	[redacted]	[redacted]
	Technical Consultant	[redacted]	[redacted]	[redacted]	[redacted]
WP 7	SP Energy Networks	[redacted]	[redacted]	[redacted]	[redacted]
	Technical Consultant	[redacted]	[redacted]	[redacted]	[redacted]

***Note:** *Travel costs, expenses and contingencies have been included in addition to the day rate per FTE.*

Based upon the financial benefits calculated within our baseline and in combination with our projected deployment opportunities across GB the full funding requested for LV Engine will be repaid to electricity customers within 7 years of the project funding award.

4.3 LV Engine will also deliver value to electricity customers for the following reasons:

- A competitive procurement and tendering process will be carried out to identify manufacturing partners who will deliver value for money by delivering a fit-for-purpose SST at the lowest possible cost, whilst also providing resource and monetary contributions towards the project.
- LV Engine will also look to collaborate with other parties with relevant experience within the power electronics industry to build upon the learnings available from relevant projects and ensure LV Engine considers the latest developments within the area and does not repeat work carried out by others.
- The outcomes of this project will largely enhance the operation and planning of distribution networks. However, the project will also benefit the transmission network by enabling more embedded generation connections to reduce transmission network losses and constraints. Furthermore, a more flexible and adaptable distribution network will directly benefit the transmission network by

allowing a future DSO to offer additional flexibility services to the TSO when required.

4.4 Is innovative (i.e. not business as usual) and has an unproven business case where the innovation risk warrants a limited development or demonstration project to demonstrate its effectiveness

If approved, this project will undertake a globally innovative distribution network trial of SSTs for the purpose of supporting and enabling the LV network of the future. Consequently, we believe this project is highly innovative and addresses a significant challenge which is relevant to all UK DNOs and has the potential to become a major enabler of LCTs.

Similarly, the study of on-load tap changers within secondary substations will inform an innovative methodology for the selection of the most technically capable and cost effective reinforcement solutions for the secondary substations of the future.

We intend to work closely with UK Power Networks to gather the learnings from both LV Engine and "Active Response". This will allow both parties to share learnings within the areas of power electronics which will directly benefit each project.

4.4.1 Technical Innovation

For a commercial low voltage supply point the BaU case is to install a conventional Low Frequency Transformer (LFT) operating at 50Hz to link an 11kV supply point to a consumer voltage at 0.4kV. Such a technology has been in use for over 100 years. As discussed earlier in this proposal, operational problems are being experienced with the use of LFTs, particularly in applications for LCT generation connected on the LV system. This proposal seeks to introduce a SST into the distribution system to overcome many of the issues experienced with LFTs.

Although first proposed in the early 1970's the commercialisation of a SST has been limited by the availability of suitable semi-conductor switching devices and the development of circuit topologies which could achieve the required functionality. There has been considerable academic activity on these two aspects, leading to the development of SSTs of progressively increasing power and voltage ranges. The largest unit to date is a SST of 1000kVA rating with a voltage ratio of 13.8/0.27kV, which has been demonstrated in a laboratory environment. However, to date no SST has been deployed on a distribution system in the UK and as far as we can ascertain in the world. The Swiss Federal Railway is currently procuring a prototype SST with a rating of 1200kVA operating from a 15kV distribution network to supply a traction load. This development is aimed at removing the conventional LFT from the locomotive to reduce the weight, volume and losses.

The present proposal for a 500kVA SST to interconnect the 11kV and 0.4kV systems therefore sits inside the envelope of the designs which have been studied in detail by academic institutions and may be delivered by multiple manufacturers. However, no such device is presently available as a proven product from any manufacturer and the deployment of the device on the SP Energy Networks distribution network represents an innovative step both for the manufacturer and for SP Energy Networks. A key feature of the SST is that unlike a LFT it will be able to supply commercial and domestic AC loads and also connect to DC loads, such as Electric Vehicle charging points and DC generation sources, such as solar panels. The provision of a LVDC network for the direct connection of customers is one of the challenging and innovative aspects of this project.

4.4.2 Network Design & Operational Innovation

LV Engine has the potential to change the way in which LV networks are designed and operated by providing flexibility and adaptability to release capacity within our existing LV infrastructure prior to traditional reinforcement. By changing the way in which we plan and design our LV networks we can ensure that the cost to reinforce the network to facilitate LCTs is minimised as much as possible. The project will produce design tools and policy documents to ensure the value of the project is adopted and implemented into our BaU toolbox.

To this end LV Engine will develop a power electronics design guidance document in partnership with UK Power Networks for the purpose of creating a new and innovative approach to network reinforcement which considers the value that can be provided by power electronic technologies as cost effective alternative to traditional reinforcement. SP Energy Networks & UK Power Networks are committed to implementing the learnings from our NIC projects into BaU and this document will help to ensure the learnings associated with our complementary NIC projects are adopted by the business, other DNOs, and our customers see a return on their investment as soon as possible.

4.4.3 SST Technology Readiness Level (TRL)

A trial of SST technology requires Ofgem NIC funding as the TRL of this device is not currently high enough for grid application. The technology has reached a level of maturity in railway traction applications, which use similar voltage levels to distribution networks. The TRL of SSTs for traction applications is considered to be 8, as prototype units have been deployed and tested in field trials. The TRL of SSTs for grid applications is considered to be 5-6, as prototype devices have been through laboratory trials.

LV Engine intends to elevate the TRL of SSTs to an 8 and provide DNOs with the toolset required to design and operate a smart and efficient distribution network of the future. However, there are yet challenges to demonstrate the performance and reliability of the technology, and an efficient fit-for-purpose design for grid applications is required.

There are still several technical and operational challenges for a SST grid application which require to be addressed before BaU adoption. Some of these challenges are a modular based design, the SST network protection design, improving efficiency and reducing losses, a compact design and developing sophisticated control algorithms to enable smart functionalities and control.

In preparation for LV Engine and to reduce the risk associated with the project we have discussed these challenges at length with multiple experts, manufacturers and academics in the area. These discussions have given us confidence that the developments required to elevate the TRL of the technology from a 5-6 to an 8 is achievable within the timescales of the project and that the learnings from the project can be implemented into BaU as soon as possible. A more detailed view on the TRL progression of SSTs is shown within Appendix H along with a projection in the TRL and SST performance we hope to achieve during LV Engine.

4.4.4 LV Engine has an unproven business case which requires a demonstration project to manage risk

To achieve the same functionality as a SST using conventional (BaU) equipment would require a combination of a LFT plus a voltage control device, such as a Static Synchronous Compensator (STATCOM), plus a separate inverter/rectifier unit to supply DC loads and DC generation sources. SP Energy Networks believes that the SST will demonstrate superior performance, in terms of cost, losses, weight and volume, to the BaU solution, but recognises the risks inherent in such a project. Without the support provided by the NIC process, the deployment of the LV Engine project would not be a viable solution and would not be within SP Energy Networks' normal mandate to use only proven equipment on their network.

By deploying a SST on the 11kV/0.4kV distribution network, which can provide supplies to both AC and DC LV systems, SP Energy Networks will be using equipment, which although tested in the factory, will not have been used operationally on any system connected to consumer supplies. Consequently, as the first project into the field, there are risks that the SST will not achieve its designed operational reliability and availability. There will be risks that the technology does not perform as expected, the manufacturer does not support the technology long term, the project costs exceed the budget, and the project timescales extend beyond those planned. However, the learning opportunities gained from the deployment of an SST and its long term operation will be invaluable for both SP Energy Networks and other UK DNOs wishing to consider similar installations.

4.5 Involvement of other parties and external funding

Key to the delivery of LV Engine is identifying project partners who can take the lead on the design and manufacture of the fit-for-purpose SSTs described within this proposal. It is important to SP Energy Networks that we identify responsible and competent partners who represent value for money for our electricity customers. Details on our existing partners and future partner selection methodology are described below:

UK Power Networks will act as a project partner and member of our design authority board during LV Engine. Collaboration between DNOs is critical to ensure our respective innovation projects are adopted into BaU practices and value is delivered to our customers. For this reason UK Power Networks will ensure LV Engine considers the requirements of DNOs across the UK and shares learnings from its complementary NIC proposal "Active Response". A list of well-defined actions have been mapped against each work package and agreed between SP Energy Networks & UK Power Networks.

Manufacturing Partner(s) - A thorough tendering process will be carried out to identify a partner(s) who represent the most value for money whilst ensuring successful delivery of the project. We will seek manufacturing partners who can contribute at least 10% of their associated project costs up front. Since no manufacturing partner will be in place prior to the start of the project SP Energy Networks will contribute 10% of the total project funding request up front and recover a proportion of this cost once a partner(s) has been identified. Manufacturers will also be examined against detailed criteria which include cost, timescales, performance, reliability, resources, and financial stability amongst others.

Academic Partner(s) - We have identified specific areas of research that an academic partner(s) will carry out during the delivery of LV Engine. These activities have been mapped against each work package within the project delivery plan. To date we have held discussions with multiple universities to identify which parties are in a position to contribute. For the purposes of maximising value to the project we intend to formalise this activity during project set up should funding be awarded. We intend to work with those who can demonstrate knowledge and experience in the subject area to allow us to build upon learnings that have been established during previous external projects.

Current LV Engine Partner Engagement

In addition to the above, SP Energy Networks have actively engaged in detailed conversation with multiple potential partners during the creation of this proposal to gain confidence in the feasibility of LV Engine:

1. Multiple suppliers, universities and research centres have been identified who are capable and willing to support the project as partners. An "Expression of Interest (EOI)" document has been distributed to allow these potential partners to formally log their interest in the project and set out how they can contribute in detail.
2. The project concept was discussed with potential partners through teleconference or face-to-face meetings. Challenges and risks were identified, and areas which potential partners can provide contributions were discussed.

3. We have been in regular contact with other DNOs to investigate opportunities to collaborate and to ensure that our submissions complement each other. We have formally partnered with UK Power Networks and agreed a list of specific actions mapped against work packages to ensure the outcomes of the project are fit for purpose and repeatable throughout the UK. We intend to continue to invite other GB DNOs to engage with LV Engine so that learnings are shared widely and the requirements of all are considered.

4.6 Relevance and Timing

When choosing our counterfactual we have carefully considered similar technologies that are both currently available and under development which can deliver similar functionality to that provided by SSTs or alternative solutions to the LV network reinforcement example described within Section 3. To ensure our business case is both relevant and credible, the roll out methodology we have developed to estimate for the number of deployment opportunities for the LV Engine solution has factored in these alternative innovative solutions (DSO flexibility, domestic battery storage). A more detailed view on how this has been reflected within our roll-out methodology is described within Appendix C.

4.6.1 Emerging needs case due to an uptake in LCTs

Whilst SST technology has been in development for some years now the needs case for applications within distribution networks has only recently emerged due to changes in the way the network is being used with the increasing uptake of LCTs as demonstrated in Figure 4-3. Broadly speaking, electricity is traditionally generated at large power plants and transferred to customers through the voltage levels from the transmission network down to the distribution network and LV customers. However, the emergence of distributed generators has caused reverse power flows and local voltages out with statutory limits.

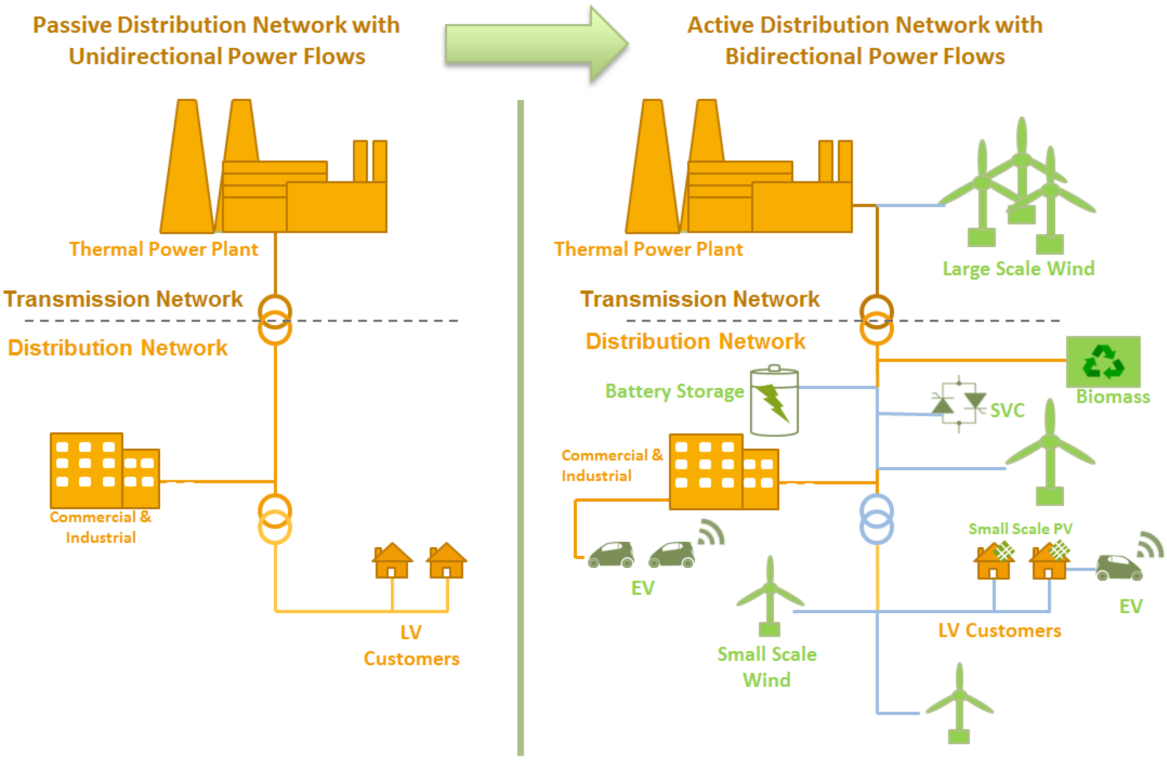


Figure 4-3: The changing utilisation of the energy network due to the uptake of LCTs

Furthermore, the LV network has been traditionally passive in nature. The network was designed with an after diversity maximum demand (ADMD) of around 2kVA per household with little consideration of distributed generation and future additional LCT demand. The emergence of EVs and Electric Heat Pumps are projected to drastically increase the ADMD resulting in an additional strain on the LV network in the form of voltage drops and thermal constraints that was not originally foreseen. Figure 4-4 shows the annual projected load growth within SPD & SPM from 2016 to 2030.

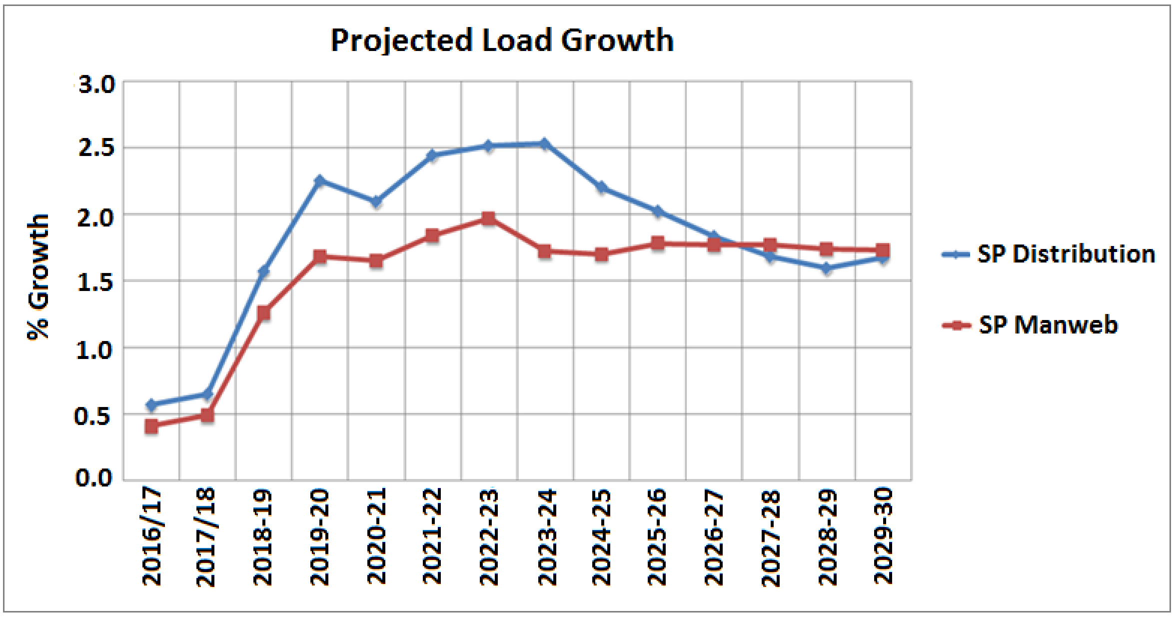


Figure 4-4: Projected load growth within SPD and SPM

The emergence of LCT demand and generation will continue to use the spare capacity that is currently available within the LV infrastructure. It is expected that a tipping point will be reached in the near future which will trigger significant reinforcement of the LV network across the UK. Consequently, an innovative approach is required to give the LV network more flexibility and adaptability to cope with the increasing uptake of LCTs, release additional capacity in our existing infrastructure and avoid significant network reinforcement. We believe the timing of LV Engine and its outcomes will coincide with this tipping point and provide a much needed alternative solution to the traditional reinforcement discussed in Section 3.

4.6.2 Improvements in the cost, performance & reliability of power electronics

Whilst the uptake of LCTs has increased in recent years, the cost, performance and reliability of power electronics has improved to the point at which solid state technology is feasible as a solution for the strain caused by LCTs and for deployment within distribution networks. As discussed within Section 4.4.2, the availability and performance of semiconductor switching devices has improved in recent years to the point at which a fit-for-purpose SST for deployment within distribution networks is deliverable within the timescales of this project. LV Engine intends to build upon these recent developments and stimulate a new market place for power electronics within distribution networks.

Dr Alastair McGibbon, Director of Power Electronics UK: *"This is therefore a very opportune moment to begin an SST project that can tie in the extensive UK supply chain in power electronics with the energy sector. As the main UK industry association in Power Electronics with over 70 members, we intend to work with you to promote the project and share learnings with the industry. This will help to ignite a new market place for power electronics within distribution networks in the UK and allow providers of power electronics to develop a strategic partnership with the industry."*

Section 5 Knowledge dissemination

Dissemination and knowledge sharing will be one of the core activities within LV Engine to ensure that sufficient and appropriate knowledge will be communicated with UK DNOs and other relevant energy industry stakeholders for optimum replication of the LV Engine solution. We have considered a specific work package (WP) to give necessary focus to knowledge dissemination activities. The following principles are considered to provide an efficient and effective approach for knowledge sharing and collating learning :

1- All the knowledge produced in the project will be captured and categorised as it materialises
2- Regular internal and external stakeholder engagement from the start of project will be undertaken
3- Different channels of communications including webinars, presentations, websites, discussion forums etc. will be utilised as appropriate
4- Data sharing will be facilitated for interested parties for ease and quick access to the data produced during the delivery of the LV Engine project

A knowledge capture and dissemination methodology has been developed to ensure that there is a flow of information from the delivery team to the project stakeholders, allowing generated knowledge to be utilised and benefits realised as soon as possible. On-going stakeholder engagement will be undertaken during the project as a feedback mechanism to ensure the knowledge generated remains applicable to all relevant Network Licensees.

5.1 Learning Generated

A robust knowledge capture methodology has been put in place to ensure that all of the learning generated is gathered and recorded during the course of the project and appropriately distributed. The project manager (PM) will hold overall responsibility for communicating project learning and collating information in a central data repository.

5.1.1 Methodology for Knowledge Capture

Within each WP, documents will be produced to capture the risks, assumptions, issues and dependencies (RAID), and learning as the project progresses. These RAID logs and learning points will be collated and included in progress meetings with manufacturers, the delivery team and academic partners. A central data repository will be set up by the PM to allow access to all the project learning and documentation for the delivery team. To facilitate the process of locating relevant information, each learning point will be categorised according to the appropriate learning objectives and potential interested parties. Open access to the data repository for the delivery team will promote transparency, personal responsibility for maintaining up-to-date records and knowledge sharing between WPs. In addition, the PM will have the authorisation to control access to any sensitive or confidential information.

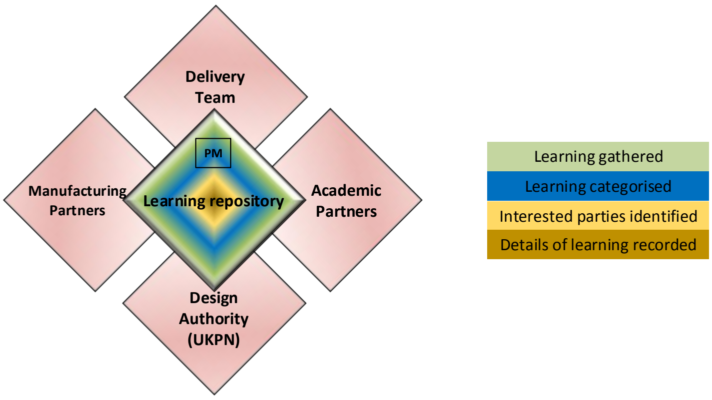


Figure 5-1: Knowledge capture methods

5.1.2 Learning objectives

The LV Engine solution is very innovative and we are expecting a wide range of technical, commercial and customer engagement learning points to materialise in the course of project. The primary expected learning for each WP and interested parties is detailed in Table 5-1. It is inherent in an innovation project that some of the learning will be unexpected and therefore it is anticipated that the list of learning objectives will be added to during the course of the project. There are a number of beneficiaries for this project which can be grouped into the following categories:

UK DNOs (D) – All UK DNOs will be consulted and updated throughout the project to ensure they can invest in SSTs as part of their BaU activities as early as possible upon project completion.

Manufacturers (M) – Transformer and power electronic manufacturers will take a keen interest in the technical and commercial outcomes of the project. We will ensure manufacturers have visibility of any learning generated to ensure the project stimulates a competitive market place for SSTs and power electronics.

Industry Groups and Professional Bodies – UK Power Electronics, Institute of Engineering and Technology (IET), and International Council on Large Electric Systems (CIGRE) will benefit from the learning related to the technical specification requirements for SSTs and the potential impact of the new technology.

Academia (A) – There have been a number of universities with relevant experience who have expressed an interest in being involved in LV Engine. The performance of the first grid application of SST can provide useful information for further academic research and developments.

Environmental Bodies (E) – The introduction of SSTs will act as an enabler for future 'green' distribution networks which can cope with increasing penetration of LCTs. For this reason we will make the learnings of LV Engine available to LCT providers and environmental bodies who may benefit from the inclusion of SSTs within the network.

Local and National Government (G) – LV Engine will help inform the development of government LCT policies at both local and national government level. Local councils may benefit from project learnings to inform any LCT developments including future EV charging infrastructure or decarbonised transport strategies.

Public (P) – The general public will be interested in the impact on their domestic supply, particularly those in the identified trial areas. EV and distributed generation owners will have an increased interest in the project findings.

Table 5-1: Expected learning from LV Engine project

Work Package	Learning Objectives	Learning Category	Interested parties
WP 1 - Technical Design	Fit-for-purpose functionalities of a MV/LV SST	Technical	D, A,M
	Control algorithms and technical requirements for optimum voltage regulation in LV networks	Technical	D, A,M
	Control algorithms and technical requirements for power flow control in the LV network	Technical	D, A,M
	Protection scheme design for a low fault current network	Technical	D, A,M
	Protection scheme for a AC/DC hybrid network	Technical	D, A,M

Work Package	Learning Objectives	Learning Category	Interested parties
WP 1 - Technical Design	Technical specification of a LVDC underground cable circuit	Technical	D, A,M
WP 2 – Suppliers ,partner selection and procurement	Market status of SST manufacturers	Technical	D, A,M
	Tender evaluation assessment process for SST manufacturing	Commercial	D, A,M, G
WP 3 – Design and Manufacturing of SST	Life cycle assessment of SST	Environmental	D, A,M, E, G, P
	The elements of design for improving reliability and efficiency of SST	Technical	D, A,M
	High frequency transformer design		D, A,M
	The process to identify laboratory tests required for power electronic innovation technology	Technical	D, A,M
	Fit-for-purpose SST topology	Technical	D, A,M
	Health and safety requirements for SST	HSSE	D, A,M
WP 4 –Network Integration Testing	Network integration tests requirements for SST and power electronic solutions	Technical	D, A,M
	Health and safety requirements for network integration testing	HSSE	D, A,M
WP 5 – Live Trial	Customer engagement methodology for access to their premises	Customer Engagement	D, A,M, P
	Method statement for SST installation	Technical	D, A,M
	System Architecture for field real-time data handling and SST control functions	Technical	D, A,M
	LVDC network installation requirement	Technical	D, A,M
	Performance data of SST in different load/generation conditions	Technical	D, A,M,P
	Performance data of LVDC network	Technical	D, A,M
WP 6- Development of Novel Approach for BaU Transformer Selection	Methodology to quantify benefits of SST functionalities and comparison with OLTC	Technical/ commercial	D, A,M, G
	Best operational practice and policy document for selecting MV/LV transformers	Technical/ commercial	D, A,M, G
	Road map for BaU SST adoption for LCT uptake	Technical/ commercial	D, A,M, G

5.2 Learning dissemination

The effective knowledge dissemination is one of the principles of NIC to ensure that other DNOs and customers will benefit from the project. In order to comply with NIC requirements we have planned for effective knowledge dissemination through various communication formats. In addition, we have already constructed a partnership with UK Power Networks and appointed them within our design authority board to ensure the LV Engine solutions can be quickly adopted by another DNO after completion. We believe the learning dissemination is an opportunity for us to gather other interested parties learning while sharing the knowledge generated in LV Engine. Power electronic solutions and their applications are growing within electricity networks, hence DNOs need to enhance the skills of their staff to understand how power electronic solutions should be designed and used in planning and the effective operation of their networks.

5.1.3 Methodology for Knowledge Dissemination

The knowledge captured in the course of the project will be disseminated based on our communication strategy which details how learning points can be shared with interested parties once captured. A combination of various tools will be utilised in order to communicate the knowledge generated from the project successfully. Different levels of detail, including the frequency and method of communication, will be appropriate for each type of stakeholder.

LV Engine will comply with SP Energy Networks' publicly available data sharing policy that will be available by the 30th September 2017. However, our communication strategy will include the following:

SP Energy Networks website – A dedicated ares within the SP Energy Networks website will be set up for LV Engine as one of our communication strategies. The webpages will raise awareness of the aims and objectives of the project, trial areas and provide all the relevant documentation produced during the project. Data sharing about the performance of the LV Engine solutions will be available through this website. The interested parties will be encouraged to register through the website to be informed about any recent updates and the progress of LV Engine.

UK DNOs workshops – We recognise that UK DNOs are a key stakeholder and effective communication with UK DNOs will help facilitate the successful roll-out of the LV Engine solution. We have included regular face-to-face workshops with other DNOs at major project milestones to discuss learning and capture any feedback. This immediate form of communication will help to share crucial information and receive feedback based on exiting learning and experience from other parties.

Webinars – In order to reach a wider audience and provide an opportunity for external stakeholders with different backgrounds to learn about the project, we plan to share the project learning and methodologies through regular webinars.

Joint presentations with UK Power Networks – Power electronics solutions and their applications within distribution networks are growing. In order to stimulate a competitive market for power electronic solution within distribution networks, we plan to arrange joint dissemination events with UK Power Networks and members of the power electronics industry within the UK. This will provide us with an opportunity to discuss how industry can support the challenges faced by DNOs by providing power electronic products and technologies that are tailored to our business needs.

LCNI conferences - We aim to present the learning of LV Engine during the LCNI conferences that will take place during the course of project. This has been included within our project plan.

Written reports – Regular progress reports and project documentations will be published on the LV Engine webpages and ENA knowledge sharing portal. This includes the project close-down report which will include all findings, methodologies and lessons learnt and will be published in accordance with NIC requirements.

International technical papers – In addition to above, we propose that we reach other stakeholders around the world and exchange LV Engine learning with other non-UK experts. That will raise the awareness within the electricity industry around the world about the innovation work in the UK and facilitate the future competitive market for SST manufacturing. Therefore, we will identify relevant international conferences and submit technical papers including the methodologies used and the learning gathered within the project.

5.3 IPR

The work undertaken as part of this NIC project will adhere to the default IPR arrangements set out within the NIC governance. Project partners and suppliers will be required to comply with the default IPR arrangements as part of the selection criteria of the competitive tendering.

Section 6 Project Readiness

6.1 Evidence of why the Project can start in a timely manner

We are confident that the LV Engine project can start in a timely manner based on the detailed ground work undertaken in the preparation of this FSP. Based on the following evidence we consider that the project is ready to start after the necessary funding is provided:

- Commitment from SP Energy Networks Management team to deliver this innovation project;
- Receipt of Expressions of Interest from a number of interested parties (ranging from SMEs to major equipment suppliers and academics) in support of the design, development and delivery of an approved SST;
- Availability of UK Power Networks for peer review as a design authority;
- Identified site trial areas for deploying different scheme designs;
- Established site trial selection criteria, and will re-evaluate identified sites to determine their suitability at the proposed time of SST deployment with respect to their low carbon technology uptake in order to ensure maximum trial benefits;
- Knowledge and learning gained from relevant NIA and NIC projects;
- Knowledge gained through supplier and academic engagement both in the UK and overseas;
- Successful track record of delivering large-scale innovation projects;
- Established Project Plan, work scope, and risk register;
- Identified project delivery structure with defined roles and responsibilities.

6.1.1 Commitment from SP Energy Networks Management team

The concept and benefits of LV Engine have been discussed extensively at different stages of the proposal preparation, with different (and relevant) managerial levels within SP Energy Networks. There has been strong support within the senior management team including the Director of Engineering Services and Director of Network Planning and Regulation to fully provide the required resources for starting the LV Engine project in a timely manner. We have also identified potential resources including planning engineers, transformer experts, operation engineers, and district design engineers within who can support delivery of LV Engine.

6.1.2 Expressions of interest from a range of interested parties

We have actively engaged with a range of interested parties (both here in the UK and overseas) and stakeholders whose knowledge and expertise have helped shape this proposal. We have requested that the interested parties fill an expression of interest form detailing their relevant experience and technical capabilities, available resources, and potential financial contribution. The responses we have received from stakeholders have been very encouraging and provided us with a confidence that it is timely to start LV Engine project. A summary of interested parties whom we have spoken with, during proposal preparation, are as follows:

- **Manufacturers -** We have been speaking to a number of manufacturers both large and small with SST experience. Based on the information gathered on research and development in the manufacturing side and also the prototypes have been developed so far, we have confidence that it is the right time to trial SST in a grid application and there are a number of manufacturers who can potentially join as a partner in the LV Engine project.

