SP ENERGY NETWORKS

LV ENGINE

Project Progress Report

Work carried out during 2020

About Report

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Report Progress

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Contents

1 Executive Summary

1.1 Background

SP Energy Networks, in collaboration with UKPN, submitted the proposal for LV Engine under the Network Innovation Competition (NIC) mechanism in 2017. WSP, University of Strathclyde, and University of Kiel have also provided technical support for the proposal preparation. Ofgem approved the proposal and issued the Project Direction on the 16th of January 2018.The project commenced in January 2018 and is due to conclude in December 2022.

The LV Engine innovation project intends to trial Smart Transformers (ST) within secondary substations as the central point of an active and intelligent 11kV and LV distribution network. The ST trialled during the project will bring together sophisticated power electronic hardware with intelligent network monitoring and control to maximise the performance and efficiency of the distribution network.

This is the third in the series of annual progress reports for the LV ENGINE project, covering the project reporting period January 2020 to January 2021, the “reporting period”.

1.2 LV Engine overview

A ST consists of a Solid-State Transformer (SST) and a Smart Control System (SCS). SST uses power electronic technologies to deliver several functionalities, SCS, however, provides the control set points to SST based on data gathered and analysed from different monitored points in the network. LV Engine aims to demonstrate the following Core Functionalities can be delivered by deploying SST at secondary substations:

- Voltage regulation at LV Networks;
- Capacity sharing with other substations;
- Cancelation of LV imbalance load seen by the HV network;
- Reactive power compensation and power factor correction at secondary substations;
- Provision of LV DC to supply rapid and ultra-rapid EV chargers.

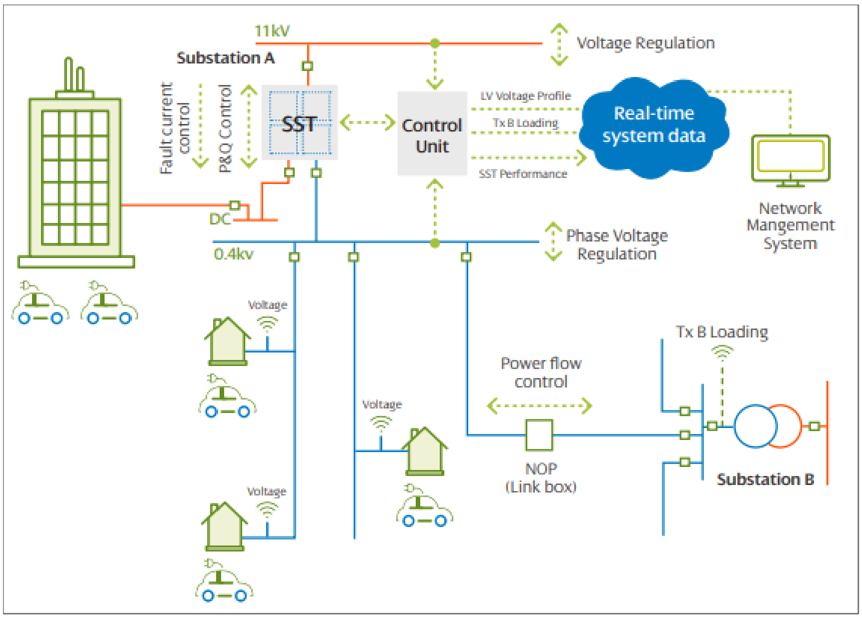

Figure 1 LV Engine project concept

LV Engine power electronics products

As the focus of the LV Engine project is to demonstrate the performance of the Core Functionalities required by the network, different SST innovative topologies may provide these Core Functionalities in an efficient and reliable manner at secondary substation. There are different possible SST topologies which have been considered as products of LV Engine:

- ***Topology 1*** - *Topology using a conventional low frequency 50Hz (LF) transformer* –This topology uses power electronics devices at the secondary side of conventional LF transformers (11kV/0.4kV). The power electronic devices can be added to the existing distribution transformers to deliver the Core Functionalities of LV Engine. The aim is to enhance Technology Readiness Level (TRL) of this product from 6 to 9.

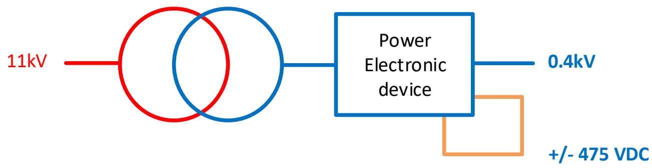

Figure 2 SST Topology 1

- ***Topology 2*** - *Topology using a High Frequency (HF) transformers* – Using HF Transformers and power electronics may allow a modular and compact design while delivering the LV Engine Core Functionalities. SPEN recognises that this topology may require a larger effort for design and manufacturing compared to the approach of retrofitting an LF transformer with power electronics. The aim is to enhance TRL of this product from 5 to 8.