- **Academics -** We have approached a number of universities who have focussed on SST related research including North Carolina State University, ETH Zurich, and University of Kiel who have offered technical support for delivery of the project. We have also spoken with Strathclyde University and Heriot Watt University to explore potential local universities roles in LV Engine. We believe there is a strong interest and support from academic side to participate in the delivery of LV Engine.

6.1.3 Independent peer review by UK Power Networks

We have provided UK Power Networks with a plan detailing the resources required and the deadlines for supporting the deliverables within LV Engine; they have confirmed that their resources are available. We believe that collaborating with UK Power Networks is a perfect opportunity to ensure the LV Engine solution is checked by another DNO for a successful GB roll-out. Appendix G shows the tasks and man-hours we have agreed with UK Power Networks to be delivered in the course of project.

6.1.4 Background Knowledge and learning gained from relevant projects

We have sought to incorporate the lessons learnt from previous relevant projects including UK NIA and NIC projects and also those outside the UK. We believe the learning from these projects will help the LV Engine team to start the project with an enhanced view on how the project should be planned and delivered. Figure 6-1 shows some of the projects that we have identified and considered their learning to help a robust start of LV Engine.

SST designs and manufacturing	HEART*	SPEED**	FREEDM***
Use of power electronics in MV and LV networks	FUN -LV (UKPN)	ANGLE-DC (SPEN)	Equilibrium (WPD)
LV Monitoring	FlexNet (SPEN)		
Network switching and remote control	Interoperable LV Automation (SPEN)	Clyde Gateway (SPEN)	FUN -LV (UKPN)
DC networks	SolaBristol (WPD)	SmartDC (WPD)	

* Project's aim was to build a prototype of a highly efficient and reliable SST
** Project's aim is to develop improve the efficiency of SST by using Sic semiconductors
***A research centre focusing specifically on SST and developing its prototypes

Figure 6-1: Innovation projects considered to inform LV Engine

As an example, UK Power Networks NIC Flexible Urban Networks Low Voltage (FUN-LV) project has been considered when developing the LV Engine project proposal. The overarching aim of UK Power Networks' project was to explore how the use of power electronics can enable deferred reinforcement and facilitate the connection of low carbon technologies and distributed generation in urban areas, by meshing existing networks which are not meshed. The core objective was to optimise the capacity among secondary substations to accommodate the forecasted growth in electric vehicle charging, heat pumps, and micro generation on existing connections by making the network more flexible and resilient through capacity sharing between substations.

Knowledge and learning from relevant NIA projects, such as SP Energy Networks' Interoperable LV Automation project, has also been considered when developing the LV Engine project proposal. The Interoperable LV Automation 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.

6.1.5 Knowledge gained through supplier and academic engagement

During the development of the proposal, SP Energy Networks has engaged with a number of potential SST equipment suppliers to seek confidence that existing technological solutions, currently being deployed in traction application (TRL 9) and prototype grid applications, can be successfully developed. We have spoken to a range of suppliers to determine their ambition and strategic intent to develop and deliver the necessary SST equipment and to ensure that there would be multiple suppliers in order to secure a competitive SST solution. Initial engagement with suppliers has provided confidence that existing technology solutions could be adapted for grid application based on existing prototype developments with different transformer ratings.

The suppliers of power electronic equipment consider that existing solutions can be developed for the required power and voltage level, and that modular solutions can be designed to facilitate easy uprating of transformer capacity.

Academic engagement has been undertaken both in the UK and overseas to gain knowledge of current and possible technology developments and seek on-going support in developing this innovation power electronic solution.

6.1.6 Capability to deliver large-scale innovation projects

SP Energy Networks has delivered several large scale innovation projects and we are equipped with the knowledge, experience, and resources to successfully conduct innovation projects such as LV Engine. The ability to succeed in such pioneering schemes is derived from previous achievements in similar value innovation projects, some of these projects are listed below:

- ANGLE-DC: This is one of our on-going NIC projects with the total budget of £14.8m started in 2016. The project has met its aims and objectives within the planned budget. In this project we have demonstrated our capability to prepare technical specifications for a power electronic solution and conduct a competitive procurement between different suppliers.
- Flexible networks for future low carbon future (FLEXNET): This project had a total budget of £6.4m. In this project, we demonstrated our capability to deliver a multi-vendor project which involved trials of different innovative methods at various parts of distribution networks located in both Scottish Power Manweb and Scottish Power Distribution. A significant amount of this funding was also returned to the customer.
- Accelerating Renewable Connections (ARC): This project had a total budget of £8.0m. We demonstrated our capability to trial a real-time active network management system which required a reliable communication architecture and control strategy to adjust the outputs of generators. We developed several technical guidance and policy documents which will be used for full business adoption;
- Visualisation of Real Time System Dynamics using Enhanced Monitoring (VISOR): This is a NIC project with a total budget of £7.37m and it involves complicated real-time modelling and analysis of transmission network dynamic conditions.

The above examples are evidence that we:

- have managed a delivery team from a variety of backgrounds, including consultants, suppliers, and academics;
- are able to set-up a strong communication structure to ensure successful management, delivery, and knowledge dissemination;

- have been capable of delivering the innovation projects with different technical requirements.

This experience will ensure that SP Energy Networks can deliver the LV Engine project successfully, generate and capture all learning outcomes within the estimated time and budget, and ensure that the opportunity to realise business as usual benefits are realised by UK DNOs.

6.1.7 Established Project Plan, Work Scope and Risk Register

We have developed a robust and appropriately detailed project plan and scope of work to ensure the successful delivery of the LV Engine project. The plan takes account of the project aims and objectives; it will consist of seven work packages. The activities, time lines, and dependencies between activities in our project plan are constructed based on information we gathered from different parties during proposal preparation and also our experience for delivery of similar innovation projects. The details of our project plan are given in Appendix D.

We have also identified risks, quantified their impact, and developed mitigation plans based on the information gathered by engaging with a number of potential SST suppliers and experience gained from delivering other innovation projects. Risks were categorised based on the relevance to different aspects of the project (Technical risks, procurement and manufacturing, Health and safety and operation, Project management). Appendix E shows the risk register developed during the proposal preparation phase. We will be updating the risk register during the delivery phase as part of our project management governance. The project manager will inform the steering board in case any risk has major impact on overall delivery of the project which may trigger the suspending the project process.

6.1.8 Identified Project management structure

We have planned a project management structure based on WPs within LV Engine and the expertise required for delivery of each WP. In order to optimise the level of interfaces and communication between delivery team and project manager, we have divided the delivery team to four distinctive teams, namely i) SST Design and manufacturing, ii) Installation and commissioning, iii) BaU integration, and iv) Knowledge dissemination. The adequate resources and expertise will be provided through internal resources, different partners, and contractors to each team. Figure 6-2 shows the LV Engine project management structure. The project manager will be one of our senior project managers within our future networks team with experience of delivering large scale and complex projects.

The Project Manager will be responsible for overall delivery of the project and also engaging with the Project Steering Board to communicate the project progress, exception reports, or any issue raised. The Steering Board includes representatives of SP Energy Networks, manufacturing partners, and academics. As part of our collaboration with UK Power Networks, their Head of Innovation will be also part of our Steering Board.

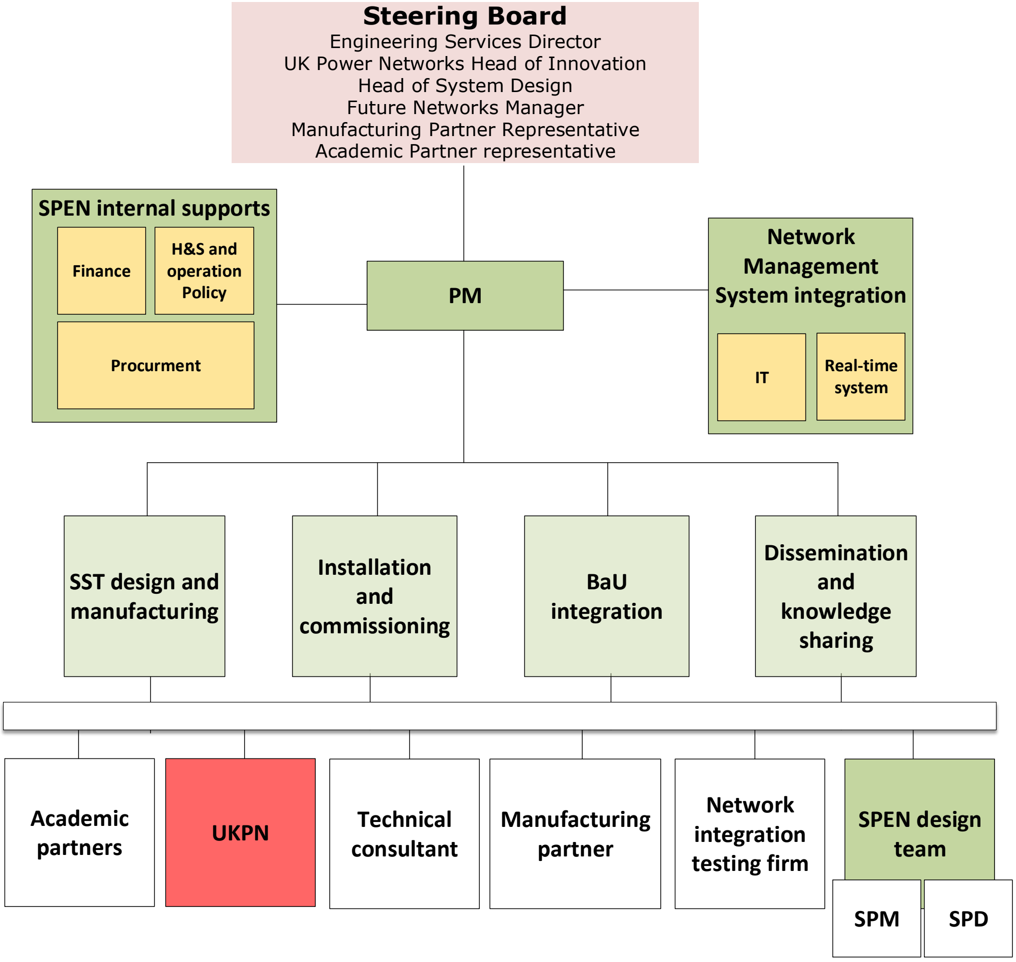


Figure 6-2: LV Engine Project Structure

6.2 Evidence of how the costs and benefits have been estimated

6.2.1 Cost estimation

- A top down and bottom up costing exercise has been undertaken for the LV Engine project, using knowledge and experience gained from other Innovation projects, and incorporating reasonable levels of contingency.
- All the activities within work packages have been identified and the required man-hours against each activity by different parties (SP Energy Networks, contractor, UK Power Networks etc.) have been estimated.
- We have extensively engaged with manufacturers and academics to discuss design and manufacturing cost of SSTs for LV Engine, our estimation is reflecting a median value quoted by manufacturers in this field plus a reasonable level of contingency.
- The project management cost is estimated based on the level of involvement and activities within each WP. We have considered a full-time project manager for the first three years of the project and then project manager time will reduce to 77% and 53% of full time in the fourth and fifth year of the project, respectively.
- The equipment costs (protection, IT, circuit breakers, monitoring equipment, etc.) are estimated based on i) Our BaU manual cost ii) the cost incurred in previous experience ii) the cost of equipment trialled in other innovation projects.
- The cost of technical services by academics and network integration testing facilities are based on unofficial quotations from these parties which we acquired as part of their Expression of Interest.

6.2.2 Benefit estimation

- The financial benefit of LV Engine is calculated based on the comparison between the reinforcement method proposed by LV Engine and a Base Case which represents the conventional reinforcement approach.
- The Base Case cost is based on SP Energy Networks' unit manual cost and in consultation with our design engineers and planning managers. The LV Engine method cost is based upon our extensive engagement with manufacturers and experience gathered during previous NIC projects.
- The unit cost for an SST has been estimated for 2023 based upon manufacturer engagement and a cost reduction curve has been applied between 2023 and 2050.
- The number of deployment opportunities for roll out across SP Energy Networks and GB is based upon the uptake of LCTs projected by National Grid annual report *Future Energy Scenarios (FES*) and the resulting reinforcement required as estimated by Electricity North Wests' within its project *LV Network Solutions*.
- The roll out methodology includes a reduction in possible deployment opportunities due to a generous market share percentage for other innovative reinforcement approaches that may be available between now and 2050 i.e. DSO flexibility, battery storage, SOPs, OLTC etc. In total the number of deployment opportunities for LV Engine between 2023 and 2050 represents 16% of the ground mounted secondary transformers within GB.
- The benefit estimation includes the impact of LV Engine on network losses and carbon emissions. This is based upon a losses and carbon calculation for an individual deployment and extrapolated across SP Energy Networks and GB using our roll out methodology.

6.3 Evidence of the measures the Network Licensee will employ to minimise the possibility of cost overruns or shortfalls in Direct Benefits

We will use established robust methodologies throughout the lifetime of the LV Engine project to minimise the risk of cost overruns. The methodologies we use are outlined as follows:

- **Ensure a competitive tendering for selecting manufacturing partner:** The greatest potential uncertainty lies around the budget for the SST, consequently to reduce the risk of cost overruns we have actively engaged with a number of potential SST suppliers during the proposal preparation phase to make a practical estimation of the equipment cost based on their responses to our Expression of Interest and follow up supplier meetings. We will prepare a more detailed equipment specification based on our project learning to ensure the most competitive costs via a competitive tender exercise. We will also closely monitor the progress in the SST design and manufacturing to ensure the cost incurred is proportional to the expected progress.
- **Breaking down the project into WPs:** The LV Engine project has been split into separate WPs with allocated budget and tolerances to minimise the possibility of cost overruns or shortfalls in direct benefits. A stage control strategy will be used to define the activities in each WP. Monthly project cost reviews and cost at completion forecasts will be also conducted for each WP to provide an accurate picture of total project cost.
- **Maintaining Project Delivery Focus and Realising Learning Objectives:** Due to the innovative nature of the LV Engine project, there is always a temptation to trial new ideas and new methods which are not in the main project objectives while the project is progressing. We acknowledge that we need to stay

focused on our project learning objectives as defined at the project outset to avoid unplanned expenditures.

- **Risk Management Process and Mitigation Plans:** We recognise that identifying risks and putting appropriate mitigation plans in place is an effective methodology to avoid possible cost overrun on the LV Engine project. We have already identified risks in LV Engine especially those which will have a financial impact on the project. We will continue to actively update the risk register and mitigation plans during the course of project.

6.4 A verification of all information included in the proposal (the processes a Network Licensee has in place to ensure the accuracy of information can be detailed in the appendices)

SP Energy Networks has endeavoured to ensure the accuracy of the information included in this proposal. The following process was undertaken to ensure that the information included in this proposal and associated appendices, prepared by an experienced technical team led by a full-time dedicated proposal manager, is up-to-date, and reflects the best knowledge available at the time:

- **Independent review by UK Power Networks:** An independent peer review has been undertaken by UK Power Networks to ensure that the delivered solution will be fit-for-purpose with suitable functionality for adoption by other DNOs into Business as Usual.
- **Academic and supplier engagement:** We have engaged with a range of potential suppliers to ensure the SST cost estimated for the financial analysis and the lead time considered in the project plan are realistic. We have discussed the LV Engine project concept with some of the experts in the field including academics (Kiel University, ETH Zurich etc.) to ensure the feasibility and applicability of the project.
- **External consultants:** WSP, experts in the various associated technical fields (including transformers, LVDC and power electronics) were engaged during the development of this proposal to verify the proposed design concept, the technical assumptions, the project risks, the project delivery programme and the costs, both CAPEX and OPEX, used in the cost benefit analysis.
- **A thorough quality control:** An independent peer-review and challenge session of the proposal was carried out by different internal and external technical experts outside of the proposal preparation team. Various cross checked between this proposal and other data sources such as full submission spreadsheet and cost benefit analysis spreadsheets have been carried out to ensure the data presented in this proposal are correct.
- **Data Assurance Governance (DAG) Review**: The proposal has been through SP Energy Networks full DAG process prior to senior management sign-off.

6.5 How the Project plan would still deliver learning in the event that the take up of low carbon technologies and renewable energy in the trial area is lower than anticipated in the Full Submission

LV Engine will still deliver its learning objectives in the unlikely event of a lower uptake of renewables and LCTs across SP Energy Networks' licence areas. LV Engine solution provides a toolbox for flexible operation of the LV networks. The demonstration of LV Engine includes three principle functionalities: i) LV voltage control ii) Capacity sharing between secondary substations and iii) provision of DC network. We will focus on demonstration of these principle functionalities and we will deliver our leaning objectives summered in Table 5-1 even in the event of low LCT uptake. We will also be able to compare SSTs performance with conventional transformers equipped with OLTC for the same level of LCT uptake.

The LV Engine project will provide valuable learning in LVDC deployment and application, it will also help upskill staff in power electronics which, in the future will be more prevalent in electricity distribution networks. The project will also develop a comprehensive SST specification and deployment policy guide which can be used by other DNOs. This learning will not depend on the rate of uptake of low carbon technologies on the LV network.

6.6 The processes in place to identify circumstances where the most appropriate course of action will be to suspend the Project, pending permission from Ofgem that it can be halted

The project manager will be responsible for monitoring the project progress and evaluating the project performance at the end of each stage of the project. Project manager consider the key performance indicators (KPI) that represent the followings:

1- Project deliverables can be delivered within the planned time and quality
2- Project learning objectives can be generated as planned
3- Project cost is within the planned budget

If any of the above KPIs indicates the project is not performing as planned, depending on the impact on the project, the project manager may escalate the issues to the Steering Board by submitting an exception report. The exception report will contain the information for the project board to decide if the project should be stopped or remedial actions are required. If the Steering Board recognises that project must be halted, they will issue a formal report to Ofgem to request permission to discontinue or delay the project, detailing the issues, meeting minutes and recommendations. Figure 6-3 shows the process to identify situations where the most appropriate course of action is to halt the project. This process will comply with NIC governance and will be delivered in the best interests of our customers.

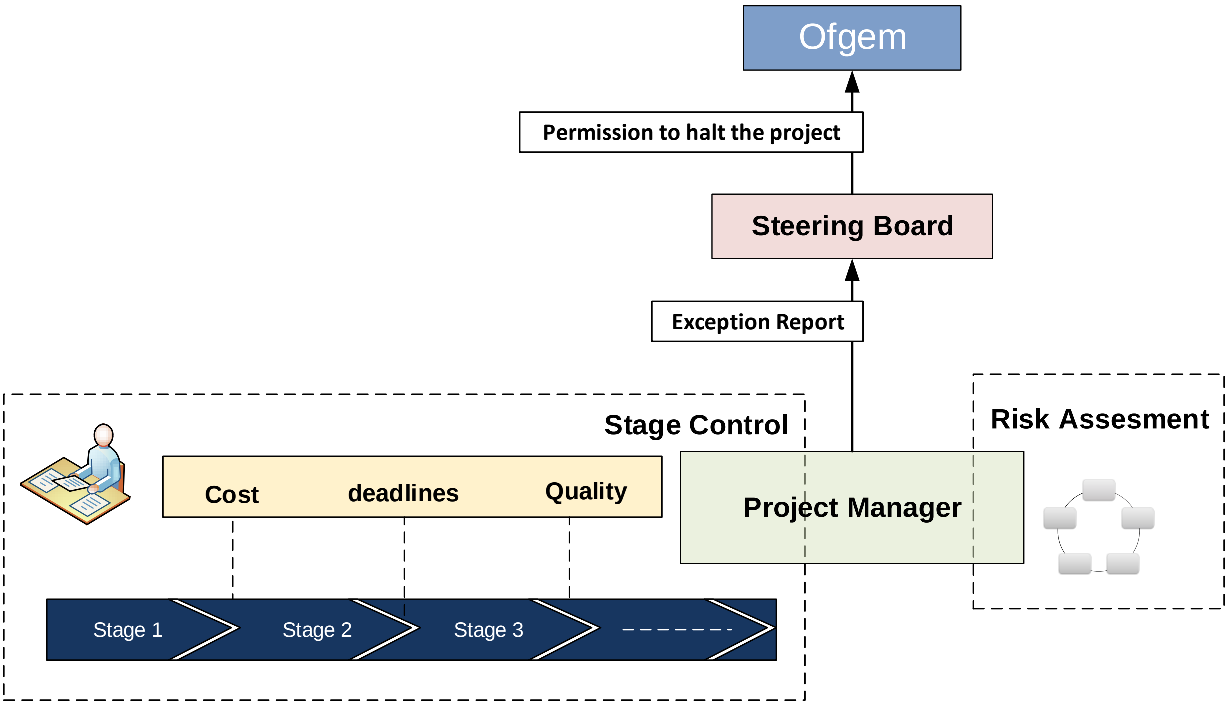


Figure 6-3: Process in place to identify if project should be halted

Section 7 Regulatory issues

LV Engine is within the scope of Ofgem NIC governance and industry regulations. We have not identified any requirements for changes to the current regulatory arrangements to deliver LV Engine and each trial scheme, both AC and DC.

The DC customers chosen for schemes 4 & 5 will be metered at DC. We have identified examples of DC meters which can be used to meter EV charging points with ISO 9001 and IEC accreditation. We intend to work with Elexon and consult IEC 62053-41 ED1 to ensure a DC metering solution is approved for use within these trials.

However, we have also considered a contingency metering design to allow standard metering procedures and equipment to be used in the unlikely event that an approved DC meter cannot be procured. Figure 7-1 shows our contingency approach to metering DC customers.

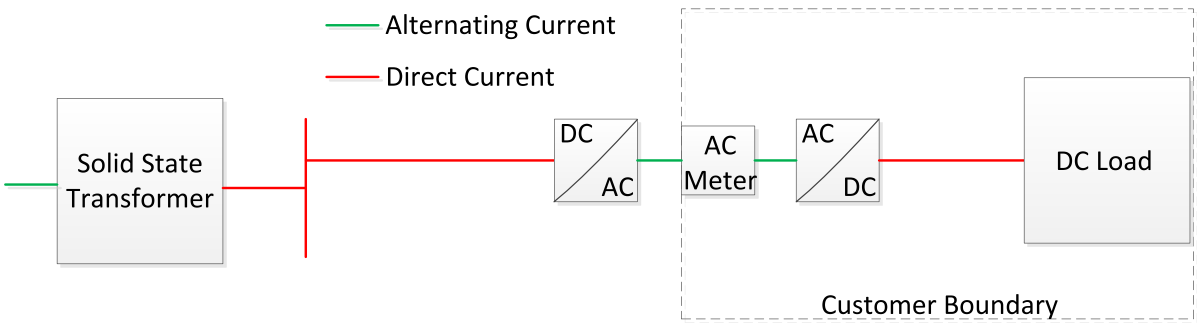


Figure 7-1: LVDC customer proposed connection methodology

If an approved LVDC meter is agreed with Elexon during project delivery we will design the schemes to include a DC meter in the place of the back to back converters shown within Figure 7-1.

During BaU adoption of the technology the intention would be to use an approved smart meter that is capable of metering at DC. However, the design shown in Figure 7-1 will allow us to demonstrate the principle of providing low voltage DC to our customers from an SST without the risk of relying upon a suitable DC meter. However, we are confident that a suitable DC meter will be procured.

7.1 Derogations

No derogations have been identified as required by LV Engine.

7.2 Licence Consents

No licence consents have been identified as required by LV Engine.

7.3 Licence Exemptions

No licence exemptions have been identified as required by LV Engine.

7.4 Changes to Regulatory Arrangements

No changes to regulatory arrangements have been identified as required by LV Engine. However, LV Engine intends to work closely with the International Electrotechnical Commission (IEC), Institution of Engineering and Technology (IET) and the British Standards Institution (BSI) to provide recommendations to changes that may be required to the relevant standards (ESQCR, Distribution code, Electricity Act 1989) so that they consider the BaU requirements of LVDC supplies in more depth.

Section 8 Customer Impact

8.1 The Project

LV Engine intends to provide new functionalities to the LV network for the purposes of making additional capacity available within our existing network infrastructure to facilitate the uptake of LCTs. The method set out by LV Engine represents a significant innovative step in how our LV networks are designed, maintained, and operated which, if successfully demonstrated, could avoid or defer significant network reinforcement and their subsequent impact on customers in the near future.

8.2 Minimising Customer Impact

LV Engine represents a globally innovative trial of SSTs as no live network trial within a distribution network has taken place anywhere around the world. Consequently, thorough mitigation measures will be put in place to ensure the project can be delivered whilst minimising risk to our customers. SP Energy Networks' procedures will be followed to ensure the operation and safety of the network is not compromised by the project.

8.2.1 Parallel Operation with Existing Secondary Transformer

The existing secondary transformer within each trial location will remain *in situ* throughout the duration of each trial and coupled with the new SST to allow supplies to be restored quickly should the SST unexpectedly fail during operation as illustrated by Figure 8-1.

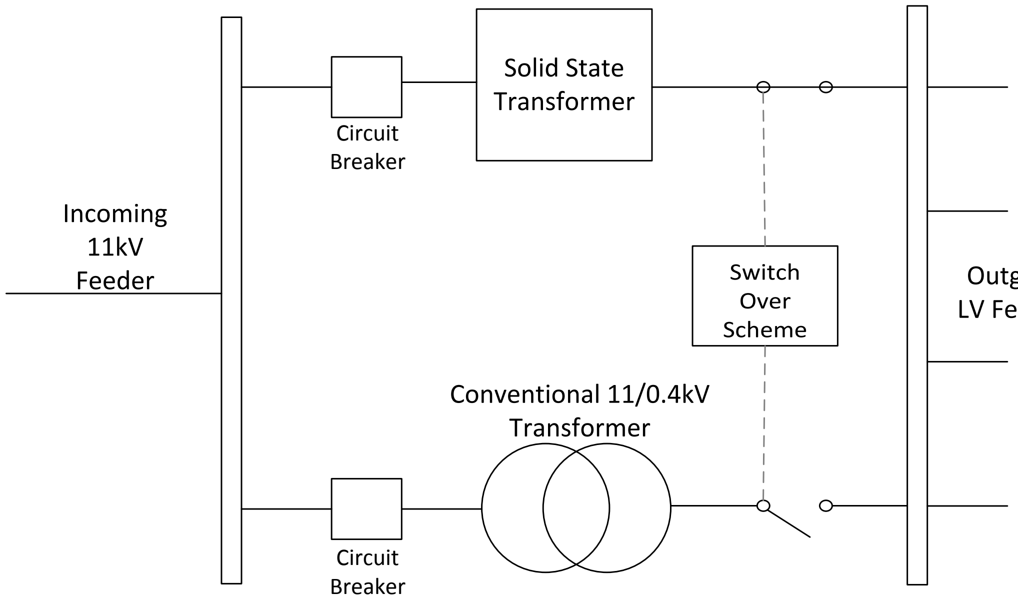


Figure 8-1: Solid State Transformer switch over scheme design

8.2.2 FAT & Network Integration Testing

To reduce the risk of SST failure during the live network trials, both SST designs will undergo thorough testing prior to deployment on our network. The testing of the SSTs will take place within WPs 3 & 4.

A detailed schedule of factory acceptance testing will be agreed between project partners and carried out within WP 3 on the SST prototypes. We will work closely with UK Power Networks and our own standards team to ensure the testing covers all aspects that are critical to the safety and performance of the designed units.

Network integration testing will also be carried out within WP 4 to ensure the devices are fit for deployment within our network and have been proven within a replica LV network.

This testing includes proving the protection design, earthing arrangements and the performance of critical SST functionalities.

8.2.3 Staggered Network Trials

Each trial scheme will be staggered within WP 5 to allow us gather learnings as the project progresses and provide us with an opportunity to alter our installation plans should any unexpected challenges occur during each trial installation. This approach will help to minimise the risk to our customers.

8.2.4 Single LVDC Customers

One of the most innovative elements of LV Engine is the provision of a low voltage DC supply to our customers. To minimise the risk of negatively impacting our customers we intend to provide DC to one customer only within trial schemes 4 & 5. This will allow us to engineer a manageable metering design and minimise the risks associated with provided DC to multiple customers for the first time.

8.3 Planned Interruptions

Switching over from the existing transformers to the new SSTs within the schemes will require planned interruptions to the LV customers. To minimise these interruptions we will look for opportunities to switch LV feeder onto adjacent transformers using the pre-existing NOPs. If this is not possible SP Energy Networks' standard procedure will be followed for scheduling outages to ensure the risk to customers is minimised.

8.4 Unplanned Interruptions

No unplanned interruptions are anticipated, however a switch over scheme will be included alongside each trial scheme to allow supply to be returned via the existing transformers should an SST fail unexpectedly.

8.5 Engagement with Customers

Customer engagement during the delivery of LV Engine will focus on the recruitment of suitable trial sites for a low voltage DC supply and access to a small number of customer premises for the purpose of installing voltage meters at strategic points along each LV feeder. The voltage meters will be used to allow the SSTs to regulate voltage at the LV busbar in real time whilst having view of the voltage profile along the length of each feeder.

We expect minimal disruption to the chosen customers during installation of these voltage monitors and no action will be required by the customers once the meters are installed. Adequate time has been set aside within the project delivery plan to gain this support and promotional material will be created to promote the project and encourage customer participation prior to installation of the SSTs on site.

8.5.1 LV Engine Customer Engagement Channels

LV Engine will be publicised to our customers using a variety of multi-media communication channels. A dedicated SPEN LV Engine website will be the main source of information for the customers within our trial areas. The SPEN website will be updated regularly with details of the chosen trial locations and how customers can participate. Local newspaper and promotional pamphlets will also be used to raise awareness of the project in these areas.

8.5.2 Customer Recruitment Process

Recruitment of suitable site to trial LVDC supply – During the process of putting together this proposal we have identified several potential sites that would benefit from a low voltage DC supply. We intend to maintain this engagement during the delivery of the project to secure these sites as trial locations for schemes 4 & 5. Our engagement methodology for these customers includes:

- Identify potential third parties through search of public domain and using existing connections and partners;
- Distribute promotional information on the benefits of DC and the LV Engine solution to identified potential third party sites;
- Face to face meetings with shortlisted sites to discuss project in detail;
- Put agreements in place with chosen sites for duration of project;
- Appoint a point of contact for chosen customers to maintain strong communication links; and
- And provide regular updates on progress of project prior to trial through face to face engagement and teleconferences.

Voltage meter installations - An external consultancy will be used to recruit customers face to face within the chosen trial sites. A promotional pamphlet will be created and distributed to each customer that will be supplied by the SSTs. The pamphlets will advertise a small financial incentive to each customer who takes part in the project and is willing to allow access to their premises for the purpose of installing a voltage metering device. Once the pamphlets have been distributed and reviewed by our customers, we intend to follow this up with face-to-face recruitment to secure their participation.

8.5.3 Managing Customer Enquiries

LV Engine will use a number of communication channels to ensure that customer questions and queries are handled in an efficient and confidential manner. The dedicated LV Engine area within the SPEN website will include a contact form to allow customers to raise any concerns they may have regarding the metering equipment that has been installed within their premises. We will also operate an SMS service to allow customers to request a call back if desired.

8.5.4 Managing Customer LVDC Safety Concerns

LV Engine will work closely with the customers chosen to trial the LVDC supply to alleviate any safety concerns that arise from the use of a DC voltage. We will build upon the learnings that are available within current safety standards to ensure all safety requirements are addressed. This will be communicated both directly with customers and via the SP Energy Networks website. These standards include:

- IEC/TS 60479-1 Effects of current on human beings and livestock
- IEC TS 63053:2017 General requirements for residual current operated protective devices for DC system
- IEC 60898-3 Circuit-breakers for overcurrent protection for household and similar installations - Part 3: Circuit-breakers for d.c. operation
- IET Code of Practice for Low and Extra Low Voltage Direct Current Power Distribution in Buildings
- Electricity Act 1989

8.6 Protection from Incentive Penalties

LV Engine will require no protection from incentive penalties.

Section 9 Project Deliverables

Table 9-1: Project Deliverables

Reference	Project Deliverable	Deadline	Evidence	NIC funding request
1	Technical specification of SST and functional specification of the LV Engine schemes' including relevant control algorithms	10/12/2018	A document detailing the technical requirements of SST including: 1. Continuous and emergency operating ratings 2. Voltage control capabilities 3. Power flow control capabilities 4. Fault control and fault ride through capabilities 5. Environment operating conditions 6. Protection requirements 7. Functional specification of the LV Engine schemes including control algorithms	10%
2	Detailed technical design of SST by the manufacturer and life cycle assessment	22/12/2019	Production of two documents: 1. Detailed design: The information will be provided as much as it complies with IRP agreement with the manufacturing partner, that can include the topology (stages) of SST, the cooling system, the choice of conductor, the control algorithm, SST protection logic, and all the lessons learnt within WP 3 2. Life cycle assessment: The results of life cycle assessment based on manufacturing and material process which will be conducted by an academic or consultant partner	20%
3	Manufacture SSTs for LV Engine schemes	11/01/2021	Manufacture SSTs for demonstrating the objectives of each LV Engine scheme as described in Section 2.1.3	20%
4	Complete network integration tests	28/09/2020	1. Shipping the SST prototype to live network integration facility 2. Complete network integration testing as per test specifications developed within Work package 1 3. Obtain a network integration certificate for SST prototypes from the chosen testing facility	10%
5	Establish the system architecture of LV Engine schemes	20/06/2021	1. Monitoring equipment is installed and measured data is sent to the SST and SP Energy Networks real time system (RTS) 2. Live performance can be monitored through a dashboard specifically designed for LV Engine schemes 3. The SSTs performance is recorded in the SP Energy Networks data historian	15%

Reference	Project Deliverable	Deadline	Evidence	NIC funding request
			4. Remote access to control and troubleshooting of SST is established	
6	Demonstrate the functionalities of SST	20/06/2022	1. Assessment of performance data in different loading/generation conditions where SST has performed LV voltage control 2. Assessment of performance data in different loading conditions where SST shares capacity with a conventional transformers or another SST 3. Assessment of performance data of LVDC network	14%
7	Best operational practices of SSTs	07/11/2022	1. A report detailing a cost benefit analysis methodology for the future deployment of LV Engine schemes as BaU 2. Providing a report recommending the methodology for selecting the best transformer schemes including use of SST or OLTC 3. Recommending a policy document which can be used for BaU adoption of SST. Providing a refined SST technical specification which can inform future SST deployment across the UK.	10%
8	Identify a trial site for replicating LV Engine solution within UK Power Networks	26/09/2022	A report detailing the following: 1. Network issues can be resolved within UK Power Networks by deploying LV Engine solutions 2. Details of the potential trial site within UK Power Networks for deploying LV Engine solution 3. Expected financial benefit by deploying LV Engine solution	1%
[Note this is a common Project Deliverable to be included by all Network Licensees as drafted below]				
N/A	Comply with knowledge transfer requirements of the Governance Document.	End of project	1. Annual Project Progress Reports which comply with the requirements of the Governance Document. 2. Completed Close Down Report which complies with the requirements of the Governance Document. 3. Evidence of attendance and participation in the Annual Conference as described in the Governance Document.	N/A

Appendices

Appendix A Benefits Tables

Method	Method name
Method 1	LV Engine Solution

A.1 Electricity NIC – Financial Benefits

Cumulative Net Financial Benefit (NPV terms; £m)								
Scale	**Method**	**Method Cost**	**Base Case Cost**	**Notes**			**Cross-references**	
				2030	**2040**	**2050**		
Post-trial solution *(individual deployment)*	Method 1	0.135	0.151	0.06	£0.05	£0.04	The LV Engine Solution cost is based upon a 2023 SST unit price of £[redacted], additional Capex of £[redacted]k and annual Opex of £[redacted]/year. The Opex cost is applied between 2023 and 2050. These cost estimates are based upon information provided by multiple vendors. These values do not include any costs associated with the carbon savings.	Appendix C
Licensee scale *If applicable, indicate the number of relevant sites on the Licensees' network.*	Method 1	369.28	615.33	6.98	32.63	59.27	A cost reduction curve is applied to the SST unit price between 2023 and 2050 along with the roll out methodology used to quantify the number of deployment opportunities for the LV Engine solution as below (cumulative): 2030: 878 2040: 3,063 2050: 4,074	Appendix C
GB rollout scale *If applicable, indicate the number of relevant sites on the GB network.*	Method 1	3,287.34	5,477.65	62.11	290.48	527.61	GB estimated deployment opportunities for the LV Engine solution (cumulative): 2030: 7,819 2040: 27,274 2050: 36,270 The total project funding will be repaid within 7 years after project starts based upon our CBA and roll out methodology.	Appendix C

A.2 Electricity NIC – Carbon and/or Environmental Benefits

Cumulative Carbon Benefit (tCO2e)								
Scale	**Method**	**Method Cost**	**Base Case Cost**	**Notes**			**Cross-references**	
				2030	**2040**	**2050**		
Post-trial solution *(individual deployment)*	Method 1	0.135	0.151	27	-25	-47	Carbon benefits include CO2 emissions associated with the civil works and timing of the LV Engine solution and the counterfactual. Also includes CO2 emission associated with the losses of both options. Our calculations do not include the CO2 benefits associated with the potential loss savings of a future LVDC network.	Appendix C
Licensee scale *If applicable, indicate the number of relevant sites on the Licensees' network.*	Method 1	369.28	615.33	46,991	129,883	147,614	Cumulative number of deployments across SP Energy Networks: *2030: 878* *2040: 3,064* *2050: 4,074*	Appendix C
GB rollout scale *If applicable, indicate the number of relevant sites on the GB network.*	Method 1	3,287.34	5,477.65	418,307	1,156,207	1,314,050	Cumulative number of deployments across GB: *2030:7,819* *2040:27,274* *2050:36,270*	Appendix C
If applicable, indicate any environmental benefits which cannot be expressed as tCO2e.	The carbon benefits listed above do not consider the savings that could be realised by enabling a future LVDC network. A LVDC network can significantly reduce network and customer losses by removing the need to continuous rectification between AC and DC. This reduction in losses could significantly reduce the energy consumed on the LV network and bring considerable carbon savings alongside the financial benefits. Increased transfer capacity at LVDC could also further reduce the need for LV cabling and the associated carbon impact by converting AC circuits to DC in the future. This has also not been included within the carbon benefits calculation.							

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RIIO NIC NETWORK INNOVATION COMPETITION

Appendix B Full Submission Spreadsheet

NIC Funding Request		2017/18	2018/19	2019/20	2020/21	2021/22	2022/23	Total
Cost	*From Project Cost Summary sheet*							
	Labour							
	Equipment							
	Contractors							
	IT							
	IPR Costs							
	Travel & Expenses							
Payments to users & Contigency								
	Decommissioning							
	Other							
	Total	121.41	698.34	2,116.99	3,768.71	783.15	806.67	8,295.28
External funding	*Any funding that will be received from Project Partners and/or External Funders - from Project Cost Summary sheet*							
	Labour	-	4.06	6.84	14.22	5.08	16.64	46.84
	Equipment	-	-	-	-	-	-	-
	Contractors	-	-	-	-	-	-	-
	IT	-	-	-	-	-	-	-
	IPR Costs	-	-	-	-	-	-	-
	Travel & Expenses	-	0.62	0.96	1.80	0.74	2.73	6.85
Payments to users & Contigency		-	-	-	-	-	-	-
	Decommissioning	-	-	-	-	-	-	-
	Other	-	-	-	-	-	-	-
	Total	-	4.68	7.80	16.02	5.82	19.36	53.69
Licensee extra contribution	*Any funding from the Licensee which is in excess of the Licensee Compulsory Contribution - from Project Cost Summary sheet*							
	Labour	-	-	-	-	-	-	-
	Equipment	-	-	-	-	-	-	-
	Contractors	-	-	-	-	-	-	-
	IT	-	-	-	-	-	-	-
	IPR Costs	-	-	-	-	-	-	-
	Travel & Expenses	-	-	-	-	-	-	-
Payments to users & Contigency		-	-	-	-	-	-	-
	Decommissioning	-	-	-	-	-	-	-
	Other	-	-	-	-	-	-	-
	Total	-	-	-	-	-	-	-
Initial Net Funding Required		*calculated from the tables above*						
	Labour							
	Equipment							
	Contractors							
	IT							
	IPR Costs							
	Travel & Expenses							
Payments to users & Contigency								
	Decommissioning							
	Other							
	Total	121.41	693.66	2,109.19	3,752.70	777.33	787.31	8,241.60
Direct Benefit	*from Direct Benefits sheet*							
	Total	-	-	-	-	-	-	-
Licensee Compulsory Contribution / Direct Benefit		*from Project Cost Summary sheet*						
	Labour							
	Equipment							
	Contractors							
	IT							
	IPR Costs							
	Travel & Expenses							
Payments to users & Contigency								
	Decommissioning							
	Other							
	Total	12.14	69.37	210.92	375.27	77.73	78.73	824.16
Outstanding Funding required		*calculated from the tables above*						
	Labour							
	Equipment							
	Contractors							
	IT							
	IPR Costs							
	Travel & Expenses							
Payments to users & Contigency								
	Decommissioning							
	Other							
	Total	109.27	624.30	1,898.27	3,377.43	699.60	708.58	7,417.44
balance	7,290.06	0.00	6,556.49	4,710.15	1,374.97	698.19	(2.61)	7,290.06
interest		0.00	51.92	42.25	22.82	7.77	2.61	127.38
								7,417.44
								7,290.06

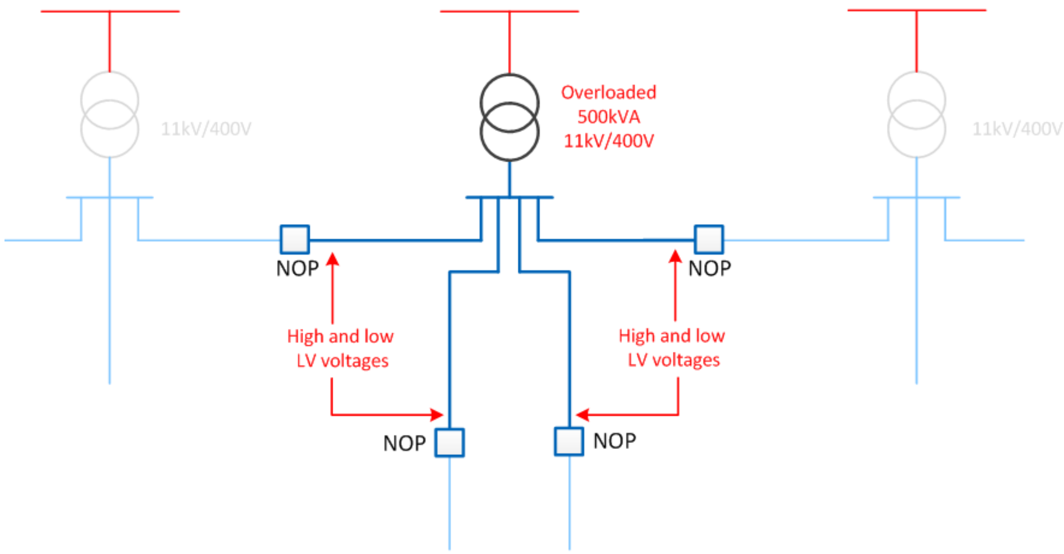
Appendix C Business Case Supplement

This Appendix details the assumptions that have been made within the Cost Benefit Analysis (CBA) of LV Engine, which have allowed us to quantify the benefits of the project to UK electricity customers. To do this we have compared the LV network reinforcement solution proposed by LV Engine to a counterfactual BaU approach and then applied a roll-out methodology to ascertain the value across SP Energy Networks licenced areas and across GB.

C.1 LV Engine Method

Appendix Figure C-1 illustrates the case study network that has been used as the basis of the evaluation of LV Engine benefits. This network is already experiencing problems due to LCT load growth in the form of electric vehicles, heat pumps and photovoltaics and so it provides us with an opportunity to consider and compare the LV Engine solution and traditional reinforcement approaches.

The 11kV/0.4kV 500kVA transformer is thermally overloaded due to the increase in demand. Furthermore, each of the four associated feeders within our case study is out with the voltage statutory limits and is experiencing both high and low volts at different times of the day. For these reasons there is a need to reinforce to overcome these challenges and provide a statutory compliant network to supply the customers connected to this LV infrastructure. Tapping of the existing transformer is not considered an effective solution for maintaining voltage levels within statutory limits as permanently fixed or seasonal taps are insufficient to manage the dynamic range of voltages due to variations in power flow through the LV network.

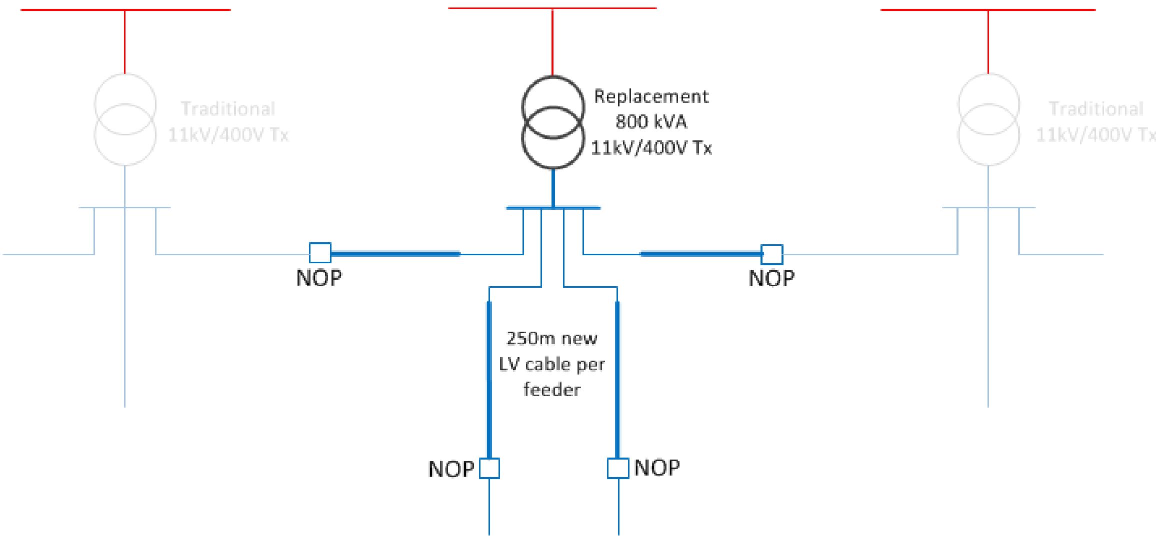


Appendix Figure C-1: LV Engine Baseline Case Study

Two solutions to the problems shown within this example are discussed within this Appendix. To quantify the benefits that could be delivered by LV Engine we have compared the benefits of the LV Engine (Method) reinforcement solution to a counterfactual traditional reinforcement solution (Base Case).

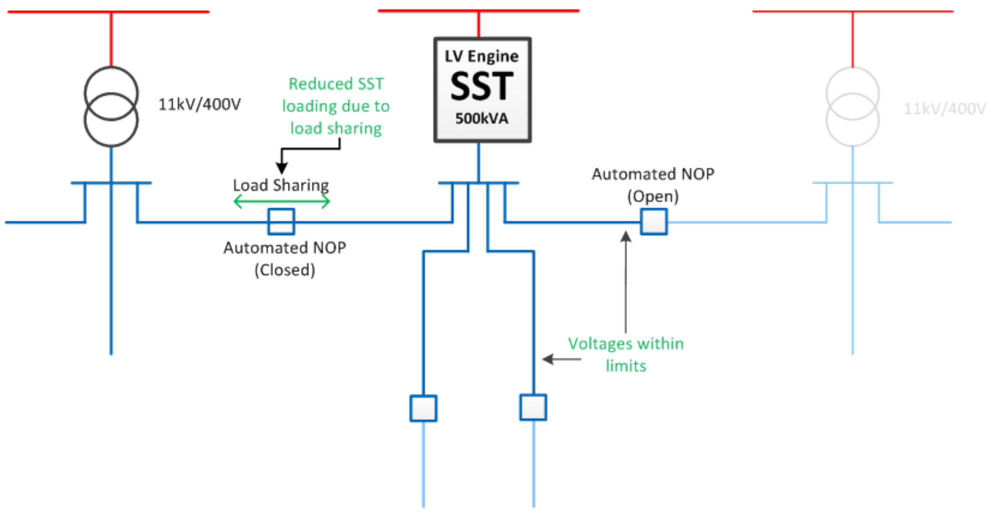
Appendix Figure C-2 shows the **traditional reinforcement approach (Base Case)**. By consulting closely with SP Energy Networks design engineers we have established a counterfactual which we believe is both credible and fairly represents the work that would take place to overcome the problems posed by this example today.

The counterfactual reinforcement approach has been designed to address both the voltage and thermal strain. To maintain the voltage along each feeder within the statutory limits of +10% and -6% the conventional practice when local tapping is insufficient is to replace the tapered part of the cable with a larger size LV cable that has a lower impedance. Furthermore, to address the thermal strain caused by load growth across the four feeders the existing 500kVA transformer is replaced with a larger 800kVA unit.



Appendix Figure C-2: Counterfactual BaU Reinforcement Approach

Appendix Figure C-3 illustrates the **alternative reinforcement proposed by LV Engine (Method)**. The existing secondary transformer has been replaced with a 500kVA SST within the existing substation. In addition, the NOPs have been equipped with automated LV circuit breakers which are controlled by the SST.

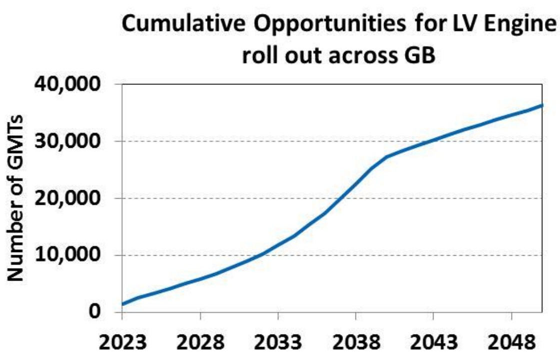


Appendix Figure C-3: Baseline LV Engine Reinforcement Approach

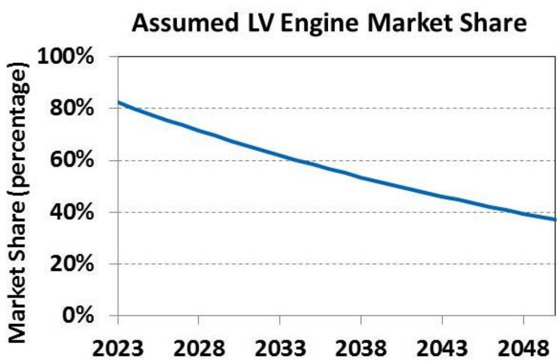
The SST is capable of regulating and optimising the voltage at the LV busbar and consequently along each feeder based upon voltage data from monitored points along each feeder. The additional interconnection via the existing NOPs allows the SST to load share with the adjacent transformers to reduce its peak loading and facilitate an increase in demand whilst remaining within its rating. Load sharing allows the SST to be sized lower than would otherwise be possible by allowing neighbouring transformers to peak shave the maximum loading. This additional LV network flexibility will also benefit the neighbouring transformers with complementary load profiles if SST capacity is available.

C.2 Roll Out Methodology

Opportunities for LV Engine have been identified when the majority of feeder circuits associated with a Ground Mounted Transformer have voltage issues. These could be voltages outside of permitted limits due to the uptake of generation, additional demand or both. Gone Green projections from National Grid's 2016 Future Energy Scenarios for future LV generation, EVs and domestic demand including heat pumps have been considered. These have been used in conjunction with the average penetration levels leading to voltage issues reported as part of Electricity North West's LV Network Solutions project. This extensive study of real LV networks showed that customers experience voltage problems when more than 30% of customers install PV generation and when more than 50% of customers install heat pumps. LV Engine is assumed to be applied based upon satisfying a proportion of the total requirements, specifically as shown in Appendix Figure C-4, a market share which reduces to 37% in 2050, when alternative techniques or products may be available for accommodating LV LCT connections economically. Appendix Figure C-5 shows the uptake of LV Engine culminating at approximately 16% of today's traditional GMTs being replaced by LV Engine SSTs by 2050.



Appendix Figure C-4: Cumulative GB Opportunities for LV Engine



Appendix Figure C-5: Assumed market share serviced by LV Engine

C.3 Financial Benefits

Financial benefits have been evaluated by comparing the total costs for the Base Case and LV Engine method which have been built up by considering the individual components.

Appendix Table C-1 summarises the Capex and Opex costs for the Base Case (counterfactual) . Capex costs include allowances for the substation items and the additional cable required along each feeder to address the voltage issues. Opex costs include allowances for inspection and oil replacement. Costs are based on the values given in SP Energy Networks' unit cost manual and or established through discussions with SP Energy Networks' Design Engineers and Asset Management teams.

Appendix Table C-1: Base Case (Counterfactual) Capex and Opex

Capex	Cost	
Substation Items	£	17,145
Cable Circuit Items	£	132,259
Total	**£**	**149,404**
Opex	**Cost**	
Annual	**£**	**74**

Appendix Table C-2 details the Capex and Opex associated with the LV Engine method should the solution be rolled out on mass as BaU at the end of the project. LV Engine Capex costs include allowances for the SST, control, protection modifications and NOP automation. Opex costs include allowances for inspection and replacement of the filters and fans. We have established these cost estimates based upon our engagement with multiple vendors and in reference to SP Energy Networks' unit cost manual and experience with other NIA & NIC innovation projects. We expect the unit cost of the SST to fall as the TRL level of the technology continues to increase. A SST unit cost of £[redacted] in 2023, falling to £[redacted] in 2050 has been reflected within the analysis of the LV Engine financial benefits. We have included a specific deliverable within the scope of LV Engine to better understand the O&M requirements of SSTs to inform how the technology could be effectively adopted by BaU practices.

Appendix Table C-2: LV Engine Capex and Opex by 2050

Capex	Cost
LV Engine	**£** [redacted]
Opex	**Cost**
Annual	**£** [redacted]

C.4 LV Engine impact on losses

The cost of losses has been included in the CBA on the basis of the value of losses, the estimated percentage change in losses and the energy supplied via the number of applications of LV Engine in GB and SP Energy Networks as determined by our roll out methodology.

LV Engine has the **potential to deliver significant savings by reducing network losses** if SSTs are rolled out across the UK. Voltage control of each phase at both LV and 11kV and the capability to provide a LVDC supply to customers can both contribute significantly to this saving. However, **this is not reflected in the benefits analysis** at this stage as the uptake rate of DC and the impact of voltage control on losses is difficult to forecast. Consequently, a **conservative approach has been taken when calculating the benefits an SST can bring to network losses.** Specific deliverables within LV Engine will allow these factors to be quantified reliably as an output of the project.

The following factors have been quantified and included in our CBA as additional losses:

SST efficiency: LV Engine will initially increase losses as the efficiency of an SST (98%) is lower than that of a traditional 11kV/LV transformer (99.4%). However, it is expected that technological advancements in semi-conductors will allow the losses experienced through an SST to match that of a traditional transformer by 2050. Consequently, these additional losses have been reflected in our CBA but reduce each year as efficiency increases towards 2050.

Base Case reduced network impedance: The counterfactual base case includes the replacement of a large proportion of each LV feeder with a larger size cable with a lower impedance. Consequently, network losses are reduced relative to the method employed by LV Engine. This has been quantified and included within our benefits analysis based upon the number of deployment opportunities calculated by our roll out methodology.

Higher utilisation of LV network: Within the benefits analysis we have included an increase in the LV network utilisation factor for both the Base Case and LV Engine methods. Therefore, the additional network losses described above are calculated based upon a higher utilisation of the network post reinforcement.

The following factors have not been included within our CBA but may dramatically reduce the losses associated with the LV Engine method:

DC supplies may dramatically reduce overall system losses, but this is not reflected in the CBA as the uptake rate is difficult to forecast at this time. Presently, rectifiers are required to convert AC voltages to DC to supply equipment requiring a DC connection such as electric vehicles and modern electronics such as mobile devices, TVs and lighting. A DC supply facilitated by LV Engine will avoid the losses in such rectifiers and reduce customers' energy consumption accordingly. According to National Grid's 2016 Gone Green Future Energy Scenario, EVs will consume 23.7TWh annually by 2040. Since rectifier losses are typically at least 8%, the supply of all EVs via a DC supply facilitated by LV Engine, but not allowing for the supply of any other types of DC load, **will mean that 1.9TWh, corresponding to approximately £92m, of customer losses could be avoided in 2040**. In addition, providing a DC supply will reduce the loading on the AC network and hence network losses would be less than the estimate used in the benefits analysis presented here.

LV Engine also has the capability to balance phases and so any apparent imbalance in the LV system can be corrected so that power flows in the MV network remain balanced. An advantage of such balancing is to reduce losses in the MV network as imbalance means that the current will be higher in at least one of the phases and hence losses are greater due to their dependency on current squared. This reduction in losses means that the impact of losses included in the benefit analysis is pessimistic.

C.5 LV Engine Solution Released Capacity

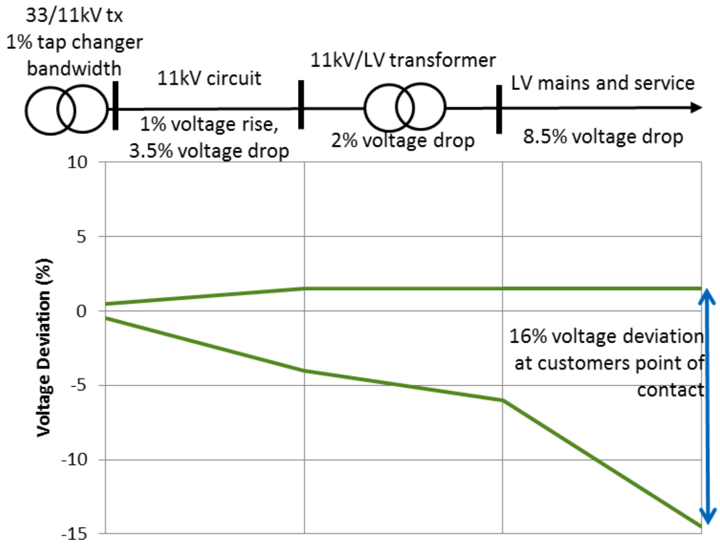
Within our financial analysis we have assumed that both the LV Engine solution and the traditional reinforcement approach provide similar network capacity. The similarities in additional capacity mean that we have not claimed any benefit in terms of released capacity for the connection of LCTs. To justify this approach we have quantified the capacity that is released when voltage regulation and load sharing with neighbouring transformers is available by the application of LV Engine.

However, it is worth noting that the LV Engine method could reduce reinforcement time and release capacity 15-18 weeks quicker than the counterfactual by avoiding the need to carry out extensive LV cabling and the associated planning and design work. This has been reflected in our calculation of the carbon benefits associated with the LV Engine method by conservatively quantifying the benefit associated with the earlier connection of Electric Vehicles and Photovoltaics to the LV network.

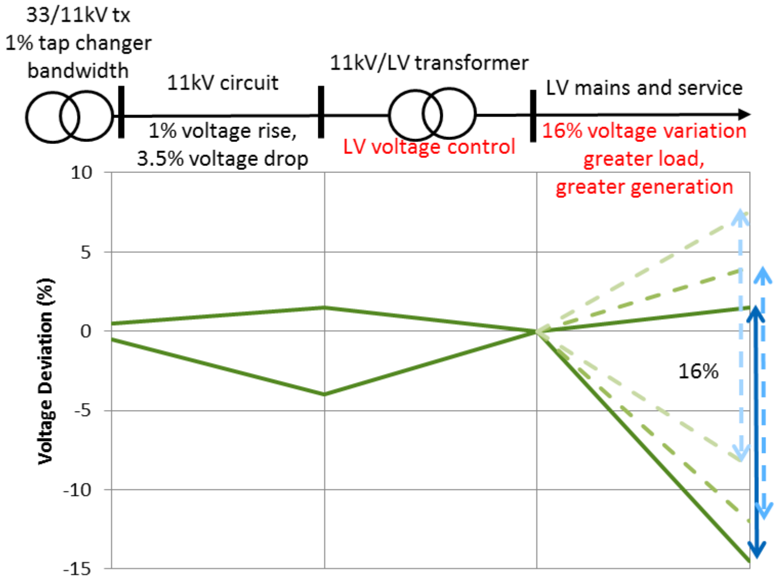
Converting existing ciruicts to DC to increase network capacity could also release additional capacity quicker when load growth due to the uptake of Electric Vehicles initiates further reinforcement.