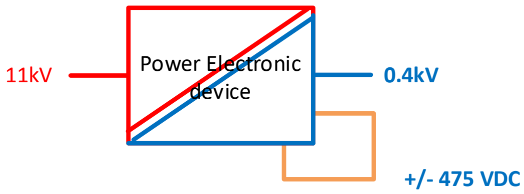

Figure 3 SST Topology 2

1.3 Project Highlights

The project highlights in this reporting period are as follows:

- **SST Design** – Following a competitive tender conducted in 2019, ERMCO-Gridbridge (EGB) was appointed as LV Engine SST manufacturing partner in November 2019. After staff mobilisation, EGB commenced the design process for both SST Topologies in early Q1 2020. The design process was initiated through the Project Inception phase, where regular detailed discussions with the SPEN team were held to translate each of the technical/functional requirements specified within the Smart Transformer Technical Specifications1 (LV Engine's Deliverable #1) to an element of the electrical, control and mechanical design.

1 https://www.spenergynetworks.co.uk/userfiles/file/LV_Engine_Deliverable1_Smart_Transformer_Technical_Specification_REDACTED.pdf

- SST Topology 1 – Detailed electrical and mechanical designed have been developed and agreed with SPEN. Different components of the design have been ordered. The majority of key components will be delivered in Q4 2020. The benchtop testing and prototyping will be the main activity in Q1 2021.
- SST Topology 2 – Detailed electrical deign and optioneering for different topologies were carried out. Extensive engagements with academic and semiconductor suppliers provided promising solutions to some of the challenges identified for development.

The SST detailed design report has been submitted to Ofgem as part of LV Engine Deliverable #2.

- **Control System Project Partner** – The Intelligent Control System project partner has been appointed. In order to ensure the best value to customer for future roll outs of controllable devices (such as LV Engine), a collaboration arrangement between Angle-DC and LV Engine have been set up to develop a holistic control system for distribution networks. The intention is to integrate the functionalities required in the two projects, identify the overlaps especially in control algorithms and develop a holistic central control system.

- **Trial sites for LVAC schemes ready for commissioning** – Progress made as planned on detailed design work for Wrexham trial sites where the aim is to demonstrate the AC functionalities of LV Engine. Several desktop studies demonstrating performance of the LV Engine schemes and the protection strategy were carried out to inform the design. Electrical design and layouts of the substation are now also completed.

- **Trial sites for LVDC schemes ready for commissioning –** The project has commissioned the design of civil and structural design work associated with the substation. Following the sign off the connection agreement, the physical plant details was finalised. The majority of electrical design have been concluded. The wayleaves for HV cable installation have been granted and acquiring legal rights required to maintain and operate the plant is in progress.

- **LV Automation –** The project has decided to appoint an LV automation supplier through a tender process, developing a fit for purpose scope for LV automation equipment and services, including engineering services required by the vendor. The tender documents were submitted in Q4 2020, with the evaluation process ongoing.

- **Project Dissemination –** The learnings of the project and its objectives have continued to be widely disseminated through ENIC, international conferences, peer-reviewed journals and a webinar in collaboration with Power Electronics UK and CSA Catapult.

1.4 Project Issues

We have encountered the following project issues in this reporting period, nonetheless there is no Material Change to be reported at this stage:

- Covid-19 Pandemic – The risk of pandemic and its impact worldwide was not expected during LV Engine programme development. The recent pandemic has introduced a number of issues to the project, nonetheless, we have been working to find alternative solutions and reduce the impacts where possible. The issues and the solutions are as follows:
  - Supply chain – The lead times for procuring some of the components have been longer than initially expected. In some cases, the suppliers temporarily suspended

all or part of the orders due to shortage of raw materials. That especially became an issue for the components required for manufacturing SSTs. EGB have reported several of the issues, however, they actively sought to change to suppliers with larger stock availability and also ordered materials/components more than the volume needed for LV Engine to make the order more attractive to the suppliers.

Business priority – LV Engine relies heavily on SPEN's design, operation and delivery staff whose core responsibility is to ensure the continuity and quality of the electricity supply to our customers. Electricity network is a critical infrastructure, new working arrangements needed to be in place to ensure health and availability of personnel. For example, site activities were prioritised or some of the staff had to participate as backup in critical operation activities. LV Engine team needed to adapt the working arrangement accordingly and delay some of the site works, site visits and face-to-face activities.