C.5.1 Voltage Regulation

Existing networks are designed to comply with these limits based upon voltage control at the 33/11kV Primary substation. Designs make allowances for each part of the network so that the total voltage variation is within the allowable 16% (-6% to 10%) under worst case loading conditions. 16% is divided between the bandwidth of the tap changer voltage control and voltage rises and voltage drops in the 11kV network, 11kV/LV transformer, LV mains and LV service. A typical design allowance for the voltage variation in the LV mains and LV service is 8.5% as illustrated in Appendix Figure C-6. The voltage variation in the LV mains and LV service cannot be greater because the voltage variation due to the 11kV/LV transformer and 11kV network must be accommodated within 16%.



Appendix Figure C-6: Existing Conventional LV Network Design



Appendix Figure C-7: LV Engine Voltage Control

Connections to LV networks are normally constrained by voltage limits at lower levels of load than limited by thermal ratings, as reported by ENW's LV Network Solutions project. Consequently, solving the voltage issues means that additional connections can be accommodated within the thermal capacity of the LV circuits, thus making better use of existing assets.

LV Engine provides voltage control in the LV system and so the voltage variation in the LV mains and LV service can be 16%, rather than 8.5% as shown in Appendix Figure C-7. There is no longer any need to make allowances for the voltage variation in the upstream components between the secondary terminals of the 11kV/LV transformer and the point where voltage is controlled at the Primary substation. Increasing the allowable voltage variation in the LV mains and LV service from 8.5% to 16% means that the connection capacity increases to 188% (8.5/16) of the existing connections, an increase of 88% of the existing capacity. 88% more load can be accommodated (solid purple line) or the 88% can be split between generation and demand (dashed purple lines).

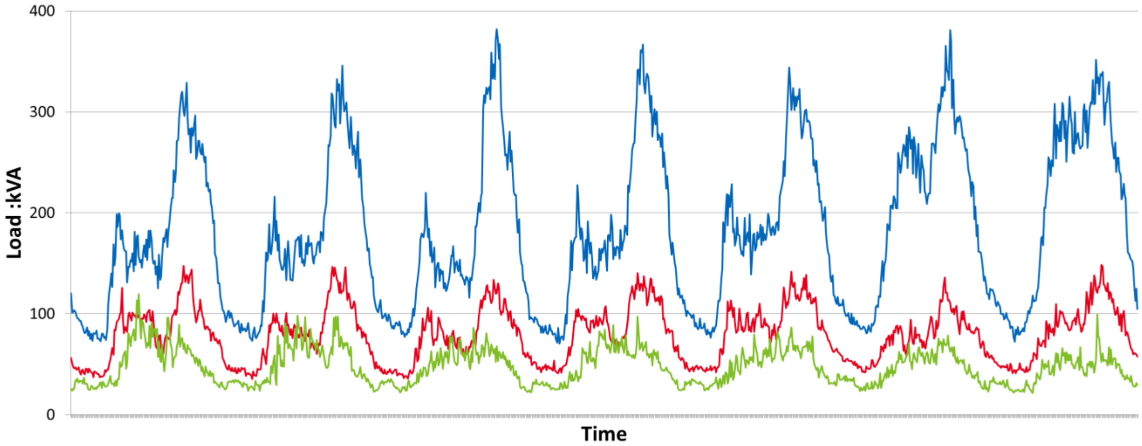
LV Engine provides suitable mitigation of voltage constraints on LV networks emanating from ground mounted 11kV/LV transformers. Ground mounted transformer ratings typically range from 315kV to 1000MVA. Based on a typical rating of 500kVA and a present typical peak utilisation of 70%, LV Engine can release 308kVA per application (70% x 500kVA x 88%). This additional connection capacity could be either new demand or generation connections.

Electricity North West's LV Network Solutions project showed that the LV circuits in their extensive study are approximately loaded at 40% of their thermal rating at present. This indicates that they can typically accommodate an additional one and a half times the existing load (60% margin divided by 40% existing utilisation). Hence it is concluded that a typical LV circuit could thermally accommodate the 88% of existing load additional capacity released by LV Engine.

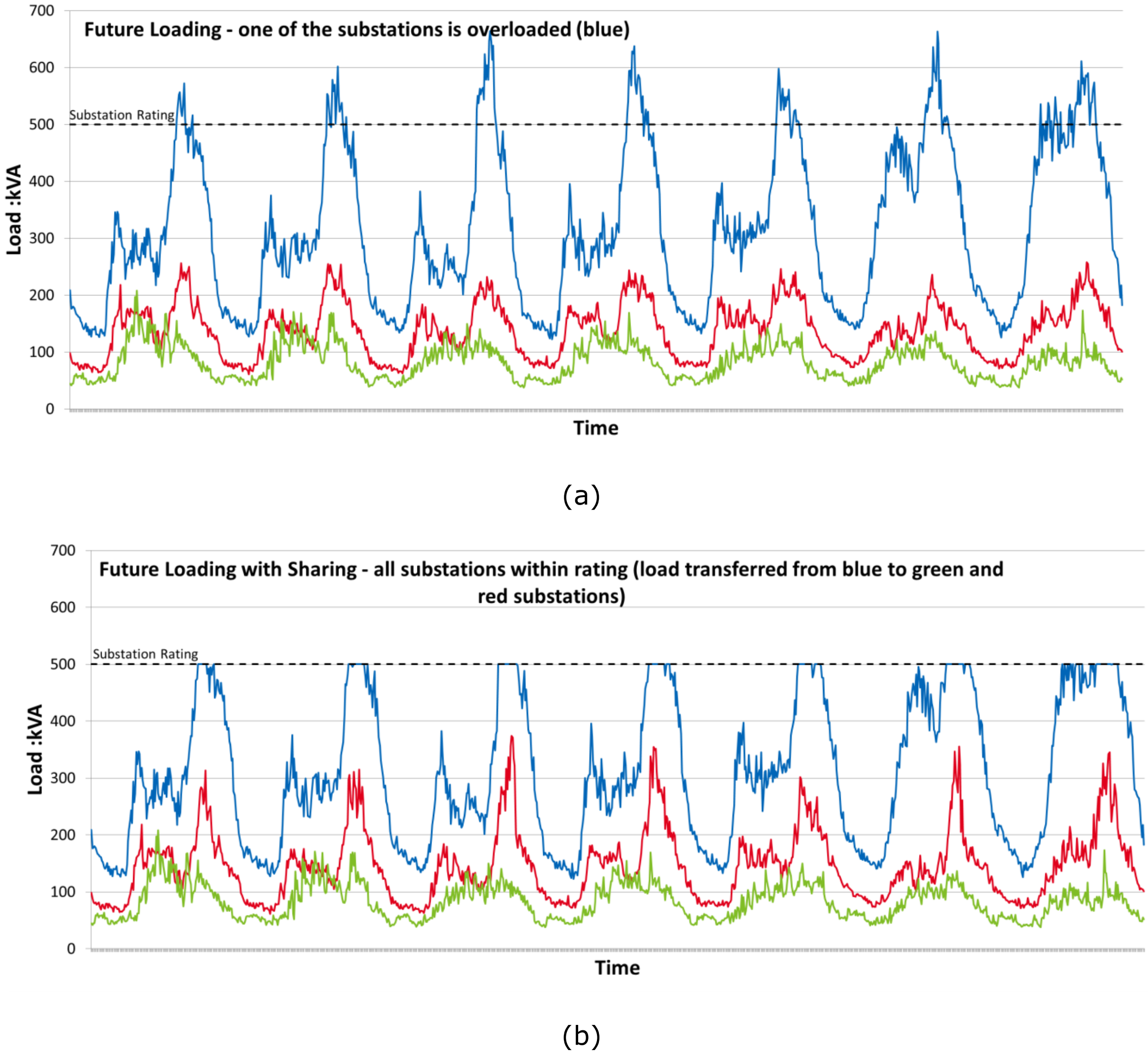
C.5.2 Transformer Load Sharing

Although it is likely that an increase in demand or generation could be accommodated within the ratings of existing circuits, it is possible that an increase in load would require the SST rating to be greater than the existing 11kV/LV transformer. However, this can be avoided as LV Engine proposes to interconnect LV substations to provide sharing with neighbouring substations and take advantage of any spare capacity there.

UK Power Networks' project FUN-LV has confirmed that such sharing between substations can create headroom between 14% and 47% of a substation transformer's capacity. Checks on three SP Energy Networks neighbouring 500kVA 11kV/LV transformers have shown variance in their utilisation that would provide capacity benefits through sharing. Detailed analysis of the loading profiles of these three SP Energy Networks substations shown in Appendix Figure C- has indicated that 300kVA of load (60% of substation rating) in excess of the substation rating can be accommodated at one of the substations by sharing with its neighbours as illustrated in Appendix Figure C- assuming that the future loading exhibits similar load profiles. Although at 60% this level of additional thermal capacity provided by sharing is less than the 88% increase in circuit capacity facilitated by LV Engine, it is considered that 60% additional thermal capacity will be sufficient to accommodate the additional load because part of that additional capacity provided by LV Engine is expected to be taken up by LV generation.



Appendix Figure C-8: SP Energy Networks Substation Loading Profiles (2017)



Appendix Figure C-9: Future SP Energy Networks substation loading profiles without sharing (a) and with sharing (b)

C.5.3 MV Network Capacity Released

In the same way that capacity is released in LV networks, LV Engine will release capacity in MV networks due to the ability to regulate MV voltages. Also the ability to share load between LV substations will mean that loads may be shared between MV feeders and the loading in MV circuits can be managed within their rating.

Additionally LV Engine's capability to balance phases and hence reduce imbalance on the MV network will release capacity on the MV network. The utilisation of a network is defined on the basis of the flow in the phase with the greatest current. Utilisation is less in an equivalent balanced system because imbalance means that one of the phase currents is greater than the others.

C.5.4 LV Engine Solution Carbon Benefits

Just as LV Engine provides financial benefits due to the method cost being less than the Base Case counterfactual, LV Engine provides carbon benefits because the LV Engine's embedded carbon is less than that of the Base Case. The carbon savings due to each application of LV Engine compared to the counterfactual has been evaluated by considering the separate components of the LV Engine approach and the Base Case in the same way that the financial benefit per application was determined. Manufacture and installation of equipment has embedded carbon which is determined through consideration of the material and lifecycle assessment. Values for the embedded carbon in cables and 11kV/LV transformers arising from previous innovation projects have been adopted in our evaluation. Where values were not available, then the embedded carbon has been estimated based upon the carbon value for the material type and the equipment weight. In the case of LV Engine's SST, the embedded carbon has pessimistically been assumed to be the same as an equivalent traditional transformer, on the basis that an SST comprises small transformers alongside the power electronics. Carbon benefits due to the application of LV Engine in GB and the SP Energy Networks region have been determined by considering the number of applications resulting from the aforementioned roll out methodology.

Operational carbon impacts arise due to losses and the associated use of electrical energy. Carbon impacts due to LV Engine's effect on losses have been evaluated using electricity conversion factors (tonnes per MWh) published by the UK government. The increase in the utilisation of existing circuits and associated increase in losses means that carbon is expected to increase also.

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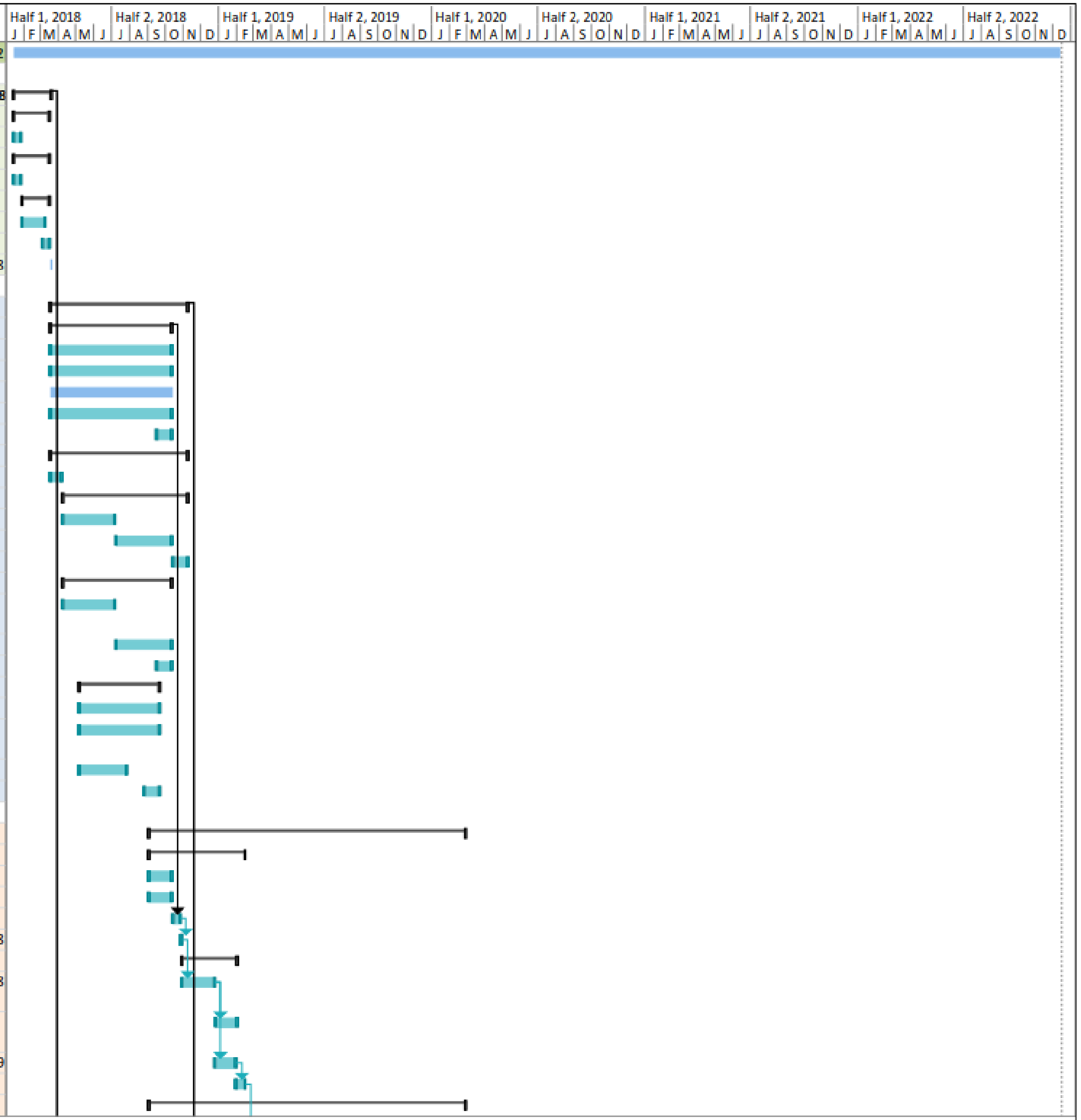
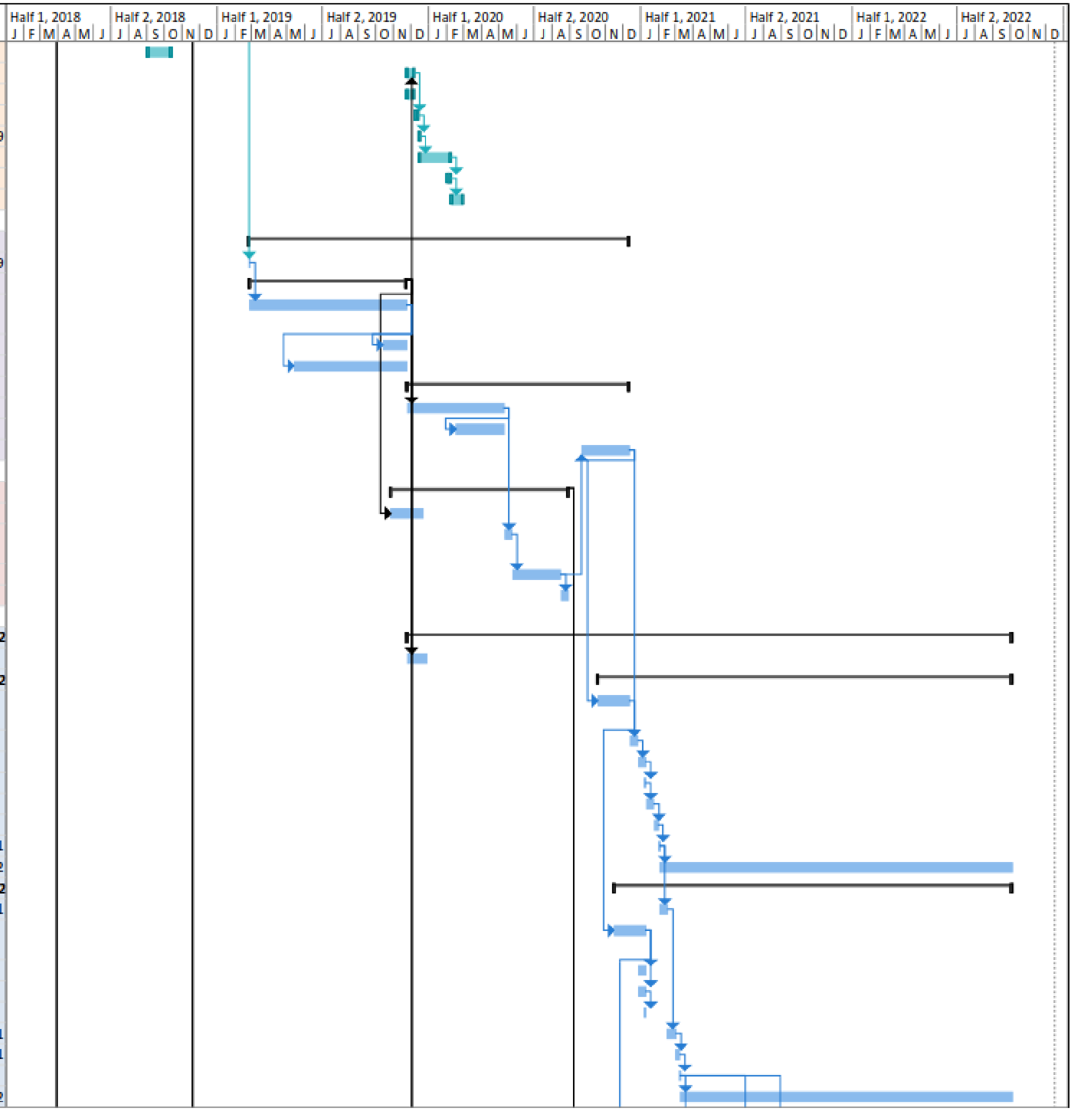
Appendix D Project Delivery Plan

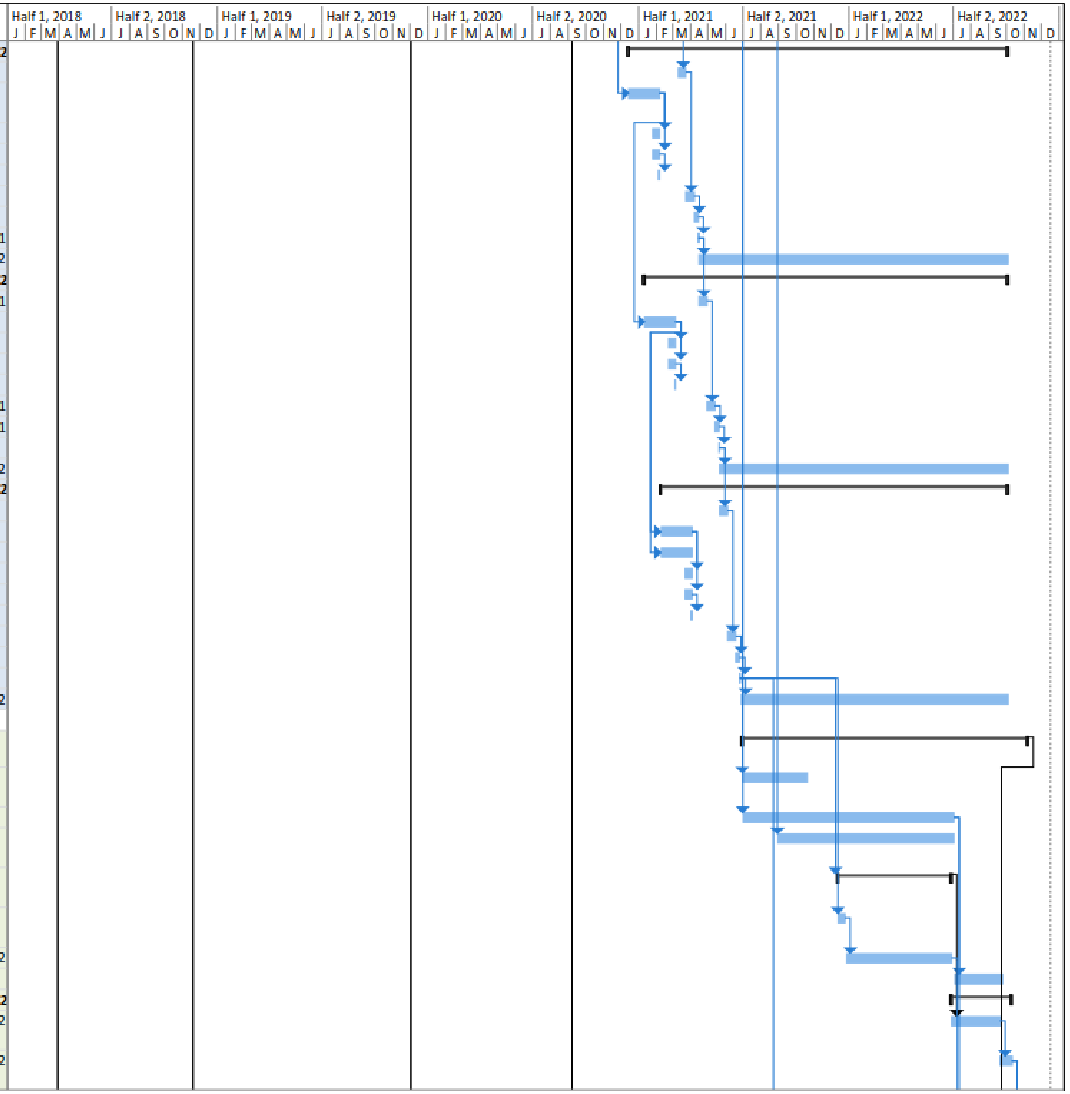
ID	Task Name	Duration	Start	Finish
1	**LV Engine Project Delivery**	1281 days	Mon 15/01/18	Mon 12/12/22
2				
3	**Project setup**	**46 days?**	**Mon 15/01/18**	**Mon 19/03/18**
4	**Develop project initiation document**	**45 days**	**Mon 15/01/18**	**Fri 16/03/18**
5	Developing scope for project partners	10 days	**Mon 15/01/18**	Fri 26/01/18
6	**Formalise team structure**	**45 days**	**Mon 15/01/18**	**Fri 16/03/18**
7	SPEN Project management, Steering board, delivery team	10 days	**Mon 15/01/18**	Fri 26/01/18
8	**Identify project partners (Academic and consultancy)**	**35 days**	**Mon 29/01/18**	**Fri 16/03/18**
9	Procurment and tender evaluation	30 days	Mon 29/01/18	Fri 09/03/18
10	Develop collaboration agreement with technical consultancy	10 days	Mon 05/03/18	Fri 16/03/18
11	Project team kick-off meeting - SPEN, UKPN, project partners	1 day	Mon 19/03/18	Mon 19/03/18
12				
13	**WP 1 – Technical Design**	**170 days?**	**Mon 19/03/18**	**Fri 09/11/18**
14	**Develop solid state transformers technical specification**	**150 days**	**Mon 19/03/18**	**Fri 12/10/18**
15	Develop hardware requirements	150 days	Mon 19/03/18	Fri 12/10/18
16	Develop control requirements	150 days	Mon 19/03/18	Fri 12/10/18
17	Develop SST protection requirements	150 days	Mon 19/03/18	Fri 12/10/18
18	Develop technical specifications for network integration testing	150 days	Mon 19/03/18	Fri 12/10/18
19	Review SST technical specification with UKPN	20 days	Mon 17/09/18	Fri 12/10/18
20	**Identify trial sites**	**170 days**	**Mon 19/03/18**	**Fri 09/11/18**
21	Review and update trial site selection criteria	15 days	Mon 19/03/18	Fri 06/04/18
22	**Private developments**	**155 days**	**Mon 09/04/18**	**Fri 09/11/18**
23	Identify Private developers for DC supply trial	65 days	Mon 09/04/18	Fri 06/07/18
24	Develop detailed plans for identified trial sites	70 days	Mon 09/07/18	Fri 12/10/18
25	Develop collaboration agreement with private developers	20 days	Mon 15/10/18	Fri 09/11/18
26	**SPEN network trial sites**	**135 days**	**Mon 09/04/18**	**Fri 12/10/18**
27	Identify potential sites in conjunction with planning managers and district engineers	65 days	Mon 09/04/18	Fri 06/07/18
28	Develop detailed plans for identified trial sites	70 days	Mon 09/07/18	Fri 12/10/18
29	Review the detailed plan of trial sites with UKPN	20 days	Mon 17/09/18	Fri 12/10/18
30	**Develop technical specifications of LV Engine schemes**	**100 days?**	**Mon 07/05/18**	**Fri 21/09/18**
31	Develop requirements for network protection and control	100 days	Mon 07/05/18	Fri 21/09/18
32	Develop requirements for communications, monitoring and integration into SPEN RTS	100 days	Mon 07/05/18	Fri 21/09/18
33	Develop requirements LV network voltage node monitoring	60 days	Mon 07/05/18	Fri 27/07/18
34	Review the LV Engine Schemes technical specifications with UKPN	20 days	Mon 27/08/18	Fri 21/09/18
35				
36	**WP 2 – Suppliers Partner Selection and Procurement**	**390 days?**	**Mon 03/09/18**	**Fri 28/02/20**
37	**SST manufacturing partner selection**	**120 days**	**Mon 03/09/18**	**Fri 15/02/19**
38	Fresh market research - Identify potential suppliers	30 days	Mon 03/09/18	Fri 12/10/18
39	Develop Tender Evaluation Criteria	30 days	Mon 03/09/18	Fri 12/10/18
40	Develop of invitation to tender documents	10 days	Mon 15/10/18	Fri 26/10/18
41	Submit invitation to tender documents	1 day	Mon 29/10/18	Mon 29/10/18
42	**Manufactures' response evaluation**	**69 days**	**Tue 30/10/18**	**Fri 01/02/19**
43	Engage with potential manufacturing partners prior to the ITT response deadline	40 days	Tue 30/10/18	Mon 24/12/18
44	Review tender evaluation within SPEN and in partnership with UKPN	27 days	Thu 27/12/18	Fri 01/02/19
45	Invite shortlisted manufacturers for face-to-face discussion	27 days	Tue 25/12/18	Wed 30/01/19
46	Place partnership agreement	12 days	Thu 31/01/19	Fri 15/02/19
47	**Scheme equipment supplier (protection, comms etc)**	**390 days?**	**Mon 03/09/18**	**Fri 28/02/20**



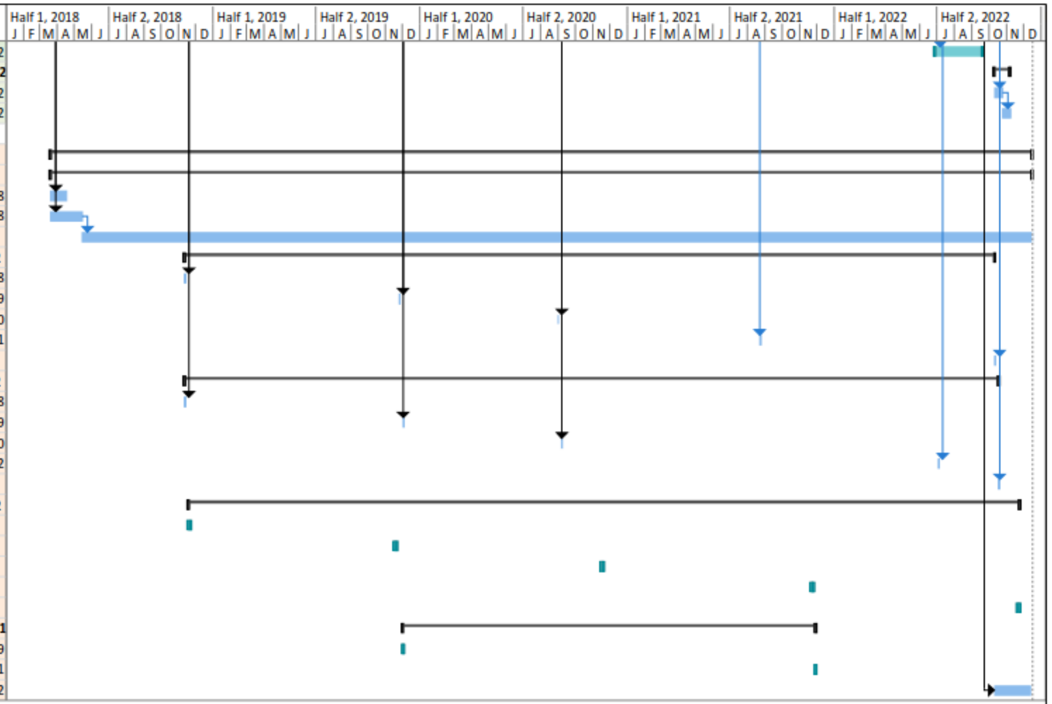
ID	Task Name	Duration	Start	Finish
48	Identify potential suppliers	30 days	Mon 03/09/18	Fri 12/10/18
49	Refine technical specification of LV Engine schemes	10 days	Mon 25/11/19	Fri 06/12/19
50	Develop tender evaluation criteria	10 days	Mon 25/11/19	Fri 06/12/19
51	Develop of invitation to tender documents	5 days	Mon 09/12/19	Fri 13/12/19
52	Submit invitation to tender	1 day	Mon 16/12/19	Mon 16/12/19
53	Suppliers' response evaluation	39 days	Tue 17/12/19	Fri 07/02/20
54	Review tender evaluation with UKPN	5 days	Mon 03/02/20	Fri 07/02/20
55	Place the contracts	15 days	Mon 10/02/20	Fri 28/02/20
56				
57	**WP 3 – Design and Manufacturing of SST schemes**	**470 days?**	**Mon 25/02/19**	**Fri 11/12/20**
58	Kick off meeting with project partners	1 day	Mon 25/02/19	Mon 25/02/19
59	**SST design**	**194 days**	**Tue 26/02/19**	**Fri 22/11/19**
60	Enhance the initial SST design proposed during tender (hardware, control algorithm, protection, coms and monitoring)	194 days	Tue 26/02/19	Fri 22/11/19
61	Carry out life cycle analysis of both SST designs	30 days	Mon 14/10/19	Fri 22/11/19
62	Review SST design with project partners	140 days	Mon 13/05/19	Fri 22/11/19
63	**SSTs manufacturing**	**275 days?**	**Mon 25/11/19**	**Fri 11/12/20**
64	Manufacturing the SST prototypes (100% DC and Hybrid AC/DC)	120 days	Mon 25/11/19	Fri 08/05/20
65	Factory Acceptance Testing	60 days	Mon 17/02/20	Fri 08/05/20
66	Manufacturing and testing the seven SSTs for live trial	60 days	Mon 21/09/20	Fri 11/12/20
67				
68	**WP 4 – Network Integration Testing**	**220 days?**	**Mon 28/10/19**	**Fri 28/08/20**
69	Refine technical specifications for network integration testing	40 days	Mon 28/10/19	Fri 20/12/19
70	Ship SST prototypes plus other associated equipment to network integration testing facility	10 days	Mon 11/05/20	Fri 22/05/20
71	Network Integration Testing of prototype units	60 days	Mon 25/05/20	Fri 14/08/20
72	Produce testing report and network integration certificate	10 days	Mon 17/08/20	Fri 28/08/20
73				
74	**WP 5 – Live network trial**	**746 days?**	**Mon 25/11/19**	**Mon 03/10/22**
75	Carry out scheme specific modelling of designed SST within chosen tr	25 days	Mon 25/11/19	Fri 27/12/19
76	**Scheme 1 trial**	**511 days**	**Mon 19/10/20**	**Mon 03/10/22**
77	Site preparation + Identify locations for installation of LV voltage node monitoring + installation	40 days	Mon 19/10/20	Fri 11/12/20
78	Shipping to local depot	10 days	Mon 14/12/20	Fri 25/12/20
79	Develop scheme installation method statement	10 days	Mon 28/12/20	Fri 08/01/21
80	District staff training workshop	2 days	Thu 07/01/21	Fri 08/01/21
81	Installation	10 days	Mon 11/01/21	Fri 22/01/21
82	Site acceptance test	5 days	Mon 25/01/21	Fri 29/01/21
83	Commission the scheme	1 day	Mon 01/02/21	Mon 01/02/21
84	Monitoring of the scheme performance and implement refinemen	435 days	Tue 02/02/21	Mon 03/10/22
85	**Scheme 2 trial**	**491 days**	**Mon 16/11/20**	**Mon 03/10/22**
86	Implement learning from Scheme 1 installation	10 days	Tue 02/02/21	Mon 15/02/21
87	Site preparation + Identify locations for installation of LV voltage node monitoring + installation	40 days	Mon 16/11/20	Fri 08/01/21
88	Shipping to local depot	10 days	Mon 28/12/20	Fri 08/01/21
89	Develop scheme installation method statement	10 days	Mon 28/12/20	Fri 08/01/21
90	District staff training workshop	2 days	Thu 07/01/21	Fri 08/01/21
91	Installation	10 days	Tue 16/02/21	Mon 01/03/21
92	Site acceptance test	5 days	Tue 02/03/21	Mon 08/03/21
93	Commission the scheme	1 day	Tue 09/03/21	Tue 09/03/21
94	Monitoring of the scheme performance and implement refinemen	409 days	Wed 10/03/21	Mon 03/10/22



ID	Task Name	Duration	Start	Finish
95	**Scheme 3 trial**	**471 days**	**Mon 14/12/20**	**Mon 03/10/22**
96	Implement learning from previous schemes	10 days	Wed 10/03/21	Tue 23/03/21
97	Site preparation + Identify locations for installation of LV voltage node monitoring + installation	40 days	Mon 14/12/20	Fri 05/02/21
98	Shipping to local depot	10 days	Mon 25/01/21	Fri 05/02/21
99	Develop scheme installation method statement	10 days	Mon 25/01/21	Fri 05/02/21
100	District staff training workshop	2 days	Thu 04/02/21	Fri 05/02/21
101	Installation	10 days	Wed 24/03/21	Tue 06/04/21
102	Site acceptance test	5 days	Wed 07/04/21	Tue 13/04/21
103	Commission the scheme	1 day	Wed 14/04/21	Wed 14/04/21
104	Monitoring of the scheme performance and implement refinemen	383 days	Thu 15/04/21	Mon 03/10/22
105	**Scheme 4 trial**	**451 days**	**Mon 11/01/21**	**Mon 03/10/22**
106	Implement learning from previous schemes	10 days	Thu 15/04/21	Wed 28/04/21
107	Site preparation in conjunction with the DC customer/private deve	40 days	Mon 11/01/21	Fri 05/03/21
108	Shipping to local depot	10 days	Mon 22/02/21	Fri 05/03/21
109	Develop scheme installation method statement	10 days	Mon 22/02/21	Fri 05/03/21
110	District staff training workshop	2 days	Thu 04/03/21	Fri 05/03/21
111	Installation	10 days	Thu 29/04/21	Wed 12/05/21
112	Site acceptance test	5 days	Thu 13/05/21	Wed 19/05/21
113	Commission the scheme	1 day	Thu 20/05/21	Thu 20/05/21
114	Monitoring of the scheme performance and implement refinemen	357 days	Fri 21/05/21	Mon 03/10/22
115	**Scheme 5 trial**	**431 days?**	**Mon 08/02/21**	**Mon 03/10/22**
116	Implement learning from previous schemes	10 days	Fri 21/05/21	Thu 03/06/21
117	Site preparation in conjunction with the DC customer/private deve	40 days	Mon 08/02/21	Fri 02/04/21
118	Installation of LV voltage node monitoring + installation	40 days	Mon 08/02/21	Fri 02/04/21
119	Shipping to local depot	10 days	Mon 22/03/21	Fri 02/04/21
120	Develop scheme installation method statement	10 days	Mon 22/03/21	Fri 02/04/21
121	District staff training workshop	2 days	Thu 01/04/21	Fri 02/04/21
122	Installation	10 days	Fri 04/06/21	Thu 17/06/21
123	Site acceptance test	5 days	Fri 18/06/21	Thu 24/06/21
124	Commission the scheme	1 day	Fri 25/06/21	Fri 25/06/21
125	Monitoring of the scheme performance and implement refinemen	331 days	Mon 28/06/21	Mon 03/10/22
126				
127	**WP 6 – Development of Novel Approach for BaU Transformer Selection**	**354 days?**	**Wed 30/06/21**	**Mon 07/11/22**
128	Develop an approach to model SST deployment and produce modelling methodology and guidance	80 days	Wed 30/06/21	Tue 19/10/21
129	SST performance analysis in different load and generation conditions	262 days	Thu 01/07/21	Fri 01/07/22
130	Compare SST performance with on-load tap changers using historic network conditions (load/generation) recorded during LV Engine	220 days	Mon 30/08/21	Fri 01/07/22
131	**Cost benefit analysis of application of SSTs in distribution networks based on lessons learnt during LV Engine**	**141 days**	**Mon 13/12/21**	**Mon 27/06/22**
132	Consulate internal end users with workshops to identify the requirments for SST CBA BaU adoption	10 days	Mon 13/12/21	Fri 24/12/21
133	Develop methodology and tools for SST CBA	131 days	Mon 27/12/21	Mon 27/06/22
134	Refine LV Engine scheme technical specification based on lessons lea	60 days	Mon 04/07/22	Fri 23/09/22
135	**Policy documents for BaU adoption of SSTs**	**75 days**	**Tue 28/06/22**	**Mon 10/10/22**
136	Develop policy document and best operational practice document on applications of solid sate transformers for BaU adoption	60 days	Tue 28/06/22	Mon 19/09/22
137	Review the policy document, technical specifications and BaU guidance documents with UKPN	15 days	Tue 20/09/22	Mon 10/10/22



ID	Task Name	Duration	Start	Finish
138	Identify trial site within UKPN for replicating LV ENGINE	60 days	Tue 28/06/22	Mon 19/09/22
139	**SST training internal courses**	**20 days?**	**Tue 11/10/22**	**Mon 07/11/22**
140	Create training course for planning and operation of SST	10 days	Tue 11/10/22	Mon 24/10/22
141	Delivery of training course to planning and operation staff	10 days	Tue 25/10/22	Mon 07/11/22
142				
143	**WP 7 – Dissemination and Knowledge Sharing**	**1239 days**	**Tue 20/03/18**	**Fri 16/12/22**
144	**LV Engine website**	**1239 days**	**Tue 20/03/18**	**Fri 16/12/22**
145	Create LV Engine webpage	20 days	Tue 20/03/18	Mon 16/04/18
146	Create the list of stakeholders (for sending update notifications)	40 days	Tue 20/03/18	Mon 14/05/18
147	Update learnings, documents and send out update notifications	1199 days	Tue 15/05/18	Fri 16/12/22
148	**UK DNOs Workshops**	**1022 days**	**Mon 12/11/18**	**Tue 11/10/22**
149	Workshop 1 - LV Engine schemes technical specifications	1 day	Mon 12/11/18	Mon 12/11/18
150	Workshop 2 - SST Design	1 day	Mon 25/11/19	Mon 25/11/19
151	Workshop 3 - Network integration testing	1 day	Mon 31/08/20	Mon 31/08/20
152	Workshop 4 - LV Engine schemes installations and performance	1 day	Mon 23/08/21	Mon 23/08/21
153	Workshop 5 - Novel approach for transformer selection	1 day	Tue 11/10/22	Tue 11/10/22
154	**Webinars (UK and international audiances)**	**1027 days**	**Mon 12/11/18**	**Tue 18/10/22**
155	Webinar 1 - LV Engine introductions, overview of SST grid applicati	1 day	Mon 12/11/18	Mon 12/11/18
156	Webinar 2 - LV Engine SST design	1 day	Mon 02/12/19	Mon 02/12/19
157	Webinar 3 - Network integration requirements	1 day	Mon 07/09/20	Mon 07/09/20
158	Webinar 4 - LV Engine schemes performance, planning and operati	1 day	Mon 04/07/22	Mon 04/07/22
159	Webinar 5 - LV Engine lessons learnt and future road map	1 day	Tue 18/10/22	Tue 18/10/22
160	**LCNI conference**	**1049 days**	**Mon 19/11/18**	**Thu 24/11/22**
161	LCNI 2018	4 days	Mon 19/11/18	Thu 22/11/18
162	LCNI 2019	4 days	Mon 18/11/19	Thu 21/11/19
163	LCNI 2020	4 days	Mon 16/11/20	Thu 19/11/20
164	LCNI 2021	4 days	Mon 22/11/21	Thu 25/11/21
165	LCNI 2022	4 days	Mon 21/11/22	Thu 24/11/22
166	**Power Electronics UK forum**	**521 days**	**Mon 02/12/19**	**Mon 29/11/21**
167	Joint dessimination with UKPN	1 day	Mon 02/12/19	Mon 02/12/19
168	Joint dessimination with UKPN	1 day	Mon 29/11/21	Mon 29/11/21
169	Close-down report	45 days	Tue 11/10/22	Mon 12/12/22



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Appendix E Risk Register

Risk No.	Issue	Risk Description	Potential Impact	Inherent Risk: Probability (1-5)	Inherent Risk: Financial Impact (1-5)	Inherent Risk: Reputation Impact (1-3)	Inherent Risk: Overall Risk (2-40)	Control	Residual Risk: Probability (1-5)	Residual Risk: Financial Impact (1-5)	Residual Risk: Reputation Impact (1-3)	Residual Risk: Overall Risk (2-40)
1. Technical risks												
1.01	Implementation of trial schemes	Trial schemes cannot be implemented as specified in the Technical Design work package	Failure of scheme to demonestrate the planned functionalities, project does not deliver its objectives, additional cost incurred to resolve the issues	2	4	2	12	1 - Demonestrate the feasibility of schemes through desktop studies for the selected trial sites 2 - SPEN design team to review the technical specification of schemes 3 - Provide the scheme requirements to the SST manufacturers as part of tendering documents	1	3	2	5
1.02	Reliability of monitoring systems	Monitoring equipment is not fit-for-purpose as becoming unhealthy or providing incorrect information, the comunication system to transfer the monitoried data is not reliable	LV Engine scheme functionalities cannot be demonstrated, project does not deliver expected learning, additional cost incurred for troubleshooting and replacing equipment	2	4	2	12	1 - Select monitoring equipment with proven track record and adequate specifications for the LV Engine schemes 2 - Learing from orther projects for deploying a reliable communication system 3 - Carry out signal strength scanning prior to site selection in case of using GPRS 4 - Pass the monitored data through a health check and data correction mechanism before the data is fed into SST control algorithm 5 - Build algorithms which allow for scenarios where data becomes suddenly unavailable	1	2	2	4
1.03	LV voltage monitoring installation	Access to customers premises for installation of LV monitoring equipment is not granted	The optimum voltage control functionality cannot be demonstrated, project does not deliver all of expected learning	3	2	2	12	1 - Early engagement with customers to raise awareness about the project 2 - Offer incentives to customers for providing access to their premises 3 - Plan for alternative node of monitoring (alternative customers) on a feeder	1	2	2	4
1.04	DC network protection	A proven and fit-for-purpose DC network protection scheme is not available	LV Engine's Scheme 4 and 5 cannot be delivered or will be delayed, additional cost required for designing a complicated protection scheme	3	3	2	15	1 - The existing experience of DC network applications in other industries e.g. rail industry will be reviewed and implemented 2 - Early market research to identify available technologies and best practices will be conduct 3 - DC technical experts will be deployed in the project to design DC scheme technical specifications	1	2	2	4
1.05	Trial site	Trial site is not available when it is required	LV Engine schemes will be halted or delayed	3	3	2	15	1 - Involve district planning and operation engineers in trial selection process 2 - Consider contingency trial sites 3 - Place an early agreement with private customers for Schemes 5 and 6	1	2	2	4
1.06	Integration to NMS	The equipment provided by the manufacturer does not comply with the security requirements and communication protocols used by SPEN corporate systems.	Delay in the project delivery, additional cost to redesign the system architecture and purchase new fit-for-purpose IT equipment	3	3	1	12	1 - Early engagement with IT to review the LV Engine schemes technical specifications 2 - Provide clear requirements for integration into SPEN NMS as part of tendering documents 3 - Review of tendering responses by IT team to ensure compliance	1	1	1	2
1.07	Cyber security	SST control and functions can be affected by cyber attacks	Damage to the SST equipment, adverse impact on customers by applying unwanted voltage control, outage of SST and adverse impact on customer supply	2	4	3	14	1 - Involved IT to review the security of proposed system architecture including third party remote access 2 - Develop security logic within SST firmware to identify unsual control commands	1	2	2	4

1.08	Cooling system	The cooling system for the SST converters proves to be unreliable	The project fails to demonstrate that the SST can achieve reliable performance with mimumum maintenance, SST outages with customers off supply.	2	2	3	10	1 - Work with suppliers to understand the design of the cooling system and how its reliability can be increased. 2 - Prolonged testing at network integration facility to demonstrate reliability 3 - Review of cooling system design by project partners 4 - Review track record of similar cooling systems to ascertain reliability and performance	1	1	1	2
			Summative Risk Scores	20	25	17	102		8	15	14	29
2. Procurement, manufacturing and installation risks												
2.01	Few suppliers of SST equipment	Limited number of tender returns from suppliers for procurement of SST.	Receipt of uncompetitive tenders that are not in line with principles of good value for money for customers; decision to halt innovation project.	2	5	3	16	1 - Informal discussions have already taken place with several potential suppliers and we are confident that we will receive several tender returns through the conventional competitive bid process. 2 - Technical specifications will be reviewed to ensure they are reasonable and realistic for commercial offerings to be received. 3 - Expression of interest document has been distributed to manufacturers to ascertain interest from manufacuters and current experience and TRL.	1	2	2	4
2.02	Failure to manufacture fit-for-purpose SST	Supplier cannot manufacture SST as per SPEN specifications	Unable to deliver project's aims and objectives; decision to halt innovation project	3	5	3	24	1 - Carry out peer-reviewed SST technical specifications by project partners 2 - Carry out competetive tendering and detailed technical evaluation of manufacturer competency and capabilities 3 - Review of manufacturer SST design by SPEN design engineers, UKPN and project partners.	1	4	2	6
2.03	Cost of SST exceeds expectations	Cost to design and manufacturer required prototypes higher than expected due to unforeseen costs not identified during early engagment with manufacturers	Project does not demonstrate that SST is a viablecommercial alternative to a conventional transformer; project budget exceeded.	3	5	3	24	1. Work closely with suppliers to ensure that the dsign is fit for purpose and cost optimised. 2. Engage with academic partners and UKPN to advise on cost optimised designs. 3. Carry out competitive tendering process to identify manufacturing partner(s) who deliver value for money	2	3	2	10
2.04	Damaged equipment	Equipment arrives on site is damaged due to improper packaging and shipment	Significant effect on delivery time and project programme	3	5	2	21	1 - Ensure proper packaging and shipment with supplier 2 - Include approperiate penalties in terms and conditions to protect the project againt damage or late delivery of the products 3 - Ensure adequate storage facilities at SPEN depots	2	2	2	8
2.05	Delay in delivery of SST to trial sites	Delay in the prototype development leads to delays in the manufacture and delivery of the production SSTs	The project fails to achieve its targeted programme installation at the trial sites and project cost over-spend resulting in late delivery of project objectives	4	5	3	32	1 - Delivery plan considers contigency time for production of SSTs 2 - Effective monitoring of the manufacturing process and define set dates for factory acceptance tests at time of contract 3 - Include appropriate penalties in terms and conditions to protect the project againt late delivery of the products 4 - Carry out competitive tendering to identify competent manufacturer with proven track record of delivering similar technologies	2	3	2	10
			Summative Risk Scores	15	25	14	117		8	14	10	38

3. HSSE and Operational risks												
3.01	Lack of experience with intallation and operation of SST	SPEN staff are unfamiliar with SST installation and operational requirements	Major injury to personnel, damage to the equipment, loss of supply to the customers during the installation and operation	3	4	3	21	1 - Carry out early engagement with operational team and provide relevant trainings 2 - Provide clear and approved method statement and risk assessment for installation 3 - Provide on site training with operational staff prior to installation with manufacturer 4 - Provide supervision by the manufacturer during the installation 5 - Review of existing SPEN H&S standards against SST installation requirements 6 - Provide detailed training courses to a wider range of staff within trial sites regions.	1	3	2	5
3.02	Lack of experience with LVDC network	SPEN staff are unfamiliar with operational and saftey requirements of LVDC supply	Major injury to personnel, damage to the equipment, loss of supply to the customers during the installation and operation	4	4	3	28	1 - Review of best practices and existing standards for LVDC operation 2 - Carry out early engagement with operational and design team to provide relevant trainings 3 - Provide clear and approved method statement and risk assessment for installation	1	3	2	5
3.03	Reliability of the scheme	Inadequate reliability and availability of SST units	The project does not demonstrate that a SST can be a suitable alternative to a conventional transformer, reduced security of supply to customers, high O&M costs.	3	4	3	21	1. Design the LV converter on a modular basis with series redundancy. 2. Use scalable output blocks to allow SST to continue to operate under degraded condition. 3. Ensure an adequate safety margin between component ratings and their operational duty.	2	3	2	10
3.04	Maintenance requirements	SST is a complex system that is difficult to maintain in reasonable timescales and costs,	Likely interruptions of supply to customers; and increased costs for additional resources in maintenance teams.	3	3	2	15	1 - Work closely with manufacturers to understand maintenance requirements and the impact on the design or selection of components 2 - Deliver detailed training of SSTs to relevant staff members throughout duration of project.	1	2	2	4
			Summative Risk Scores	13	15	11	85		5	11	8	24
4. Project Management risks												
4.01	Higher project costs	Cost of the complete scheme is higher than anticipated	Exceedance of project budget; and risk of halting the demonstration project.	2	4	2	12	1 - FIDIC contract terms should be used, such that the contractor takes on the risk; 2 - Commodity price to be hedged. 3 - Contingency funding deemed to be reasonable and sufficient 4 - Use learnings from previous innovation projects to allowed project to identify risks early on 5 - Maintain and update risk register to allow project to react quickly to any unforseen issues and costs.	1	3	1	4
4.02	Resources	Sufficient resources are not available in SP Energy Networks to deliver the project	Delay in delivery of the project and impact on quality of deliverables	3	4	3	21	1 - Effective engagement with Director level within SPEN to provide clear understanding about project size and resource requirements 2 - Use competent external resources where necessary 3 - Careful review of resource requirements again upon project set up to ensure adequate skill based is put in place prior to start of project	1	2	2	4
			Summative Risk Scores	5	8	5	33		2	5	3	8

Appendix F Project Delivery Team Structure

Specific roles and responsibilities have been defined for each project tasks and deliverable. These roles are relevant to the activities identified within each project work package and the project structure shown in Figure 6-2.

Project Manager (PM) - The LV Engine Project Manager (PM) will be responsible for the successful day-to-day delivery of the LV Engine project against key performance indicators, the project programme and budget. The PM will liaise with various parties including the Project Steering Board, SP Energy Networks H&S, Operational, Legal and Commercial Departments, Policy, Standards, Design Departments, Project delivery team and internal and external stakeholders.

Project Delivery Team – The project delivery team will consist of internal SP Energy Networks staff, technical consultant, academics and manufacturing partner. They will support the PM throughout the duration of the project and carry out the tasks allocated to the team. The final delivery team members will be identified during project set up to ensure that all project deliverables are completed within time and budget.

Manufacturing Partner(s) – This party is responsible for the design, manufacturing and testing of SSTs for the LV Engine schemes and support the team during installation, commissioning and troubleshooting required in the course of project.

Design Authority Board - UK Power Networks will carry out an independent review of the different design and deliverables of LV Engine. This will ensure that the delivered solutions are fit for purpose with suitable functionalities for adoption by other UK DNOs into their BaU practices. UK Power Networks will also identify a potential trial site for replication of LV Engine solution within their Licensees.

Consultancy Support - Technical consultancy will work with internal SP Energy Networks staff and provide support in the following areas where required: SST specification, design of LV Engine schemes, development and deployment, system modelling and trial site selection, algorithm development for power control, harmonic and fault level studies, protection and earthing studies, LVDC distribution network specification, policy and technical guidelines documentation and training.

Network Integration Testing Facility - The testing facility will provide technical support during WP 2 & 3 and carry out suitable network integration testing of the SST prototypes during WP 4. They will be responsible for de-risking the SST solution prior to deployment within SP Manweb (SPM) and SP Distribution (SPD) networks.

SPM & SPD District Support – The districts will be responsible for providing support during trial site selection and SST deployment during the live network trials. They will carry out the installation of each SST scheme as detailed within WP 5.

SP Energy Networks Real Time Systems Team and IT – Responsible for the effective integration of each trial scheme's monitoring into SP Energy Networks' Network Management System. IT team will also support the preparation of LV Engine IT system architecture and compliance with IT security requirement.

Academic Partners - Input of specialist knowledge in order to optimise the SST technology solution. Detailed studies on the reliability, O&M requirement and operational performance of the SSTs will be delivered by the academic partner. In addition, our academic partner support with the delivery of a detailed life cycle analysis of the chosen SST designs.

Stakeholder Engagement Team – Responsible for delivering the LV Engine stakeholder engagement methodology and providing assistance and guidance during project dissemination events and interaction with customers.

Knowledge Manager - The knowledge manager will be internally resourced within SP Energy Networks, and will be responsible for the on-going capture and dissemination of appropriate project learning through all relevant communication channels.

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Appendix G UK Power Networks cost breakdown for collaboration within LV Engine

Work Package	Deadline	Task description	Man-days	Cost
WP 1- Technical design	12/10/18	Review developed SST technical specifications	5	£2,601.10
	12/10/18	Review developed technical specifications of each LV Engine scheme	5	£2,601.10
WP 2- Procurement and Partner selection	01/02/19	Review tender documents for SST manufacturing supplier and tender evaluation	5	£2,601.10
	07/02/20	Review each LV Engine scheme tender documents	5	£2,601.10
WP 3- Design and Manufacturing SST	22/11/19	Review SST design topology, control algorithm, cooling system, monitoring, SST protection and enclosure	20	£10,404.40
	11/12/20	Review the manufacturing process and attend critical progress meetings	10	£5,202.20
	08/05/20	Review FAT schedules and results	5	£2,601.10
WP 4- Network integration testing	14/08/20	Review test schedules and witness the test	10	£5,202.20
	28/08/20	Provide recommendation for any refinements before live trial	2	£1,040.44
WP 5- live network trial	01/02/21	Review the site design and installation method statement of Scheme 1	10	£5,202.20
	09/03/21	Review the site design and installation method statement of Scheme 2	10	£5,202.20
	14/04/21	Review the site design and installation method statement of Scheme 3	10	£5,202.20
	20/05/21	Review the site design and installation method statement of Scheme 4	10	£5,202.20
	25/06/21	Review the site design and installation method statement of Scheme 5	10	£5,202.20
WP 6-Development of novel transformer selection approach	10/10/22	Review SST BaU adoption documentations:	10	£5,202.20
	26/09/22	Identify a trial site for LV Engine solution within UK Power Networks	45	£23,409.90
		Total Labour	**172**	£89,477.84
		Travel & Expenses		£17,895.57
		Total cost		**£107,373.41**

Appendix H SST Background, Design, TRL Development

The purpose of this Appendix is to give more details on the background to SSTs and the design factors that will be considered during the tendering of the manufacturing partner and the design stage of LV Engine. It also gives a review of SST TRL and a future projection for the technology.

H.1SST architecture

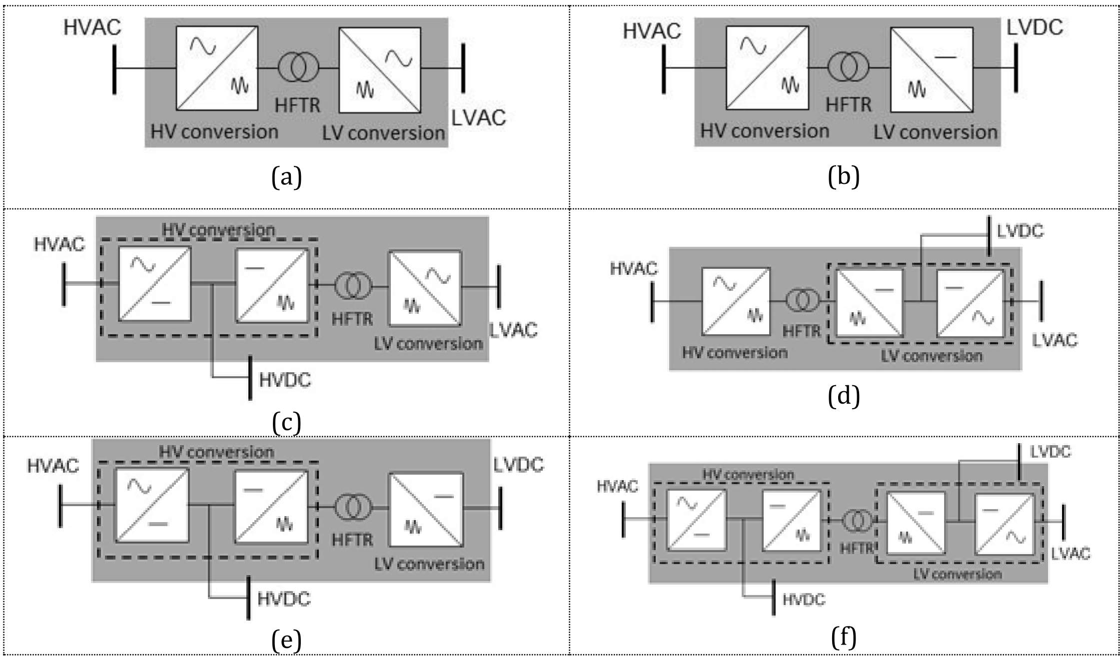
In general, a minimum architecture of an SST comprises of HV converters, HFTRs, and LV converters. The basic control functions include controlled power flow transfer (using phase angle control), fault isolation, power factor correction at HV and LV sides, and power quality decoupling between the HV and LV sides.

This minimum architecture, as illustrated in Appendix Figure H-1(a) has been implemented for designing low power supplies since the 1970's to provide a reliable and stable source of power for sensitive applications. High power and high voltage applications however require additional value streams for the SST to compete with conventional power in-feed arrangements. The architecture of SSTs for Smart Grid applications hence usually include DC access, providing a direct benefit over the use of conventional transformers, either at the HV side or at the LV side depending on the use case and characteristics of the interconnected networks. These architectures inherently provide the following additional features:

- Components: DC access either at HV or LV sides
- Control functions: power flow routing between different interconnected networks, dynamic voltage regulation, voltage dips compensation, outage and fault management, black start capability, increased headroom for renewables

HVDC access, architectures in Appendix Figure H-1(c) & (e), has been in focus since 2009 due to the advancement in HVDC technology using modular designs to provide HVDC line tapping that can provide a reliable power supply to remote communities.

The business case for using DC power in the medium voltage, for instance for high power DC loads such as data centres, where there are high gains in efficiency that directly translate into reduced operational costs and cooling requirements, have led to intensive research and advancements of SST technology that fits into the Distribution grid applications. All possible SST architectures are summarised in Appendix Figure H-1.



Appendix Figure H-1: (a) HVAC/LVAC connection, (b) HVAC/LVDC connection, (c) HVAC/HVDC/LVAC connection, (d) HVAC/LVDC/LVAC connection, (e) HVAC/HVDC/LVDC, (f) HVAC/HVDC/LVDC/LVAC.