- Delay in SST Topology 2 design – We encountered some challenges in developing SST Topology 2, especially for the design of power electronic modules interfacing the HV network. 1.2kV Sic modules, which are commercially available in the market, were initially considered for manufacturing the HV stage of SST Topology 2. However, after several design optioneering and thermal studies, it appeared that size and reliability of the SST may not be realistic/acceptable for grid application in the secondary substations. Following these findings, EGB team carried out extensive fresh market engagement and it appeared that we can rely on 2.0kV Sic modules which will be commercially available in Q1 2021 with the early product release can be used by EGB team in late Q4 2020. Deploying the 2.0kV Sic modules can significantly reduce the size and design complexity of the SST Topology 2. This change in strategy to achieve a better product has delayed the completion of SST Topology 2 design for around four months compared to the initial plan which was scheduled for completion by end of 2020. EGB has now validated the thermal behaviour of the 2.0kV units and we are certain that we can go ahead with this product.

1.5 Key lessons learnt

- Problems with heat and condensation can occur in some controllable link box switch designs. This was found during previous NIC projects, but technical details were not reported in their dissemination reports. This is an on-going problem leading to plans by one manufacturer to completely re-engineer their controllable link box switch design. These re-designed controllable link box switches will not be ready within the LV Engine project timescales.

- The UPFC[1] design is preferable over the back to back (AC/DC/AC) design for SST Topology 1 solution. As the UPFC design offers a more efficient, smaller footprint, more reliable and less expensive solution than the back to back design. In addition, UPFC does not limit the fault current to the LV network whereas back to back arrangement does have this limitation;

- The voltage at SST LV terminal should remain stable in the event of sudden change in demand to ensure the quality of supply to the customers is not affected. For that reason, SST control strategy in response to active (P) and reactive power (Q) setpoints is to revert to voltage control mode after achieving the setpoint. In another words, SST will not lock to the P&Q set points after achieving them but will lock to the resultant voltage after achieving P&Q set points;

[1] Unified Power Flow Control

- The services expected from SST (e.g. voltage control, imbalance cancelation, power factor correction etc) at full rating may not be required at the same time. Designing SST for provision of all services concurrently at full rating leads to unnecessarily overdesigning the product. Instead, priority of services can be considered so that some of the services may gracefully be degraded if SST reaches its thermal ratings;
- DNO LVAC switchboards used in GB secondary substations are typically based on ENA TS 37-2 (PENDA[1]) which in turn references IEC 61439-5 (PENDA). These specifications and standards are not currently applicable to DC switchboards. LVDC switchboard manufacturers are currently quoting us switchboard designs based on IEC 61439-2 which is the standard in common use in the industrial and commercial standard. We are developing our own technical specification which will reference and be in-line with IEC 61439-2. However, if there is to be a nationwide rollout of LVDC switchboards, then it might be better to revise ENA TS 37-2 and IEC 61439-5 so that they are applicable for DC applications.
- One of the safety requirements identified for the application of Voltage Regulating Distribution Transformer (VRDT) at the secondary substation is to avoid any tapping (automatic or manual) when operation staff are conducting any switching operation. This can be allowed by isolating the power supply to the local control unit.
- Safety documents for operation and installation of the SST and LVDC should be completed, approved and understood by operation and delivery staff before commissioning day. Due to the very innovative nature of this project, relevant operation and delivery staff should be involved in safety documents' development.

1.6 Summary of key activity in next reporting period

In the next reporting period, the project's critical path will be:

- Completion of manufacturing and factory acceptance test of SST Topology 1;
- Completion of design and manufacturing SST Topology 2;
- Installation and commissioning the DC site at Falkirk Stadium;
- Progress on installation and commissioning trial sites in Wrexham
- Development of safety documents, operation and manual documents and delivery of relevant training prior to any commissioning.
- Submission of LV Engine Deliverable #3 and #4
- Delivery of strong dissemination in various forms

[1] Public Electricity Network Distribution Assemblies

2 Project Manager's Report

This section provides an overview on the project progress made in this reporting period (16th January 2020 – 16th January 2021)

2.1 Project Progress

The project's Work Packages were progressed well during this reporting period. The key project highlight is the completion of the SST Topology 1 design with all the components ordered and ready to start the benchtop testing stage. In summary, the following progress was made in each Work Package:

Work package 2 (Project Partner Selection & Procurement):

- The intelligent Control System has been appointed. In order to ensure the best value to customer for future roll outs of controllable devices (such as LV Engine), a collaboration arrangement between Angle-DC and LV Engine has been set up to develop a holistic control system for distribution networks. The intention is to integrate the functionalities required in the two projects, identify the overlaps especially in control algorithms and develop a holistic central control system.
- Following the market research and development of LV automation technical specification, the procurement process started and progressed in 2020. It is expected that the procurement and project award will be concluded in early Q1 2021.
- Extensive market research and manufacturer engagement were carried out to evaluate the existing product and the market status for LVDC switchgears. LV Engine strategy has been to adapt the off-the-shelf products with no or little alternation/enhancement requirements.