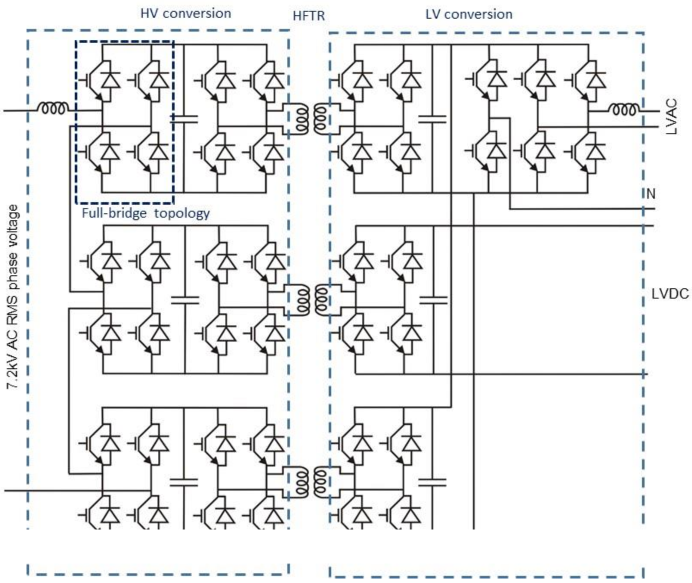
Topologies and Configurations

The most commonly used power electronics converter topology for Smart Grid applications is the two-level converter, also referred to as a full-bridge topology, in the form of voltage source converter (VSC). VSC based topologies are mature technologies that have been implemented in a wide range of grid connected applications since the 1990s at all grid voltage and power levels, especially for integrating renewables in compliance with the grid connection codes and HVDC interconnections. The implementation of a full-bridge topology for the HV conversion stage of an SST requires having a series connection of these units to overcome:

1) **The limitation of existing semiconductor device voltage blocking capability**: Using the highest available Silicon IGBTs, an SST can only interconnect a 2.4kV AC on the HV side. An approach to overcome this challenge is to connect many IGBTs in series. However, this can lead to stressing of certain devices and low reliability. A second common approach is to connect many full-bridges in series on the HV side, where active balancing can be achieved.

2) **The limitation of the HFTR ratings**: The design for high power applications is usually carried out in the range of 50kVA to some few hundreds to reduce the core stress and reduce losses. This also leads to the requirement of using modular designs.

Hence, the common design approach for SST today is the input in series and the output in parallel (ISOP) configuration using Silicon IGBTs and medium frequency transformers (1 to 10 kHz), as shown in Appendix Figure H-2, which has been found to offer a good trade-off between efficiency and power density for the MV voltage and power range. A minimum number of three HV conversion modules per phase are required for an 11kV/0.4kV AC and DC applications using the state-of-the art semiconductors and HFTRs. The efficiency recorded at full load and light load for SST is currently lower than conventional transformers. During our engagement with some of the manufacturers, we received the results of laboratory tests of SST prototypes that show the efficiency can be as high as 98%. This is the status of SST today and we are hoping to achieve at least the same level of efficiency (98%) within LV Engine by deploying cutting-edge semiconductor technologies and optimising control algorithm.



Appendix Figure H-2: Commonly used SST configuration and topology (per-phase) for Smart Grids applications

The use of multilevel topologies in the same configuration is an alternative to improve further the power quality and efficiency. Also, some manufacturers have utilised resonant tank at the HF link to improve the efficiency further especially at full load (yet sacrificing the performance at light load). Some academic demonstrators have used three-level' topologies: neutral-point clamped and flying capacitor, yet there was little or no improvement on the expense of more components count. The cascaded full-bridge modular multilevel converters (MMCs) gained a huge interest due to the requirement for higher efficiencies in HVDC systems, and these have been studied as an input stage of the SST for creating an MVDC grid. The size remains an issue with a separate the MMC approach; and this renders the configuration in Appendix Figure H-2 as the convention of SSTs today.

H.2 SST origin, advancements

The concept of the SST dates back to the 1968 with the introduction of the "Electronic Transformer" for fault current limiting and interruption and voltage regulation in low power applications. It has since found different applications in different markets, where its maturity and introduction to each market has different TRLs due to different limitations, requirements and challenges of each market. Advancements in HVDC MFTR and HFTRs for low power supplies are the main enablers for the Smart Grid applications of SSTs, where there are some common requirements and similar benefits.

Academia and industry R&D has increased since 2015 for the application of SSTs within Smart Grids. This is mainly due to advancements in two main technologies: the power semiconductor devices and the HFTRs. It is important to note that, in 2015 SiC high power modules were mass produced, allowing high frequency switching for high power applications and consequently resulting in a decrease in magnetic components' sizes and comparable technology costs as for to the Silicon based designs.

H.3 Maturity, limitations and future outlook till 2050

There are two main elements that have a high impact on the design optimisation and technology advancement of SSTs. These are;

High Frequency Transformers (HFTR)

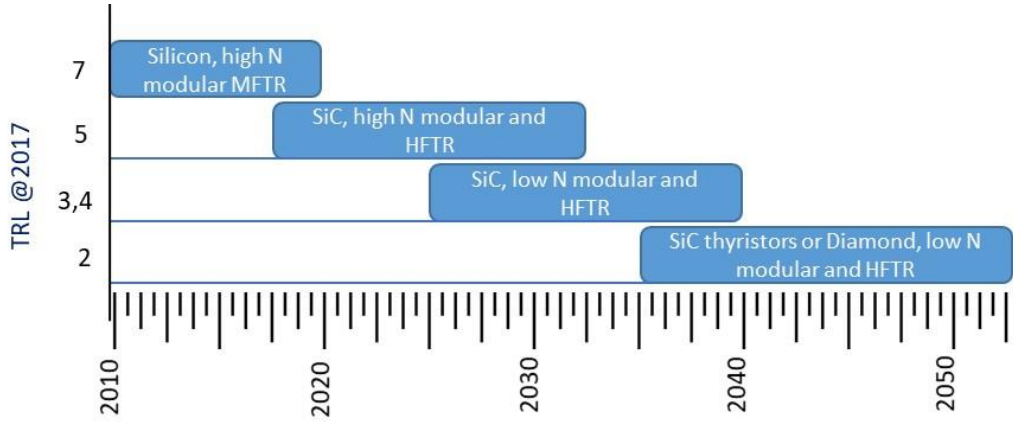
Conventional 50Hz transformers are mature technology. Using these mature designs for MF and HF applications provides a reduction in core material quantity as a function of transformer frequency, and hence the losses globally decrease. This however introduces a technology limitation as the core losses intensity increases, leading to high temperature gradient and requirement for higher cooling requirements. In conventionally wound transformers, a considerable amount of leakage flux enters the core, resulting in localized core saturation and hotspots. This becomes a very critical issue especially for high-power high-frequency transformers. Coaxially wound transformers are seen to be a viable alternative in that the leakage flux is contained within the inter-winding space, with very little or none of it permeating the core. Such transformers can also realize multiple benefits of a low distributed and controllable leakage inductance, robust construction, low electromechanical forces, and low core and copper losses.

At the lower end of the power scale there have been advancements driven by the requirement for high efficiency inductive charging where there is a significant air gap between the primary and secondary coils of the transformer. Although the application is different from the Smart Grid's, the technology can be conveniently introduced into an ISOP SST due to its modularity.

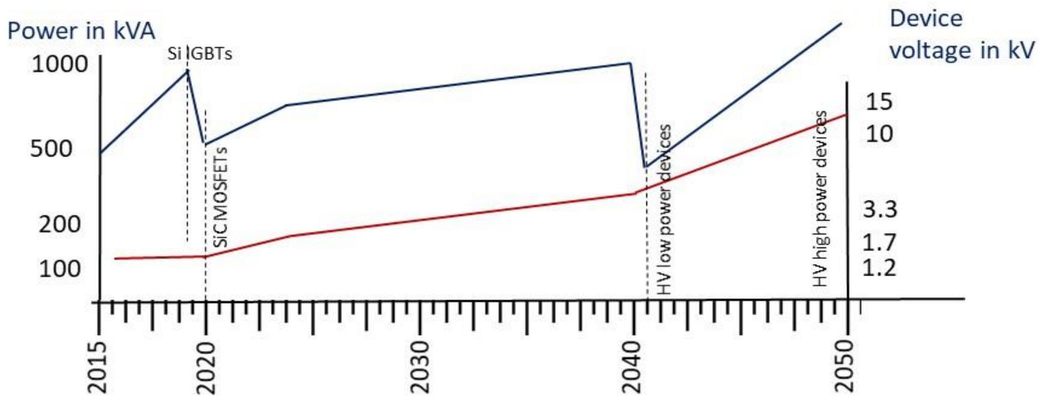
To optimise the design of a HFTR to decrease its losses and size, an optimised selection of core material, wire material and construction type for a specific range of operating frequency is required. It was found that nanocrystalline core material and Litz wire windings for the transformer design have the potential of optimising the HFTR for the SST application in distribution grids. However, the R&D of magnetic materials for transformers, filters and other passive components is not currently carried out on a large. These components remain bespoke at a premium cost, and their introduction as off-the-shelf will have a high impact on the cost of the SST.

Semiconductor Devices

Appendix Figure H-3 illustrates the evolution and TRL of high power semiconductors for utilisation in Smart Grid products as observed in 2017, and Appendix Figure H-4 illustrates the impact of the introduction of these devices on the SST rating. There is currently huge activities and R&D investment dedicated to developing HV (>10kV) and high power (>1MVA) semiconductor packages for the smart grid towards 2050. In an optimistic view, a single optimised SST will be rated for more than 5MVA with and efficiency more than 99% due to the reduction of number of modules and hence the reduction of the volume of magnetic components.



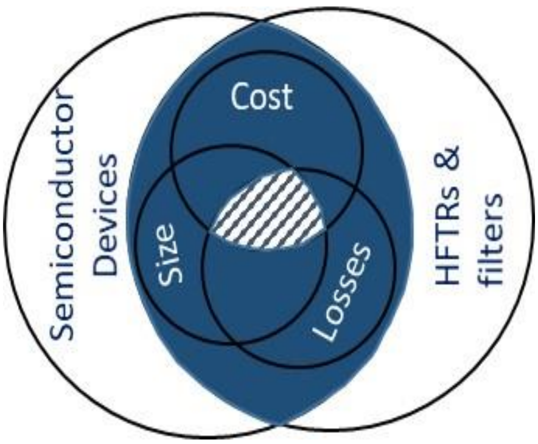
Appendix Figure H-3: Maturity of devices and magnetic components (N=number of)



Appendix Figure H-4: Evolution of semiconductors & SST implementation ratings (single unit); red: voltage, blue: unit rating.

H.4 Limitations

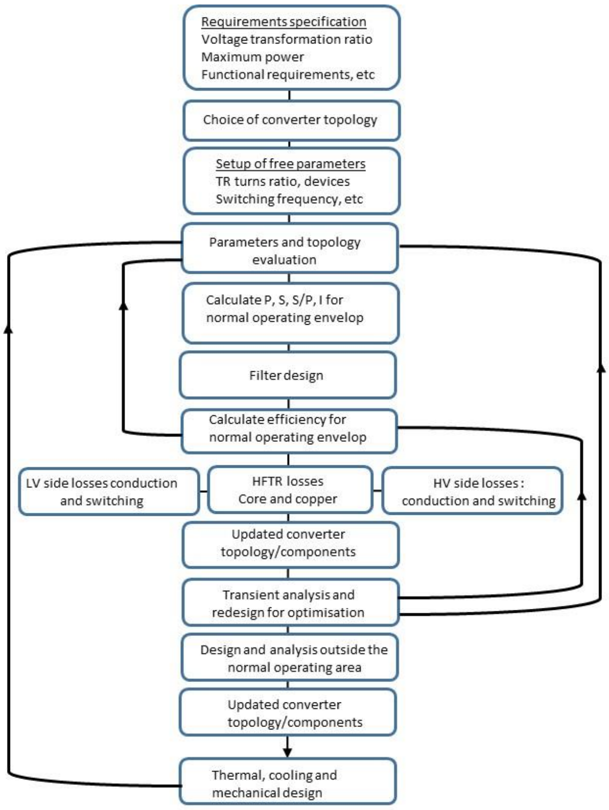
Possible worst case characteristics of transient over voltages are not only linked to the selection of appropriate protection devices and semiconductor blocking voltages, but also to a suitable design of the passive components (i.e. HFTR, input filter and DC-link capacitors).



Appendix Figure H-5: Metrics of design optimisation

An optimised design usually entails voltage utilization of power devices between 40% and 70% to fulfil protection, availability, and steady state operation. This makes a strong case for devices with higher voltage blocking capability in optimising the SST design. An optimised design is usually a trade-off between cost, size and losses using state of the art components as illustrated in Appendix Figure H-5. It is challenging to design for the shaded area, as this will require all components to be designed specifically for the SST application and by definition will increase the cost unless there is a mass production requirement.

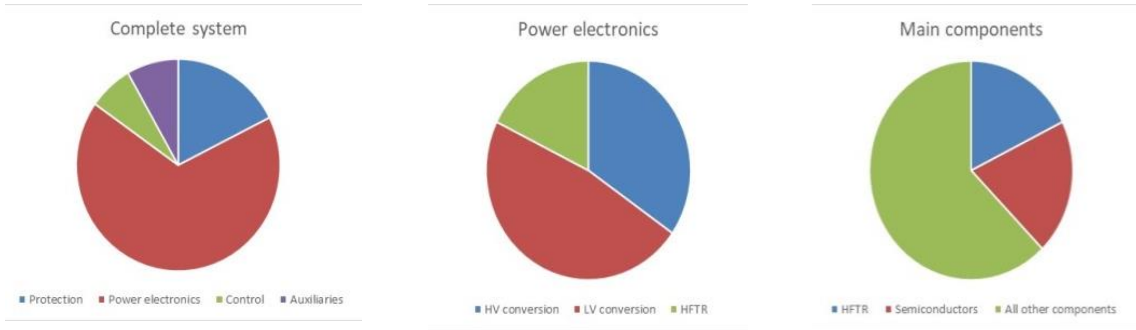
The optimisation of SST design using off-the-shelf components is usually carried out through many rounds of adjustments as shown in Appendix Figure H-6 resulting in bespoke components. Learnings from the early demonstrators in 2020 and the subsequent roll-out of the technology has the potential to result in optimised components for the specific applications of SST and hence a standardised designs and low cost of the equipment.



Appendix Figure H-6: Steps of design optimisation

H.5 Future Outlook - Cost

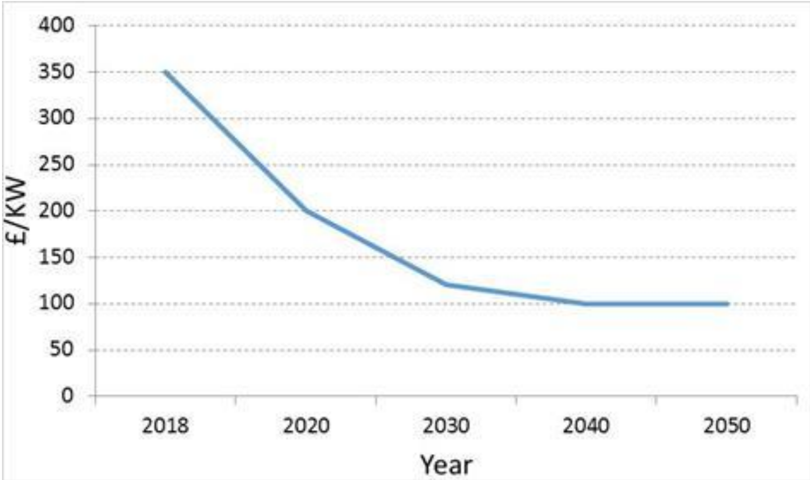
It is expected that the cost of SST technology will reduce and become more competitive to other smart solutions. A qualitative breakdown of costs of different SST elements is provided in Appendix Figure H-7, using a generic ISOP topology. The power electronics section includes the HFTRs, filters, capacitors, heat sinks and other cooling arrangements (this is the main element that can be optimised for size, cost and efficiency). Note that the cost of semiconductors on their own is not higher than 15% of the full SST depending on the topology. Nonetheless, any improvement of the design does impact the other elements of the full circuit either in count or in efficiency.



(a) (b) (c)

Appendix Figure H-7: Costs breakdown; (a) for the complete SST, (b) Breakdown of power electronics, (c) 2nd breakdown of power electronics. LV and HV conversion in (b) include filters and heat sinks, the split between can widely vary with the design.

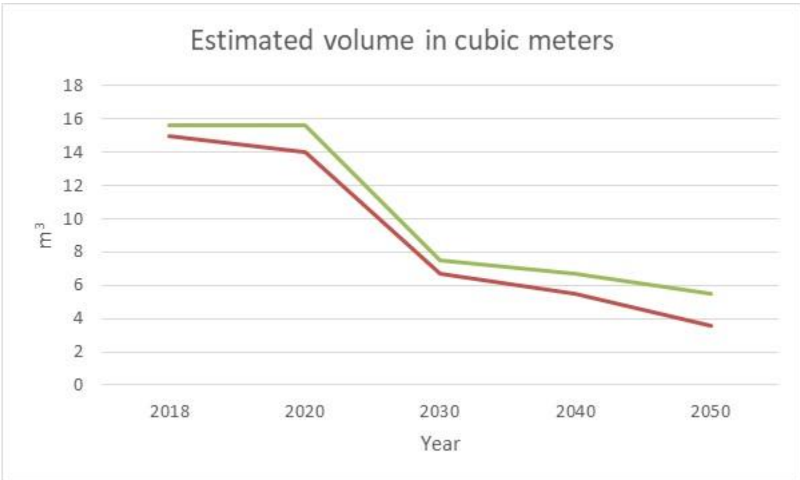
One method for reducing the costs further is to **replace the silicon-based power electronics with HV silicon carbide (SiC) and/or diamond**. This will reduce the filtering requirements, component count, mechanical enclosures and other circuit auxiliaries. An optimistic view, predicts a reduction in cost of about 71% by 2050 compared to the lowest estimate of today's SST (Appendix Figure H-8).



Appendix Figure H-8: SST cost projection between 2018 to 2050 £/kW,

H.6Future Outlook - Size

Even with very low losses, the resulting high power density may still require oil cooling to reduce the size. A volume range is predicted in Appendix Figure H-9, with the lower limit assuming oil cooling and the higher limit assuming air cooled equipment both taking into account the improved efficiency and reduction of components count towards 2050.



Appendix Figure H-9: Volume reduction of SST (m3). Range varies with cooling, topology and losses (Red: Optimistic, Green: Pessimistic)

H.7 Future Outlook - Losses

Evolution in devices' ratings, improved topology, reduced HFTR losses and numbers of modules are all elements that are **expected to increase the efficiency to more than 99.6% at full load** by 2050. In addition, a flat efficiency over the loading curve is expected with the use of advanced control techniques to detect the operational point of the SST and adjust the switching frequency to optimise the operation dynamically. **It is expected that the SST will have superior performance over the conventional transformer over the daily load curve.**

Appendix Table H-1 is a technology brief which shows the progression of the key SST parameters. It also includes a projection of the TRL level of SSTs between 2018 and 2050 based upon market research and publically available information.

Appendix Table H-1: Solid State Transformer Technology Brief and TRL Projection

Data type	Variable	unit	Time horizon 2018	2020	2030	2040	2050	Comments
1 Technology performance characteristics								
Size	Reduction in occupied volume	%	0%	20%	25%	30%	35%	Increase in power density due to the introdcution of WBG HV devices, reduction of number of HFTR, and the advancement in HFTR material.
Effeciency	At full load AC/AC (using a DC link)	%	96.00%	98.00%	99.00%	99.55%	99.67%	Evolution in devices, Improved topology, Reduced HFTR losses/number of modules are expected to increase the efficiency
	Light load AC to AC (using DC link)	%	92.00%	93.00%	94.00%	97.00%	97.00%	Using advanced control techniques for different operational modes, the light load effeciency will improve and may provide advantage over some conventional transformers.
	At full load AC to DC	%	98.20%	98.50%	99.00%	99.58%	99.70%	
	Light load AC to DC	%	95.00%	96.00%	97.00%	98.00%	98.00%	Advanced control systems can bring the effeciency flat over a wide range of operational points
	HFTR losses	%	0.80%	0.80%	0.60%	0.39%	0.39%	Development of lower loss core materials and improved winding layout to reduce stray losses
Capacity	Voltage ratio HV/LV line to line RMS	kV/kV	11/0.4	11/0.4	33/11/0.4	33/11/0.4	132/33/11/0.4	Some SST applications at the 132kV in connection with HVDC can be expected esp. for remote grids, Some R&D for connecting telecommunications base station in developing countires will drive the technology in addition to the HV SiC packaging
	Anticipated take up capacity	kW	1000	1000	2000	3000	5000	Maximum power transfer per SST installation for integrating/interconnecting networks in Smart Grid platform, 1 MW is assumed as the sweetspot for microgrids today. High power density and reliable devices will bring higher power applications.
Security of Supply	Reliability	Annual Visits	2	1	1	1	1	Assumed figures - due to transient events at the network level
	Availability	Energy availability % of total hours/year	99.5%	99.8%	99.9%	100.0%	100.0%	Modularity, redundancy and robustness will allow live exchange of faulty modules without outage
	Maintenance - frequency		Every 2'nd year	Every 2'nd year	Every 5'th year	Every 5'th year	Every 7'th year	To change faulty modules, and regular maintenance tasks e.g. cooling system checks
2 Technology readiness and maturity (TRL Progression)								
Maturity	AC/AC SST for low power applications and low voltage ratio	TRL	9	9	9	9	9	off-the-shelf component
	LVDC-SST		8	9	9	9	9	
	HVDC-SST		9	9	9	9	9	
	HV/LVDC-SST		4	7	9	9	9	
	DC networks/microgrids		6	7	9	9	9	Prototypes in Data centres, DC distribution for ships, etc
	HFTR		4	7	9	9	9	
	DC/DC converters (low voltage ratio at high power)		5	7	9	9	9	
	Technology readiness of overall SST system		5	7	9	9	9	2018 TRL based upon engagment with manufacturers to assess the latest developments in the area.
3 Possible implementation constraints								

Size	Magnetics volume in % of 2018 volume	%	100%	90%	90%	85%	85%	This is a relevant mature technology with very little activities in R&D. There's however R&D into superconducting materials which may have a long term effect on the physical size. The view however reflects the status of the technology today, and how the converter can be optimised to make full use of the existing technologies.
	HV isolation volume in % of 2018	%	100%	100%	100%	100%	100%	This is a relevant mature technology with very little activities in R&D.
HFTR	Tappings	N/A	12:01	12:01	12:01	12:01	12:01	With the advances in semiconductors, mutliple tappings are not required.
	Voltage transformation ratio	N/A	13:1	13:1	20:1	30:1	30:1	If a single level SST were to be used, an HFTR of high voltage ratio is needed, which can lead to significant design problems due losses gradient and voltage stresses. However, some R&D exists which will lead to higher voltage ratio and higher effeciency
	Maximum frequency	kHz	350	350	350	350	350	There is no obvious need for increased frequency
	Maximum rating	kW	20	100	200	300	500	Higher figures are achieved for MFTRs
4 ***Costs***								
Investment costs of system components	Full SST (AC/DC/AC) equipment cost per unit - optimistic	£/kW	340	204	136	112.2	100.0	Taking into account mass production cost reduction towards 2020, in addition to trends in cost reduction of semiconductors and magnetics. With increased effeciency, cooling requirements will decrease and more compact designs will result. 2040-2050 new semiconductors will be introduced keeping the costs flat but improving performance.
	Cost reduction from 1 unit in 2018 as base - optimistic	%	0	40%	60%	67%	71%	A huge reduction in material count and cooling requirements due to the advances in HV semiconductors
O&M costs	O&M costs	% of investment costs per year	1%	1%	1%	1%	1%	Assumed flat - monitoring, DSO services, remote control, ...
Economic lifetime	For full SST	Year	30	40	50	70	>70	Increase in economic life due to robustness in components, operational experience, application targetted designs. It is expected that the SST will be fit and forget by 2050
5 ***Environmental impact and public acceptance***								
Environmental impact and public acceptance	Height for ground-level street installation	m	2.5	2.5	1.2	1.2	1.2	
	Footprint	m2	6.0 - 6.25	5.6 - 6.25	5.6 - 6.25	4.6 - 5.6	3.0 - 4.6	Assumed reductions based in reductions in componets esp magnetics
	Noise generation (comment : no building for noise purpose)	dB	55	45	40	30	30	The noise level is affected by the switching frequency and cooling requirements, using SiC devices 2020 allows for high frequency switching and hence low acoustic noise. Also, the expected effeciency improvements will lower the cooling requirements and hence provide even more reduction towards 2050. Advanced noise cancellation techniques from 2030 onwards.
	EMC		No issue	No issue	No issue	No issue	No issue	
6 ***Dynamic performance of the technology***								
Adaptive control	commercial availability	Yes/No/Not Applicable	No	Yes	Yes	Yes	Yes	Adaptive/advanced control implemented to improve effeciency and dynamic performance.
Self tuning control	commercial availability	Yes/No/Not Applicable	No	Yes	Yes	Yes	Yes	Online gain adjstment to cope with highly dynamic power flow through many interconnected networks.
Grid code compliance	Ability to comply with existing grid codes	Yes/No/Not Applicable	Yes	Yes	Yes	Yes	Yes	
Virtual rotating mass	commercial availability	Yes/No/Not Applicable	Yes	Yes	Yes	Yes	Yes	Increased transient power rating in converters, energy storage - black start
Network models/simulation	necessity of network /model simulations	Detailed/Generic	Detailed	Detailed	Generic	Generic	Generic	With advanced controls, SST will test the grid upon installation and adjust its gains. High modularity would facilitate switching in only required modules

Appendix I SST Technical Specification

I.1 Introduction

This specification defines the functional requirements for a SST for use of the SP Energy Networks' distribution network to interconnect MV and LV systems. The electrical and physical environment where the device will be installed is also defined. In their responses suppliers should confirm that their equipment is able to operate under these environments. The functional requirements of the SST are defined in this document and suppliers shall confirm that their proposal is able to match the requirements. The contract stage specification will include an Appendix containing schedules to be completed by the supplier confirming their compliance with this specification. The specification is intentionally functional, the technology and the topology of the convertors is at preference of the suppliers. SP Energy Networks intend to procure two designs of SST for operation in field trials, which can assess the merits and demerits of different solutions. It should be noted that this technical specification document will be modified and developed further as part of WP1-Technical Design of LV Engine.

I.2 Evaluation Criteria

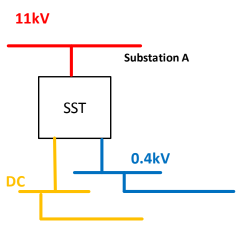
Each proposal received will be considered on its merits in terms of its ability to meet the following criteria, which will be used to evaluate the competing submissions. The following list is not in a priority order.

2.1 Compliance with the functional requirements as defined in this specification
2.2 Volume occupied by the SST
2.3 Operating losses, i.e. from input MV terminals to output LV terminals, including any auxiliary power demand
2.4 Capital cost (CAPEX) of the SST
2.5 Operating cost (OPEX) of the SST, including capitalisation of operating losses (as 2.4), maintenance costs, spares utilisation, etc.

I.3 SST Requirements

The SST shall have a nominal power rating of 500kVA. The manufacturer shall advise if this rating can be achieved with air or liquid cooling and whether forced or natural cooling is required. To minimise maintenance requirements, Scottish Power Energy Networks have a preference for an Air Natural (AN) design. The SST primary terminals will be connected to an 11kV Medium Voltage (MV) distribution system. The SST secondary terminals will be connected to a Low Voltage (LV) distribution system, with the capability to supply AC and/or as shown in Appendix Figure I-1.

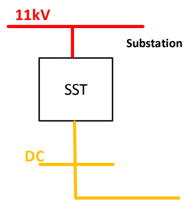
Design 1



0.4kV, 3 – phase AC output, with a neutral connection

0.4kV, 2 – pole DC output, with a ground connection

Design 2



0.4kV, 2 – pole DC outputs, with a ground connection

Appendix Figure I-1: Design1 and Design 2 schematic diagram

The ratings (in kVA) of the individual output stages of the SST will be specified at a later stage of the project, based on customer and trial site requirements. The choice of DC output stage voltage may change depending on customer and trial site requirements. SP Energy Networks intend to procure both designs for SST for the trial installations. Manufacturers may propose to supply either Design 1 or 2 or both, as suits their technology. A total of six SST units will be procured for the trails. The number of units of Design 1 or 2 required will depend on the specific needs of the sites chosen for the trials, but in total the number of units will not exceed six.

I.4 System operating conditions

Appendix Table I-1: System Operating Conditions

	11kV system	0.4kV system
AC system voltage		
- Nominal	11kV	0.4kV
- Maximum continuous	12.1kV	440V
- Minimum continuous	10.34kV	376V
AC system frequency		
- Nominal	50Hz	50Hz
- Maximum continuous	50.5Hz	50.5Hz
- Minimum continuous	49.5Hz	49.5Hz
- Exceptional continuous maximum	51Hz	51Hz
- Exceptional continuous minimum	49Hz	49Hz
- Short time conditions	51 – 51.5Hz (30 min)	51 – 51.5Hz (30 min)
	49 –47.5Hz (30 min)	49 –47.5Hz (30 min)
Short circuit level		
- Maximum for switchgear rating	TBC kA	TBC kA
- Maximum for scheme operation	TBC MVA	TBC MVA
- Minimum for scheme operation	TBCMVA	TBC MVA
Negative phase sequence voltage	2%	2%
Insulation coordination		
- LIWL	125kV	-
- Power frequency withstand level	36kV	3kV

I.5 Environmental Conditions

The SST will be housed indoors or in weather-proof enclosure. The SST should be able to operate at its maximum design power rating under the following environmental conditions.

Appendix Table I-2: Environmental Conditions

Ambient temperatures	
Maximum outdoors	+40°C
Maximum indoors	+35°C
Average	+20°C
Minimum indoors	5°C
Minimum outdoors	-25°C
Relative humidity range	10 – 100%
Altitude	<1000m
Isokeraunic levels	N/A
Seismic ground acceleration	
- Horizontal	0.1g (TBC)
- Vertical	0.1g (TBC)
Pollution levels	Light (Class I)

I.6 SST Functional Requirements

The following capabilities shall be built into the design of the SSTs as far as possible to allow the project to build a positive and competitive business case. In some cases the capability would be useful, but is not a major driver for the project.

- Control of transferred real power (provides network controllability).
- Allow bi-directional power transfer, with rapid power reversal
- Independent control of reactive power at each end (i.e. the SST decouples the voltage at each end).
- Fine-grained control of voltage and power factor (these can be set to improve voltage profiles and network losses).
  - Voltage control range of ±5%
  - Power factor control range, 0.9 lag to 0.9 lead
- Mitigation of voltage dips/sags and swells (as per STATCOM operation).
- Mitigation of existing harmonic distortion to improve power quality. [If possible]
- Balancing of power and voltage between phases, depending on SST topology and controls.
- Fault current management
- Potential to use SSTs as "circuit breakers" to interrupt fault currents.
- Provision of a DC link for:

  1) Direct DC connection of Low Carbon Technologies (LCT).
  2) DC supply to large industrial customers.
  3) DC supply for mass Electric Vehicle (EV) charging.

- A modular design that allows the capacity of the SST to be increased by plugging in an additional "capacity block".
- Series redundancy in the design, to allow the SST to continue in operation with one or more sub-modules failed and by-passed

It is anticipated that an external control facility for the SST will be developed by SP Energy Networks. Based on the monitoring of signals from the LV distribution network, algorithms will be developed which will control the operation of the SST to optimise the power flows in the network. SP Energy Networks will work closely with the SST suppliers in the development of these control algorithms.

I.7 Technical Requirements

As well as delivering the functionality listed above, the SSTs must be technically fit-for-purpose and suitable for inclusion in a live trial within the SP Energy Networks distribution network. Some of the key design constraints that shall be considered are described below.

1) **SST Operating Losses**
The SST losses shall be stated by the manufacturer and shall include all losses between the 11kV terminals and the 0.4kV (AC and DC) terminals, including all losses in power electronic modules, high frequency transformers and the auxiliary power losses (cooling, control system power, etc.). As a guide to the anticipated losses, an extract from EU Commission regulation 548/2104 for losses for dry-type medium power transformers is shown below.

Appendix Table I-3: Maximum losses for a 3-phase dry type medium power transformer

	Tier 1 (1 July 2015)		Tier 2 (1 July 2021)	
Rated Power (kVA)	Maximum Load Losses (W)	Maximum No-Load Losses (W)	Maximum Load Losses (W)	Maximum No-Load Losses (W)
400	5500	750	4500	675
630	7600	1100	7100	990
800	8000	1300	8000	1170

Note: *The maximum allowable losses for kVA ratings that fall in between the ratings given above shall be obtained by linear interpolation.*

I.8 Noise Requirements

The SSTs shall be designed to produce a maximum audible noise of no more than 59dB, as measured at 1m from the equipment. This may be achieved by increasing the power electronics switching frequency or deploying a sound proof enclosure, or any other suitable method.

I.9 Substation Footprint

The maximum substation footprint of the SST shall not exceed 2.5m (l) x 2.5m (w) x 2.5m (h). This shall include all necessary switchgear, LV cabinets, cooling etc. Manufacturers should confirm that they can achieve this footprint and advise if they can propose any design measures which could provide any reduction in these dimensions.

I.10 Lifetime

The SST equipment should be designed for a lifetime of 30 years. The manufacturer will be required to provide instructions for end of life disposal and re-cycling of the SST material.

I.11 Reliability and Availability Targets

The SST shall be designed to achieve a Forced Outage Rate (FOR) of 1 or lower per annum. The SST shall be designed to achieve a Forced Energy Unavailability (FEU) of <0.15% per annum. The SST shall be designed to achieve a Scheduled Energy Unavailability (SEU) of <0.15% per annum.

The manufacturer shall advise on the level of spare equipment which is required to achieve the above reliability and availability figures. SP Energy Networks will procure and store the recommended level of spares.

I.12 Maintenance

The manufacturer shall advise on the maintenance regime proposed for the SST. Ideally annual maintenance is not required and the target SEU can be achieved by not more than a 1 day outage every 2 years. Solutions with minimum maintenance requirements shall be consider favourably.

The manufacturer shall provide an Operating and Maintenance manual for the SST and suitable training for the owner's personnel. SP Energy Networks personnel will undertake the necessary routine maintenance on the SSTs.

I.13 Warranty

The manufacturer shall provide a three (3) year warranty on all of the equipment which comprises the SST.

I.14 Additional Project Design Considerations

I.15 SST Protection

The SST shall be capable of detection and self-protection in the event of internal faults. The initial response should be to isolate or by-pass any faulty sub-modules, allowing the device to remain in operation. If this is not possible, or redundancy levels have been exceeded, the SST should initiate a trip from the MV and LV supply systems.

The units shall include a suitable protection arrangement that is capable of clearing LV faults within an acceptable timeframe. SP Energy Networks will consider any innovative solutions to this challenge.

I.16 DC Earthing

A suitable DC earthing arrangement shall be designed for both Design 1 and Design 2 to enable a DC supply to be provided to customers safely.

I.17 SST Monitoring

The SST(s) shall incorporate adequate monitoring which captures the key performance indicators, i.e. temperature, three phase current and voltage, harmonic distortion etc. and presents the data in such a way that it can be communicated using conventional protocols and media.

SP Energy Networks are considering developing a Real Time System for monitoring and controlling multiple SST devices to optimise system-wide performance. SST suppliers should comment on the ability of their technology to communicate with a remote Real Time System, to both send and receive data and which communication protocols are supported by their control system.

I.18 SST Generated Harmonic Distortion

The manufacturer shall provide information on the level of harmonic distortion generated by the SST at the MV and LV terminals. Any such distortion will be assessed following the guide lines in Engineering Recommendation G5/4 – 1.

I.19 Overload capability

The manufacturer shall indicate what overload (in kVA) capability (in time) is available when the SST is operating at full load (500kVA), at maximum operating temperature (35ºC) and minimum operating temperature (5ºC).

Appendix J SST Comparison with other technologies

For SP Energy Networks the "Business as Usual" approach would involve the procurement and installation of conventional LFT units, operating at 50Hz, for the connection of Low Voltage power supplies. In this Appendix we provide a comparison of the functionality which can be achieved by the development and trial installation of a SST with the conventional LFT solution. However, in order to achieve a "like for like" comparison of functionalities which the SST can provide, the LFT needs to be augmented in some cases by additional technologies, such as OLTC, DC Inverter (DCI) and STATCOM.

J.1 Power flow control

An SST can provide precise (fine) control of power in either direction, by adjustment of the operating conditions of the power electronic converters. An LFT may allow power flow in either direction without any control. On-load tap-changers are typically not widely used on distribution LFT units, due to reliability and maintenance issues associated with the moving parts of the operating mechanism.

J.2 Voltage control

The SST can provide precise (fine) phase voltage control for the LV system, by adjustment of the operating conditions of the power electronic converters. A LFT incorporating an OLTC can provide a stepped (coarse) voltage control of the LV system which may not suitable for LV network experiencing imbalance voltage profile and requires a dynamic fine voltage regulation. In summary, the following limitations have been the main barriers to rolling out of OLTCs:

- **Frequent tapping:** There are some evidences around the mechanical stress on OLTCs as a result of frequent tapping in response to daily voltage variations. That has adverse impact on OLTC life time and O&M. This problem will become worse in an area with high uptake of LCTs.
- **Step voltage control:** OLTC essentially relies on the tap steps (2.5%) of the existing transformers. With this tapping granularity, the voltage control of LV feeders with different length and different LCT uptake can be challenging if even possible.
- **Impact on MV voltage:** Tapping to adjust secondary voltage can impact the MV voltage. With the deployment of multiple OLTCs, the MV voltage control may become more challenging and add complexity to the AVC operation at the primary substation.

J.3 Reactive power control

The SST contains independent converters on the MV and LV sides of the unit and can provide independent control of reactive power absorption and generation on the MV and LV systems. In this way it can influence the voltage profile on the distribution systems, reducing operating losses in the wider network. To achieve the same functionality a LFT would require an additional STATCOM unit on the LV system to provide the equivalent absorption or generation of reactive power, LFT fitted with OLTC would not be able to provide reactive power compensation.

J.4 Dynamic reactive power response

In addition to its steady state reactive power control capability the SST will be able to respond to dynamic events, providing rapid absorption of generation of reactive power as required to respond to system perturbations. A similar capability can be achieved by a LFT plus STATCOM combination.

J.5 Load balancing

As the SST de-couples the MV converter from the LV converter via a DC link, any unbalance in the LV loads is not transferred to the MV system, i.e. the SST has an inherent load balancing facility. An LFT would simply pass the load imbalance through to the MV system. The provision of a STATCOM could provide load balancing for the LV system, however, the algorithm for load balancing is incompatible with normal reactive power or voltage control. A sophisticated control system would need to be developed to automatically change between normal operating states and unbalanced load state, e.g. when a load imbalance beyond a certain threshold was detected.

J.6 AC and DC output stages

It is a prime requirement of the SST that it can provide AC (0.4kV) and DC (0.4kV or 800V) output stages for both the trial sites and for future commercial operation. A LFT can inherently achieve an AC output stage, but to create a DC output would require the addition of separate DCI unit.

J.7 Harmonic generation and filtering

As a power electronic converter a SST will generate low levels of harmonic distortion and the design of the unit will need to comply with the requirements of Engineering Recommendation G5/4-1. By control action it may also be able to act as an active filter, reducing distortion created by other non-linear loads on the network. A LFT is a passive device with respect to harmonic distortion, neither generating nor actively attenuating harmonic distortion.

J.8 Fault current capability

Depending on the design of the converters the SST may have the capability to limit or block the flow of high current levels arising from faults on the LV system. In fault conditions a SST only delivers its load current, i.e. it cannot pass high levels of fault current. However, this may be an issue for LV protection systems, which may rely on such fault currents to blow fuses, which isolate the faulted parts of the system. A LFT will allow the passage of fault currents limited only by the impedance of the transformer, but such currents are coordinated to blow protective fuses.

J.9 Operating losses

Discussions with equipment suppliers indicate that a SST could have operating losses, i.e. from MV to LV connections of between 2% to 4%. This compares unfavourably with a LFT with losses less than 1.0%. However this disadvantage reduces when the losses of a DCI and STATCOM are included assessed as 0.5% each, bringing the comparable operating loss to less than 2.0%. As SST component technology advances, principally due to the use of more advanced semiconductor materials, such as Silicon Carbide and Diamond, the losses of a SST will decrease to match those of a LFT.

J.10 Audible noise

The design target for the SST will be to achieve a noise emission level which is comparable with existing LFT installations. A figure of 59dBA has been issued to potential suppliers as a design target and indications are that this should be achievable.

J.11 Volume

As the SST is an indoor installation, requiring a cooling system, it is unlikely to achieve the compact design of a LFT. A target volume of 2.5 x 2.5 x 2.5m has been advised to potential suppliers, who have indicated that this is achievable. As discussed above, for a "like for like" comparison a compact LFT solution needs to be augmented by additional equipment, such as DCI and STATCOM units, which need to be included in any comparison of volume.

J.12 Technology Readiness Level (TRL)

Based on discussions with multiple suppliers and academics and reviewing the available literature, we consider that the SST presently has a TRL of 5 to 6. Thus all of the prototype sub-systems which comprise a SST have been developed, but no full pilot system, with the functionality described above, has been implemented. In comparison a LFT, even requiring additional existing technologies to achieve the same functionality as a SST, is considered to have a TRL of 9, i.e. available for full scale deployment.

Appendix Table J-1 shows a comparison of a 500kVA 11/0.4kV SST with the competing technologies such as transformers using OLTC, STATCOM, and DCI to create a 0.4kV DC bus. Combinations of technologies are included to provide "like for like" comparisons.

The focus for the comparison is the functionality which can be achieved on the LV network (0.4kVac/0.4kVdc), rather than on the MV network (11kV).

Appendix Table J-1: Technology Comparison Matrix

Functionality	SST	OLTC	OLTC+ STATCOM	OLTC + DCI	OLTC + DCI + STATCOM
Power flow control	Yes (fine)	No	No	Yes	Yes
Reactive power control	Yes	No	Yes	No	Yes
Voltage control	Yes (fine)	Yes (coarse)	Yes (fine)	Yes (coarse)	Yes (fine)
Dynamic response	Yes	No	Yes	No	Yes
Load balancing	Yes	No	No	No	No
AC voltage output	Yes	Yes	Yes	Yes	Yes
DC voltage output	Yes	No	No	Yes	Yes
Harmonic generation	Yes	No	Yes	Yes	Yes
Fault current limiting	Yes	No	No	Yes (DC)	Yes (DC)
Fault current interruption	Yes	No	No	No	No
Operating losses[1]	2%	<1.0%	1.8%	1.8%	2.3%
Technology readiness level	6	9	9	9	9
Fire risk assessment[2]	Low	High	High	High	High
Audible noise	Medium	Medium	Medium	Medium	medium
Scalable solution[3]	Yes	No	No	No	No
Relative costs[4]	High	Low	Medium	Medium	High

Notes

1 Operating losses for each item of equipment based on a 500kVA rating are assumed to be as follows: SST = 2.0% on 500kVA, OLTC = < 1.0% (i.e. the transformer) on 500kVA, Statcom = 0.5% (assuming 1% on 250kVA), DCI = 0.5% (assuming 1% on 250kVA)
2 Power electronic equipment (SST, STATCOM, DCI) is assessed as low risk due to the absence of oil. The transformer fitted with the OLTC is assessed as high risk if it is oil-filled. If dry-type then Low risk.
3 Scalability relates to the ease of being able to extend the power capability or output voltage capability of the device.
4 The base cost is taken to be a standard transformer, with a VTC retrofitted. The additional relative costs of power electronic solutions reflect their Technology Readiness Level (TRL).

Appendix K LVDC Networks & Benefits

K.1 Introduction

One of the innovation aspects of LV Engine is the provision of LVDC networks. The benefits of DC networks have been discussed and demonstrated through desktop studies, niche applications and a few live trials around the world[1]. To our best knowledge there has not been any LVDC network trial within the UK. There are institutions (IEC & IET), Universities, industry parties, research and working groups suggesting that LVDC is emerging with a growing needs case. LV Engine will allow UK DNOs to understand the ability of LVDC to reduce network reinforcement and will provide the learnings and technical recommendations neccessary for the BaU adoption of LVDC networks. This Appendix provides a review of the potential benefits of DC networks and the challenges to adopt this technology into "business as usual".

K.2 Growing need for DC by customers

The case for DC in buildings has grown with the dominance of extra low voltage DC equipment in both residential and commercial premises. Information technology equipment, mobile devices, modern LED lighting, and TVs are the main appliances which need DC voltage supplied through AC/DC conversion. It is estimated that currently around 35% of residential home power consumption is DC based loads, with increasing uptake of EVs and energy efficient appliances likely to increase this proportion. In addition to DC loads, there has been an increase in the uptake of building integrated LV Renewable Energy Sources (RES), in particular PV, which generate DC power. However, this also needs to pass through a DC/AC conversion for local consumption or exporting to the distribution grid. Each AC/DC conversion and vice versa will result in an energy loss. As an example, the cumulative energy losses of the DC/AC and AC/DC conversion when powering DC appliances through local PV systems are in the range of 5-7%[2]. "Smart DC Edison", a UK innovation project carried out by the University of Bath investigated the benefit of a DC supply to their library. It was demonstrated that a DC supply to 50 adapted computers resulted in a 30% reduction in energy consumption. A 25% reduction in consumption from lighting was also observed. Another growing application of DC is in data centres. In an ABB built data centre, up to 10% improvement in energy efficiency, 15% savings in capital costs, 25% savings in space, and 20% savings in installations costs have been realised by using DC technology[3].

EV charging infrastructure is expanding and rapid DC chargers seem to be one of the preferable charging technologies with the electricity demand of 50kW to 350kW. Charging of EVs in the AC distribution network will incur further losses given the AC/DC conversion needed to charge the batteries. The losses associated with conversion can be reduced when supplying charging points with DC. IEC 61851-23:2014 standard states a range of 200V to 500V DC can be applied for the charging of passenger vehicles. It is likely to see 400V DC is the most common voltage for fast DC charging points. Street lighting is another application where LVDC can provide further efficiency. A field trials in the Netherlands (see Figure K-1) demonstrated the energy efficiency of street lighting

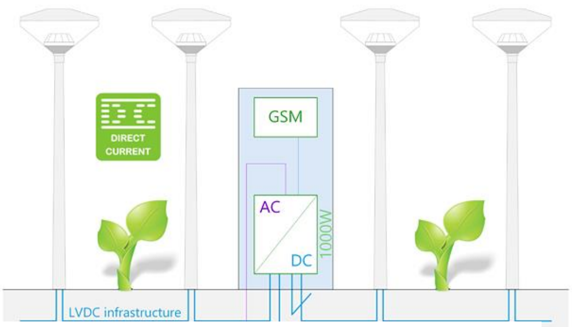


Figure K-1: DC supply to street lighting

[1] "Construction of actual LVDC distribution line", CIRED, 2017
[2] "Household DC networks: State of the art and future prospects", Sep. 2015, http://www.insightenergy.org/static_pages/publications
[3] Efficient DC power supply for data centres, available at: https://www.electricalreview.co.uk/features/9475-efficient-dc-power-supply-for-data-centres+&cd=3&hl=en&ct=clnk&gl=uk

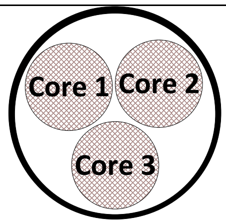
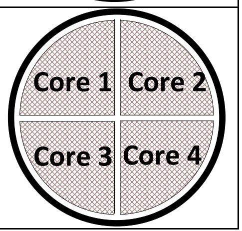
networks when supplying new LED lighting modules with DC[1]. To the best of our knowledge the performance benefits (installation costs and energy savings) of integrated EV charging and LED street lighting on a LVDC network have yet to be fully quantified. Most of the AC/DC conversation devices require a three stage conversion process AC/DC/device DC. A DC supply would enable a reduction in the number of conversion stages to a two stage DC/device DC only. This can reduce losses due to this conversion by 2.5-10%[2]. Also, the introduction of the new USB Type-C standard (provides data and power up to 100W) will eliminate the need for many adapters to convert 230V AC to lower voltages and then into DC to connect electronic devices. Such new generation of technology inherently requires a LVDC supply.

K.3 LVDC Networks

With the growing need for DC demand, there is an opportunity for the DNOs to provide LVDC to customers. DC supply can result in further efficiencies if the AC/DC conversion is undertaken at the network level. In this case, control of the network would be even stronger as the procurement, operation and maintenance of the AC/DC converters are in the care of DNOs and highly efficient devices can be utilised. In addition to improving the overall efficiency of energy consumption and generation at LV networks, there are further network benefits by enabling LVDC distribution networks:

- **Increased transfer capacity within thermal constraints**
  An LVDC distribution system can offer a higher power carrying capacity than the traditional 400V AC systems. This higher power transfer capacity can be achieved by using DC voltages that are within the insulation withstand capability of the conventional LV cable circuits. LVD 2006/95/EC allows the use of LVDC voltages up to 1500V. This voltage level (±750V) has been successfully trialled in Finland for LV underground cable circuits[3]. There is even an opportunity to convert the existing AC cables for DC operation to increase the power transfer capacity. In this way, the costly and lengthy network reinforcement projects can be avoided. Table K-1 shows the additional capacity released by converting a 3-phase 400V AC network to different DC voltage levels. University of Manchester has conducted a similar capacity released calculation considering typical UK LV underground cables[4].

Table K-1: Capacity can be released by operating at DC compared to 3-phase AC network*

	Core 1	Core2	Core 3	Core 4	Additional capacity	
Unipolar	+400	0	0		-39%	
	+500	0	0		-24%	
	+750	0	0		14%	
Bipolar	+400	-400	0		22%	
	+500	-500	0		52%	
	+750	-750	0		128%	
Unipolar	+400	0	+400	0	22%	
	+500	0	+500	0	52%	
	+750	0	+750	0	128%	
Bipolar	+400	-400	+400	-400	143%	
	+500	-500	+500	-500	204%	
	+750	-750	+750	-750	356%	

* The power factor in the AC system has been assumed to be 0.95

[1] Direct Current B.V, "The First DC Smart Grid for Public Lighting," 2014. [Online]. Available: http://www.directcurrent.eu/en/news/news-archive/112-first-dc-smart-grid-for-public-lighting

[2] Hammerstrom, D.J.: 'AC versus DC distribution systems, did we get it right?' IEEE Power Engineering Society General Meeting, 2007

[3] Feasibility of Low Voltage Cables for Use at 1500V DC Distribution Networks. Tampere University, Finland.

[4] "Transition from alternating current to direct Current low voltage distribution networks", IET Generation Transmission & Distribution September, 2015

- **Increase in transfer capacity due to reduced voltage drop**

The transfer capacity within LVDC network is also higher than LVAC networks considering a more stable and controllable voltage profile offered by LVDC[1]. In a DC network, the inductances effects on voltage profiles will be very limited. In addition, the reactive power in a DC network does not exist, hence, the impact of reactive power supply on the voltage profile can be eliminated resulting in less voltage drop compared to AC.

The less voltage drop in LVDC networks over LVAC networks allows for longer feeders before voltage drop becomes an issue. This can reduce the number of substations that are required in an area to supply customers. Figure K-2 shows the results of study conducted by University of Strathclyde which compares the increased power transfer capability over distance of a bipolar DC network operating at ±200V vs a conventional 230VAC supply whilst staying within a voltage drop of 3%[2].

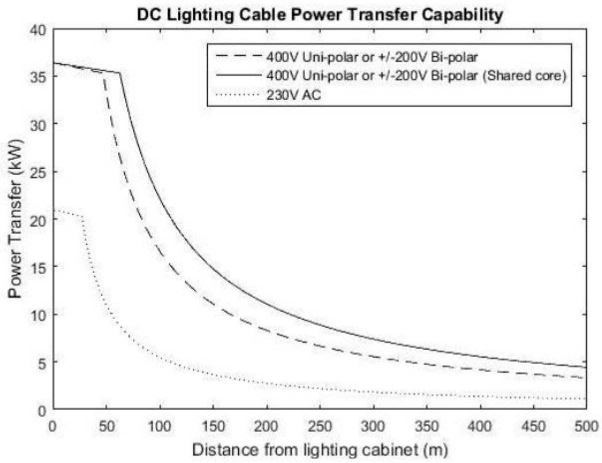


Figure K-2: Power transfer capabilities of AC vs DC

In addition, DC network does not have the same issue as imbalance phases in AC networks. Imbalance LV AC network may trigger significant network reinforcement [3] or require costly exercise of changing the phase connection of the customers. Higher network losses is another issue of imbalance AC networks. Scottish and Southern Electricity Networks estimated that imbalance network loading can contribute up to 12% of the LV network losses, this can potentially be avoided by operating at DC.

All aforementioned benefits have driven more push for trials, developing standards and technologies for LVDC applications. It is envisaged that the provision of LVDC networks by DNOs to the clustered EV charging points would be the need in very near future. Using DC provides more controllability on voltage and power flow in the LV network and that can also facilitate the deployment of vehicle to grid (V2G) solutions. Furthermore, utilities can further provide DC networks for the connection of renewable energy sources and to create a micro-grid, where the power is generated, controlled, stored (using DC battery storage) and consumed locally. Whilst the benefits of deployment LVDC have been demonstrated within some limited applications and it seems it is a promising choice for connecting LCTs, there are still multiple challenges that must be overcome before the full adoption of this technology as BaU. Some of them are:

1- **Technical:** More learning, standards, and technical specifications are required to build the confidence in safe operation of LVDC
2- **Commercial:** An approved metering mechanism is yet to be confirmed and tested
3- **Regulatory:** The electricity regulatory framework needs to provide the requirements for connection and operation at DC voltage, as the current regulations only answer the AC requirements

LV Engine aims to provide learnings and technical recommendations for these challenges by trialling the first LVDC at a utility scale in the UK.

[1] "Advanced LVDC Electrical Power Architectures and Microgrids", IEEE Electrification Magazine, 2014
[2] "Feasibility of Direct Current street lighting & integrated electric vehicle charging points", 2016
[3] Utility-Scale Estimation of Additional Reinforcement Cost from 3-Phase Imbalance Considering Thermal Constraints", 2017

Appendix L Site Selection Criteria

In order to obtain trial sites which fully explore and demonstrate the functionalities provided by SSTs, a set of criteria must be defined and applied to identify the trial sites which will be used during the live network trials.

The chosen trial sites should demonstrate and deliver the objectives of each LV Engine scheme. Furthermore, any identification process will not be carried out in isolation, but in collaboration with internal and external partners to utilise all available expertise and knowledge.

Subsequently, we have proposed a methodology which captures all the available knowledge and defines a list of criteria which will allow the proposed sites to be compared.

The methodology to identify the LV Engine trial sites includes the following:

1- Development of site selection criteria based on LV Engine schemes
2- Internal engagement with network planning and operation engineers
3- Data collection and heat map analysis of LCT integration at SPD and SPM
4- External Engagement to identify customers interested in a DC supply

L.1 Development site selection criteria based on LV Engine schemes

The key objectives which each schemes of LV Engine will aim to demonstrate are listed in Table Appendix Table L-1:

Appendix Table L-1: Preliminary demonstration objectives of each LV Engine Scheme

Scheme	Preliminary demonstration objectives
Scheme 1	• Optimum LV phase voltage regulation • Optimum capacity sharing between a SST and a conventional transformer • Fault level control at SST • Modular design
Scheme 2	• Optimum LV phase voltage regulation Optimum capacity sharing between a SST and two conventional transformers • Fault level control at SST • Modular design
Scheme 3	• Optimum LV phase voltage regulation • Optimum capacity sharing among two SSTs and one conventional transformer • Fault level control at two SSTs • Modular design
Scheme 4	• Provision of DC to a customer with SST at 100% DC output • Design and protection of LVDC network • Safety requirements for LVDC network • Modular design
Scheme 5	• Provision of a hybrid LVDC and LV AC by SST • Design and protection of a hybrid LVDC/AC network • Safety requirements for LVDC network • Modular design

In order to demonstrate the aforementioned objectives, we will require installation sites which provide the opportunity by holding key characteristics. Appendix Table L-2 provides a summary of criteria, defining each of site requirements in order to demonstrate the SST benefits listed above.

Appendix Table L-2: Site Criteria

Criteria	Description
Site with Imbalanced Loads	To demonstrate the ability of an SST to regulate LV phase voltages, the site should have imbalanced loads across the phases.
Growing LCT Integration (PV, HP, EVs)	Growing LCT integration implies that the site has a potential to demonstrate the benefits of SST and DC supply which would offer better power transmission efficiently
Site with Daily Voltage Fluctuation	The chosen trials sites should demonstrate a large variation in network voltage due to a high uptake of LCTs (PV, EHP, EVs). This will allow the schemes to demonstrate the capability of an SST to regulate phase voltage adequately.
Smart Meter 2 Integration	Each scheme may benefit if the chosen sites include customers with SMETS2 meters so that voltage data can be used should it be available within the time scales of the project.
Maintenance Access	The site should have an access route to support any maintenance that will be required throughout the duration of the network trials.
Highly Loaded Transformer and capacity availability in neighbouring transformers	A highly loaded transformer will provide an opportunity to demonstrate the load sharing capability that SSTs can offer to alleviate congestion at peak loads.
Complementary Load Profile	The chosen trial sites would benefit if the neighbouring transformers have complementary load profiles or spare capacity available to allow the benefits of load sharing to be demonstrated adequately.
Available NOP	The chosen network sites will require Normally Open Points (NOP) within each feeder to allow capacity sharing between neighbouring transformers.
Available space alongside existing conventional transformer	There needs to be physical space available within the existing substations to allow an SST to be installed alongside the pre-existing transformer and to allow the switch over schemes to be installed.
GPRS Signal Scanning (Adequate Reception)	Depending on the comms approach taken the trial locations may require a strong adequate GPRS signal strength to allow network monitored data to be shared with the SSTs
Close Distance to DC Consumer	The chosen installation location for Schemes 4 & 5 should be as close as possible to the selected DC customer to reduce the requirement for extensive DC cabling. If possible we will look for opportunities to convert existing LVAC cable to DC.
Commercial Arrangement for DC Supply	The chosen trial sites for schemes 4 & 5 must include LVDC customer who can demonstrate the benefits of a DC supply. We will target EV charging points and LED street lighting.

L.2 Site criteria applied to proposed sites

Appendix Table L-3 highlights the desirable criteria which will apply to each of the schemes shown in Section 2. A detailed review of the site selection criteria for each scheme will be carried out within WP 1 to ensure the sites selected adequately demonstrate the functionalities of each SST being trialled.

Appendix Table L-4: SST Criteria Applied to Scheme

Criteria	Scheme 1	Scheme 2	Scheme 3	Scheme 4	Scheme 5
Phase Imbalanced Loading	✔	✔	✔		✔
Growing LCT Integration	✔	✔	✔	✔	✔
Daily voltage fluctuation	✔	✔	✔		✔
Smart Meter 2 Integration	✔	✔	✔		✔
Access for Maintenance	✔	✔	✔	✔	✔
Highly Loaded Transformer	✔	✔	✔		
Complementary Load Profile available	✔	✔	✔		
NOP available between neighbouring substations	✔	✔	✔		
Space available for parallel operation with existing transformer	✔	✔	✔	✔	✔
GPRS signal scanning - adequate reception	✔	✔	✔	✔	✔

L.3 Internal engagement with network planning and operation engineers

As a DNO, we would seek to engage with multiple teams and disciplines from across our business. There would be two key outcomes to this engagement;

- Identifying sites that can demonstrate the full functionalities of an SST.
- Explaining the benefits that SSTs can offer to resolving system issues

In order to achieve these outcomes, we intend to distribute a questionnaire which will set out a series of questions to help identify any sites where the full functionalities of an SST can be demonstrated. In addition, internal presentations will be held to raise awareness of the SST technology and its applications throughout the business.

Finally, we will use SP Energy Networks' geographical assets and customer database to identify substations which have a significant amount of LV LCT penetration (as this is where SSTs can raise efficiency).

L.4 External engagement to identify customers interested in DC supply

Through SP Energy Networks previous innovation work and business as usual practices, we have built up a significant network of external contacts. As we are embarking into a new area of innovation, we would seek to utilize these contacts to identify customers who would be interested in converting their current AC supply to a DC based system or a hybrid of the two. This process will reveal sites available to us for consideration. We will focus on **LED street lighting and rapid Electric Vehicle charging as a preference,** which could provide the biggest direct benefits to both consumers and DNO, by allowing the project to investigate the ability of LVDC to reduce consumer losses whilst also reducing network reinforcement by increasing cable transfer capacity. We have already identified some potential external stakeholders who have large DC consumption and are interested in developing smart energy solutions. These include:

- EV charging point suppliers and manufacturers
- Local councils with on-going EV charging point and street lighting developments
- Large car parks
- Shopping centres
- Data Centres

Appendix M Potential Trial Sites & Maps

Through investigation and discussion with our colleagues, we have identified several sites where SSTs could be applied with anticipated benefit. The site and potential benefits of introducing a SST into the area have been noted in each case.

M.1 Proposed Sites – Private Developments

During the duration of the development of this proposal we have been in close conversation with multiple private developments who are interested in a potential AC and/or DC supply from an SST during this innovation project. These conversations are ongoing and are dependent on the outcome of the funding request. Should LV Engine be awarded funding we will continue to engage with these third parties to select a trial site that can demonstrate the benefits of LVDC using an SST.

M.2 Proposed Sites – SP Energy Networks Network Trail Sites:

The following sites have been identified internally at SP Energy Networks which could be used to demonstrate the functionalities and benefits of each trial scheme. During work package 1 we will carry out a fresh review of potential trial sites to ensure sites are selected which maximise the learnings that come out of each trial scheme.

M.2.1 Wrexham – Heol Glyndwr Secondary (SPM)

This is a residential area which is saturated with PV. The site was investigated as part of the project Flexnets. The substation was deliberately overloaded with PV to demonstrate the ability of an on-load tap changer to regulate the voltage. However, the study did not go ahead and a tap changer was never installed. Consequently, the LV network is experiencing voltage spikes that are above the tolerance (260V+). Wrexham city council had originally approach SP Energy Networks and asked to install 3000 PV arrays in the area and have an ambitious sustainability / low carbon strategy for the area.

M.2.2 Milton Rd /Terrace, fed from Johnston Street S/S

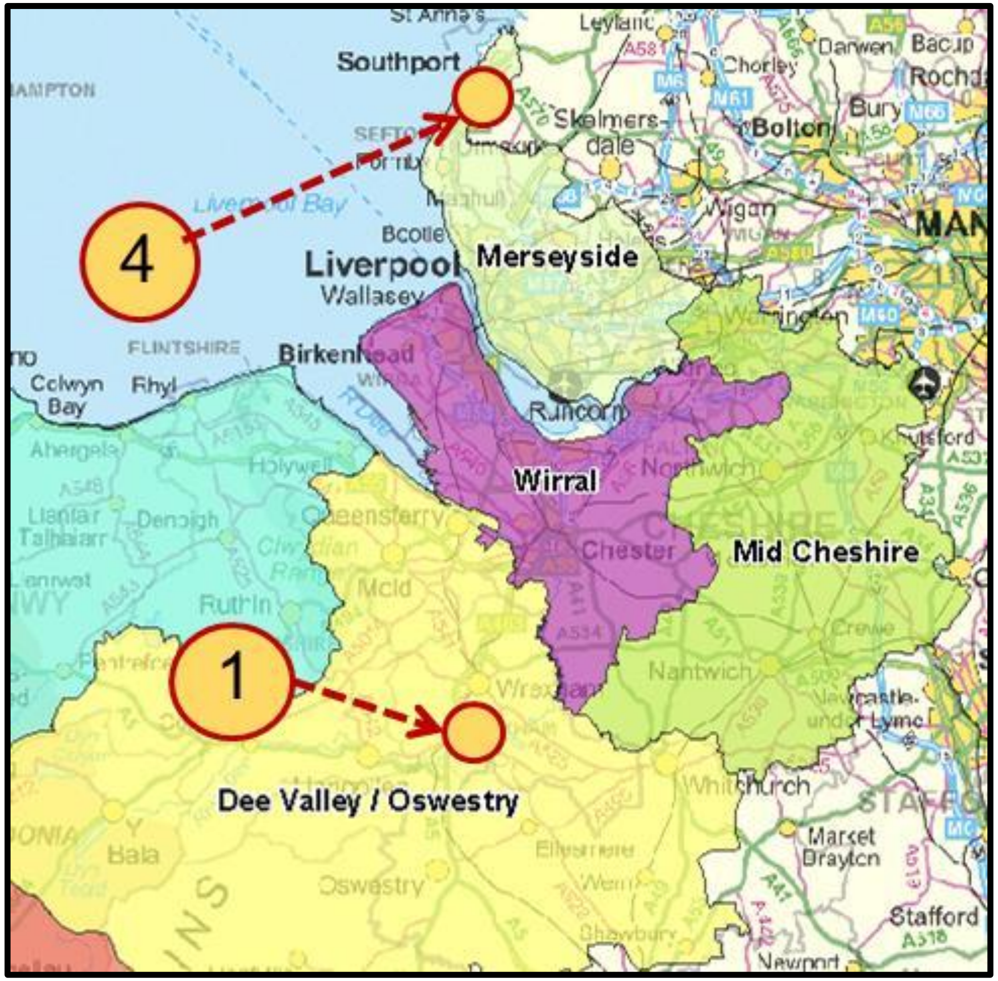
The voltage profile in the existing LV Network at Milton Rd /Terrace, fed from Johnston Street S/S, has existing issues, with voltage rises at the feeder exceeding the statutory limits. Due to the fact that the existing LV cables are through privately owned gardens and no way leaves are currently in place, the proposed solution is to install a new substation and overlay the LV cables.

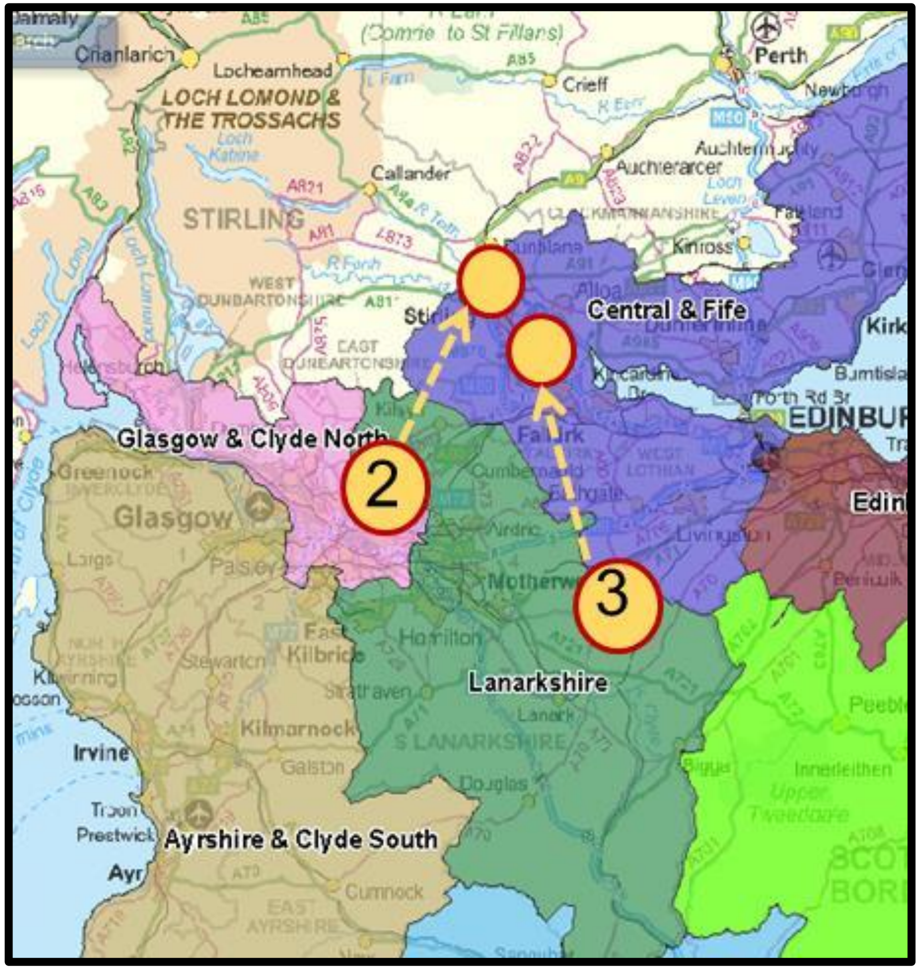
M.2.3 Cowie Housing

An area of social housing with a large uptake of PV which is experiencing voltage regulation issues and may require significant network reinforcement. It is likely that an intermediary solution will be required while infrastructure is being deployed to avoid equipment damage.

M.2.4 Southport Uprating / differential protection scheme (SPM)

At Southport there is a project to uprate the network from 6.6kV to 11kV. There is currently a fault level issue that could be improved if SSTs were installed in the area. The network in the area is being converted from X-type to Y–type network with a differential protection scheme to combat issues with high fault level in the area. This could potentially be a site to demonstrate load sharing between multiple substations whilst allowing the network area to be converted to y-type but maintaining network interconnection and flexibility.



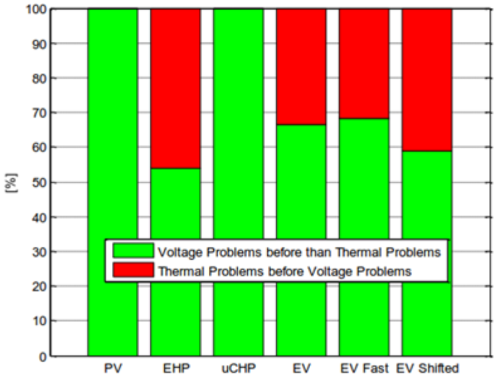


Appendix Figure M-1: Potential trial sites identified during proposal preparation

Appendix N A summary of UK Low Carbon Networks Fund Projects demonstrating LCT impacts on LV Networks

LV Network Voltage Solutions (ENW)

- Desktop study on existing feeders showed that over 60% of feeders with more than 25 customers experienced voltage issue due to PV uptake
- Customers may experience voltage outside statutory limit with 30% PV penetration
- The first occurrence of problems as penetration increases is driven by voltage issues in all the feeders examined. For the EHP and EV case, the first occurrence of problems is driven by voltage and also by thermal issues



My Electric Avenue (SSE)

- The peak demand for residential EV charging was found to coincide with the traditional evening peak, the After Diversity Maximum Demand (ADMD) observed in the Project for non-electrically heated households with a 3.5kW EV charger is approximately 2kW, double the conventional demand observed in the Project.
- Project demonstrates that 32% of UK LV feeders will require intervention to protect against thermal or voltage problems at EV penetration levels exceeding 40%.

Customer-Led network revolution (NPG)

- The measured peak value of PVs is often greater than the rated peak value
- Suggesting that a network designer may consider 0.25kW greater than its rated value
- Reasonable to assume that there will be at least one time during the year when the peak power generation for a group of PV panels is reached simultaneously

New Thames valley Vision (SSE)

- Probabilistic assessment carried out in I2EV highlights that technical problems in the LV networks may occur for EV penetrations larger than 30%.
- Reverse power flows are found in PV scenarios with a percentage penetration greater than a 25% uptake. As anticipated Summer has the worst impact on the network. On average over-voltages occur in scenarios with a PV uptake of 15% and above.
- Potential concentration of EVs and HPs closer to the end of the LV feeders could create significant voltage drop issues.

DS2030

- In the Urban based LV network the The 500kVA 6.1/0.433kV feeding transformer was found to be overloaded in 2034 by approximately 30% and for this reason the studies were repeated with a replacement 800kVA transformer to eliminate the overload

Appendix O Recent publications on SST

- L. Ferreira Costa, G. De Carne, G. Buticchi and M. Liserre, "The Smart Transformer: A solid-state transformer tailored to provide ancillary services to the distribution grid," in *IEEE Power Electronics Magazine*, vol. 4, no. 2, pp. 56-67, June 2017.

- G. De Carne, G. Buticchi, M. Liserre and C. Vournas, "Load control using sensitivity identification by means of smart transformer," *2017 IEEE Manchester PowerTech*, Manchester, United Kingdom, 2017.

- S. Bhattacharya, "Transforming the transformer," in *IEEE Spectrum*, vol. 54, no. 7, pp. 38-43, July 2017.

- Liang Wang, Donglai Zhang, Yi Wang and Huan Liu, "High-frequency solid-state transformer power conversion technologies for energy internet," *2017 IEEE 3rd International Future Energy Electronics Conference and ECCE Asia (IFEEC 2017 - ECCE Asia)*, Kaohsiung, Taiwan, 2017, pp. 1397-1401.

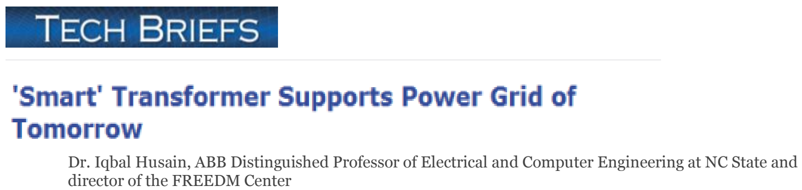
- A. Q. Huang, "Medium-Voltage Solid-State Transformer: Technology for a Smarter and Resilient Grid," in *IEEE Industrial Electronics Magazine*, vol. 10, no. 3, pp. 29-42, Sept. 2016.

- J. S. Lai, W. H. Lai, S. R. Moon, L. Zhang and A. Maitra, "A 15-kV class intelligent universal transformer for utility applications," *2016 IEEE Applied Power Electronics Conference and Exposition (APEC)*, Long Beach, CA, 2016, pp. 1974-1981.

- A. Afiat Milani; M. T. A. Khan; A. Chakrabortty; I. Husain, "Equilibrium Point Analysis and Power Sharing Methods for Distribution Systems Driven by Solid-State Transformers," in *IEEE Transactions on Power Systems* , 2017.

- J. E. Huber and J. W. Kolar, "Solid-State Transformers: On the Origins and Evolution of Key Concepts," in *IEEE Industrial Electronics Magazine*, vol. 10, no. 3, pp. 19-28, Sept. 2016.

- J. Ramos-Ruiz, H. Krishnamoorthy and P. Enjeti, "Adding capacity to an existing electric power distribution network using a solid state transformer system," *2015 IEEE Energy Conversion Congress and Exposition (ECCE)*, Montreal, QC, 2015, pp. 6059-6066.



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Appendix P Step changes in global LCT uptake driven by policy makers and car manufacturers

FINANCIAL TIMES

Diesel engines + Add to myFT

UK plans to ban sale of new petrol and diesel cars by 2040

Michael Gove prepares to follow lead set by France two weeks ago

theguardian

Household batteries will be key to UK's new energy strategy

UK to pioneer energy innovation through batteries in homes as energy department announces £246m research funding

SSTs will act as an enabler of DC technologies including household battery storage

electrek

JULY 4

Electric cars reach record 42% of Norway's total new car sales with boost from Tesla Model X

Fred Lambert - Jul. 4th 2017 7:34 am ET @FredericLambert

SOLAR POWER PORTAL

Consumers could drive UK solar capacity as high as 44GW by 2050: National Grid

CNN tech BUSINESS CULTURE GADGETS FUTURE STARTUPS

Future Tense

India to sell only electric cars by 2030

by Jackie Wattles @jackiewattles

June 3, 2017: 5:22 PM ET

theguardian

Black cab turns green as all-new electric London taxi launches

Cab maker ditches diesel to produce a petrol and electric-powered taxi that will be rolled out in November

BBC NEWS

France is set to ban the sale of any car that uses petrol or diesel fuel by 2040, in what the ecology minister called a "revolution".

Nicolas Hulot announced the planned ban on fossil fuel vehicles as part of a renewed commitment to the Paris climate deal.

He said France planned to become carbon neutral by 2050.

Appendix Q Expression of Interest

SP ENERGY NETWORKS

Request for expression of interest in collaboration in SPEN Network Innovation Competition project

1. Introduction

SP Energy Networks are planning to submit a proposal to the **2017 Networks Innovation Competition (NIC)** held by Ofgem. As part of the process we are seeking to identify possible project partners who can support the design and manufacture a fit for purpose **Solid State Transformer (SST)** whose high level functional specifications are set out within this document.

At this stage we are looking for an expression of interest only from manufacturers and academic bodies in response to this document who feel they can contribute towards this project. A response form is included at the end of this document which shall be returned to Anthony Donoghue at adonoghue@spenergynetworks.co.uk by 28th April 2017. We will consider those who can contribute towards all or elements of the requirements described within this document.

The initial project proposal was submitted to Ofgem for comments on the 4th April 2017 and a full proposal is due by the end of July 2017. A full competitive tender process will be carried out to identify the project partner(s) should the proposal receive final approval from Ofgem towards the end of 2017.

2. NIC Proposal Overview

The project intends to trial a number of **500kVA SSTs** within our distribution network at the **11kV/400V level** to enable the increasing uptake of low carbon technologies (LCTs) whilst alleviating the resulting strain that is put onto the LV network. This will enhance the flexibility of the LV network of the future and defer costly network reinforcement that would otherwise be required. Please see the accompanying ISP proposal for more details on the project and its proposed scope.

We are considering **two SST designs** (as below) which are both capable of providing an LV DC supply. Both design options will be included as part of a live network trail under multiple applications.

1) Primary: 11kV AC and Secondary: 400V AC (250kVA) & LV DC (250kVA)
2) Primary: 11kV AC and Secondary: LV DC

We are now in the process of shortlisting the potential trial sites, which we will continue to investigate before the trial sites are finalised and agreed. However, the SSTs that are developed will be trialled within LV networks which may have some of the following characteristics:

- A high uptake of multiple forms of LCTs (Photovoltaics, Electric Vehicles, Battery Storage etc)
- Voltage regulation issues.
- Reverse power flows.
- Large industrial customers with LV DC supply requirements i.e. Data Centres etc.

Prior to a live network trial the SST units will be tested at the Power Networks Demonstration Centre (PNDC) in Cumbernauld to de-risk the technology. This test intends to ensure the design of the SST(s) is fit-for-purpose for network applications and does not have an adverse impact on our customer's

SP ENERGY NETWORKS

security of supply. The maximum timescale for the entire project including design, manufacturing, installation, performance assessment and knowledge dissemination is around five years.

3. Partner Financial Contribution

As part of the NIC governance the project consortium must cover at least 10% of the project costs upfront. This is due to the R&D nature of the innovation competition. The remaining 90% of the funding required by the project will be provided through the NIC funding mechanism should the project be approved by Ofgem. The 10% contribution from each major partner must be in the form of a transfer of cash into the project bank account at the beginning of the project. To this end, SPEN are looking for any major project partner to individually contribute 10% of their associated costs upfront alongside any other additional resources the partner should wish to contribute.

Contrastingly, project suppliers may act as consultants to provide valuable expertise to the project i.e. universities or research institutes. However, there is an expectation that such entities may provide discounted resources should they wish to be viewed as a partner.

One of the key objectives of this project is to open up a new market place for SSTs within distribution networks across the United Kingdom. Consequently, any project partners that are capable of contributing towards this project will place themselves at the forefront of this emerging industry by developing a product that has been technically and commercially proven as part of a cutting edge network trial.

4. IPR Requirements

Each project partner must agree to the standard IPR agreement set out in Ofgem's NIC Governance document. A copy of the document can be found at:

https://www.ofgem.gov.uk/network-regulation-riio-model/network-innovation/electricity-network-innovation-competition

5. SST Functional Requirements

The following capabilities must be built into the design of the SSTs as far as possible to allow the project to build a positive and competitive business case:

- Control of transferred real power (provides network controllability).
- Allow bi-directional power transfer.
- Independent control of reactive power at each end (decouples the voltage at each end).
- Fine-grained control of voltage and power factor (these can be set to improve voltage profiles and network losses).
- Mitigation of voltage dips/sags and swells (as per STATCOM).
- Mitigation of existing harmonic distortion to improve power quality.
- Balancing of power and voltage between phases, depending on SST topology and controls.
- Fault current management.
- Potential to use SSTs as "circuit breakers" to interrupt fault currents.

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SP ENERGY NETWORKS

- Provision of a DC link for:
    1) Direct DC connection of LCTs.
    2) DC supply to large industrial customers.
    3) DC supply for mass EV charging.
- A modular design that allows the capacity of the SST to be increased by plugging in an additional "capacity bank".

6. Technical Requirements

As well as delivering the functionality listed above, the SSTs must be technically fit-for-purpose and suitable for inclusion in a live trial within our distribution network. Some of the key design constraints that must be considered are described below.

6.1. Transformer Losses

We intend to develop an SST that can satisfy European legislation on the maximum load and no load losses allowed across a dry type distribution transformer. This is considered as the losses across the high/medium frequency transformer within an SST and not the losses due to the power electronics switching.

As set out within "commission regulation (EU) 548/2014" the maximum load and no-load losses for a three-phase dry-type medium power transformer can be seen in the Table 5.1 below.

Table 5.1: *Maximum losses for a three-phase dry type medium power transformer*

	Tier 1 (1 July 2015)		Tier 2 (1 July 2021)	
Rated Power (kVA)	Maximum Load Losses (W)	Maximum No-Load Losses (W)	Maximum Load Losses (W)	Maximum No-Load Losses (W)
400	5500	750	4500	675
630	7600	1100	7100	990
800	8000	1300	8000	1170

Note: The maximum allowable losses for kVA ratings that fall in between the ratings given above shall be obtained by linear interpolation.

6.2. Noise Requirements

The SSTs that are designed must produce a maximum audible noise of no more than 59dB. This may be achieved by increasing the power electronics switching frequency or deploying a sound proof enclosure, or any other suitable method.

6.3. Substation Footprint

For the new SSTs described above we hope to achieve a maximum substation footprint of 2.5m x 2.5m x 2.5m. This must include all necessary switchgear, LV cabinets, cooling etc.

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However, we hope to realise a significant reduction in the footprint of a traditional secondary substation so a reduction in this figure would be desirable.

6.4. Additional Project Design Considerations

SST Protection - The units must include a suitable protection arrangement that is capable of clearing LV faults within an acceptable timeframe. We will consider any innovative solutions to this challenge.

DC Earthing – A suitable DC earthing arrangement must be designed to enable a DC supply to be provided to customers safely.

SST Monitoring – The SST(s) must incorporate adequate monitoring which captures the key performance indicators i.e. temperature, three phase current & voltage, harmonics etc. and presents the data in such a way that it can be communicated using conventional protocols and media.

7. Response Form

Please include details to address the requirements set out within this document in the response form in Appendix A. Please feel free to adapt the size of the response boxes to suit and include any additional information that you feel may add value.

Please send your response to:

Anthony Donoghue

email: adonoghue@spenergynetworks.co.uk
Telephone: +441416146904

Appendix A – Expression of Interest Response Form

Company Name:
Point of contact:
Contact phone number:
Contact Email Address:
Company Address:

Technical Scope and Innovation Strategies	Response
Note: Based on the requirements set out within this document and the accompanying attachments, please list all the solutions already available and/or the innovation strategies that could be developed within the time scale of this innovation project (Jan 2018 – Dec 2022) 1. Degree of compliance with our scope of work. 2. Deliverability within the time scale. 3. Flexibility to adapt solutions to the project's requirements. 4. Details on any SST testing facilities available both in country and abroad.	
Full Proposal Preparation	**Response**
Note: Description of the kind of technical support that can be offered to SPEN innovation team during the full proposal preparation stage (April 2017 – Oct 2017) The services may include (but not limited) contributions to: • SST manufacturing cost estimation • Developing SST high level technical specification • Cost benefit analysis • Proposing innovative solutions for improving efficiency and performance of SST for grid applications • Proposing innovative solutions for a cost effective design of SST for grid applications • Identifying risks in manufacturing and installations of SST	
Partner Contribution	**Response**
Please advise the percentage of the costs that the partner wishes to contribute to the project. For consultancy and academic entities please include types (resources, material etc) of non-monetary contributions.	

Resource Availability	Response
Note: Please discuss the availability of resources within your company to support this project throughout its deployment stage. SPEN will require you to identify 1. Project Manager 2. Technical lead(s) The project manager will be our point of contact throughout the proposal development and deployment. Please provide a project organisation chart, the company's technical capabilities and CVs of any named individuals	
Multiple-Partnership	**Response**
Note: Please comment on your willingness to partner with other SMEs and competitors as a part of this project. 1. Working with other SMEs and competitors as an integral part of this project. 2. Examples of successful delivery of multi-vendor solutions. 3. Proven record to deliver Innovation Projects. Provide references if required.	
Knowledge Dissemination	**Response**
Note: As a part of this innovation project you shall be expected to share your findings with other stakeholders. Please state your degree of compliance regarding the same. Please see the NIC Governance document for more details on IPR requirements. https://www.ofgem.gov.uk/network-regulation-riio-model/network-innovation/electricity-network-innovation-competition	
Additional Information	**Response**
Note: Please include any additional information that you feel may be relevant and has not been discussed above and any deviation to the requirements detailed in this document	

Appendix R Letters of Support

LV Engine is supported by and will work closely with a range of industry bodies and organisations across multiple industries to ensure the project considers the requirements of all stakeholders and builds upon the latest learnings available. Below is an extract of a selection of the letters of support we have received during the course of preparing this proposal:

UK Power Networks: *"This letter sets out UK Power Networks commitment to support SP Energy Networks 2017 NIC project LV Engine … We support the objectives of LV Engine and believe the project complements our 2017 NIC proposal Active Response…We believe that deployment Solid State Transformer within secondary substations can deliver much needed functionalities to 11kV and LV networks…"*

Glasgow City Council: *"…We are in support of LV Engine's objectives of enabling a higher penetration of LCTs…To this end we are supportive of a potential trial of a Solid State Transformer at Duke Street Car Park alongside our pre-exiting plans to install 200kW PV and fast Electric Vehicle charging points…"*

International Electrotehnical Commission (IEC): *"...LV Engine with the trial of LVDC as shown in your "Scheme 4 & 5" in real fields aligns perfectly with the IEC LVDC SyC focus, and the learning and outcomes of the LVDC deployment will definitely provide an important source to inform LVDC standards development. We will work closely with the IEC UK National Committee LVDC members to ensure the best use of your experience from the [V Engine for future LVDC standards development..."*

Institution of Engineering and Technology (IET): *"...LVDC distribution systems are considered a key option for better use of energy and management, and improved exploitation of renewable and distributed energy resources. IET has already recognised the potential LVDC benefits and has prepared and published a new Code of Practice on LVDC power distribution. We strongly believe this effort will be complemented by "LV Engine objectives which provides a LVDC supply..."*

British Standards Institution (BSI): "...*BSI is interested in this project which present the first DNO-led project on LVDC as the findings therein would support the development of a new standard for supporting LVDC in public networks. We would expect the LVDC field trials to provide a firm understanding for a UK position in IEC SyC LVDC. This can be both valuable in terms of maintaining fit-for-purpose standards, but also for ensuring the UK maintain a position of strategic importance within the international community, i.e. the UK is leading research into new areas for the benefit of the LVDC industry. We are pleased to be partners on this project and commend it for consideration..."*

PowerelectronicsUK: *"As the main industry association in Power Electronics with over 70 members we intend to work with you to promote the project and share learnings with the industry on the outcome. This will help to ignite a new market place for power electronics within distribution networks..."*

University of Kiel: *"…The Chair of Power Electronics finds the LV Engine project interesting and well focused. It is particularly relevant the design of Smart Transformer with stages of different power to supply both DC and AC grids and different trial schemes showing the different possible system level optimization of the Smart Transformer…The Chair has already collected 8 million Euros for many projects focused on smart transformer…"*

ETH Zurich: *"…having discussed the proposal with you in detail we see the value that the project could bring by elevating the TRL of SSTs for deployment within distribution networks…ETH Zurich is conducting research on SSTs for more than 8 years…it is the right time to carry out a trial of SSTs for grid applications…We believe the functionality that will be demonstrated by LV Engine to be both technically feasible and deliverable within the timescale of the project…"*

University of Strathclyde: *"We support the objectives of the project and see particular value in the learnings and innovations which will arise from the LVDC network trial using Solid State Transformers...From our research and active international engagement in this topic we believe it is very timely to carry out an innovation project to trial an LVDC supply from a Distribution Network Operator in order to see the considerable benefits afforded to network licensees and electricity consumers..."*

Power Networks Demonstration Centre (PNDC): *"…the PNDC is in support of the objectives set out within the proposal for LV Engine…PNDC will help shape the test environment… experience and test network capability will de-risk the LV Engine project and ensure the outcomes are positioned for success…"*

Building Research Establishment (BRE): *"...BRE are particularly interested in the principle of enabling greater penetration of Low Carbon Technologies (LCTs) into the existing LV network as well as the potential provision of low voltage DC supply to electricity customers. To this end BRE is delighted to support the proposal and our potential future involvement..."*

Direct Current BV: *"...We see a great future for DC, and strongly believe projects such as "LV Engine" with field trials of LVDC will accelerate the wider adoption of LVDC, particularly in street lighting and EV charging. Therefore, we look forward to working with you on this innovative project..."*

Franklin Energy: *"...Franklin Energy is excited to support the LV Engine and SP Energy Networks to help identify trial sites for LVDC supply for EV charging, battery storage and PV optimisation. We believe that a DC supply could help by reducing the costs of DC rapid chargers (£15,000 each), help with the uptake of V2G and help with domestic battery and PV installations..."*

Chargemaster: *"...We have long-term relationships in place with all the major EV manufacturers and operate the largest EV charging network in the UK, with over 4000 charge points and over 8000 paying subscribers. As such we have first-hand experience of network constraints in terms of capacity. Innovative potential solutions such as LVDC are of interest ... We are in an ideal position to help SP Energy Networks identify and manage appropriate trial sites for this project..."*

WSP: *"…WSP has noted the considerable level of interest in SST technologies from both large and small to medium sized enterprises (SME) who are working in this area…WSP strongly supports the proposal from SP Energy Networks to develop and deploy SST units on its distribution network. If successful, this initiative will pave the way for further up-take of power electronic solutions to support the changing nature of the loads and generators…"*

ofgem

Appendix S Glossary of Terms

Acronym	Definition
ADMD	After Diversity Maximum Demand
AC	Alternate Current
BaU	Business as Usual
DC	Direct Current
DG	Distributed Generation
DNO	Distribution Network Operator
DSO	Distribution System Operator
EVs	Electric Vehicles
EOI	Expressions of Interest
GB	Great Britain
IET	Institute of Engineering
IGBT	Insulated Gate Bipolar Transistor
CIGRE	International Council on Large Electric Systems
KPIs	Key Performance Indicators
LCTs	Low Carbon Technologies
LFT	Low Frequency Transformer
LV	Low Voltage
MV	Medium Voltage
MMC	Modular Multilevel Convertors
NOP	Normally Open Point
OLTC	On Load Tap Changers
PM	Project Manager
RAG	Red, Amber, Green
RES	Renewable Energy Sources
RAID	Risks, Assumptions, Issues, and Dependencies
SPD	ScottishPower Distribution
SPEN	ScottishPower Energy Networks
SPM	ScottishPower ManWeb
SST	Solid State Transformer
STATCOM	Static Synchronous Compensator
TRL	Technology Readiness Level
UKPN	UK Power Networks
VSC	Voltage Source Convertor
WP	Work Package