Work package 3 (Design and manufacturing SST):

- After appointment of the SST Manufacturing Partner, ERMCO-GridBridge (EGB), in Nov 2019 the design of power electronic devices started in early 2020 and developed as the main activity during 2020. The design of two SST Topologies has progressed as planned:
    - SST Topology 1 – Detailed electrical and mechanical design has been developed and agreed with SPEN. Different components of the design have been ordered and are were delivered in Q4 2020. The benchtop testing and prototyping will be the main activity in Q1 2021.
    - SST Topology 2 – Detailed electrical deign and optioneering for different topologies were carried out. Extensive engagements with academic and semiconductor suppliers provided promising solutions to some of the challenges identified for development.

  The SST detailed design report has been submitted to Ofgem as part of LV Engine deliverable #2.
- Kiel university conducted desktop studies on the performance of the SST during the fault and provide academic recommendations if there would be any other alternatives to oversizing SST Topology 2 which can be considered in LV Engine design.
- LV Engine control philosophy development has progressed with our Control System Project Partner, Nortech. A report demonstrating different objective functions and algorithms that may be used for delivering LV Engine core functionalities. A report covering the control philosophy is currently being drafted with the plan to be finalised by end of Jan 2021.
- A Life Cycle Assessment (LCA) was conducted on the basis of the detailed technical design of the SST. The study focused on the LCA for the SST Topology 1 and compared it to a conventional ground mounted, oil-filled transformer following the ISO14040[1] standard framework and methodology. The LCA report has been submitted to Ofgem as part of LV Engine deliverable #2.

- The activities for benchtop testing and prototyping SST Topology 1 have just recently started following delivery of the SST components (semiconductors, magnetics etc) to EGB.
- The plan for Factory Acceptance Tests and developing specification for the test rig which needs to be set up in EGB facilities in Raleigh and Dyersburg have started in Q4 2020.

Work package 4 (Network Integration Testing):

- An initial document detailing the network integration testing specifications and test procedure developed, however this will be updated in 2021 after finalising the Factory Acceptance Tests procedure with EGB.
- Conducted market research to identify suitable network integration facility to deliver Work Package 4.

Work Package 5 (Live Network Trial):

- The detailed design work for Wrexham trial sites progressed where we aim to demonstrate the AC functionalities of LV Engine:
    - Conducted load flow studies to identify any thermal stress on the network assets and non-compliant voltage condition under different operation scenario;
    - Conducted fault level and protection grading studies to provide settings for the LV circuit breaker which will be deployed in this project;
    - Developed substation layout designs and interfaces between different plant in the substation;
    - Engaged with Wrexham Council for project dissemination and also explored opportunities for adding the LV DC trial to the Wrexham sites;
    - Continued data analysis on the smart meter data and monitored data collected at the secondary substations;
    - Conducted planning exercises with the delivery team for site preparation and commissioning next year.
- The detailed design and stakeholder engagement for Falkirk trial site has progressed. The focus in this site is to demonstrate the LV DC application. The following progress was made:
    - Connection agreement with the Falkirk Council for provision of LVDC supply has been signed off;
    - The wayleaves for installation of 11KV connection to LV Engine substation have been granted;
    - The lease agreement document for the LV Engine substation has been prepared and is now under review;
    - Initial substation layout design (electrical and civil) and the enclosure requirements have been developed;
    - Earthing studies including site measurements were conducted;
    - A multi-party none-disclosure agreement was signed off by project partners (SPEN, Falkirk Council, EGB and Tritium). Regular technical discussions with each partner to detail out all the requirements for the LVDC supply and interface with DC EV charger were carried out.
    - Initial LVDC protection strategy has been developed and agreed among SPEN, EGB and Tritium. A scope of work was developed for a detailed protection study that demonstrates the feasibility of the protection strategy and provides recommendation on protection settings. Appointment of the consultant is in process.

Work package 6 (Development of novel approach and BaU integration):

- Safety procedures development and documentations started in Q2 2020. This includes the Power System Safety Instructions (PSSIs) and Management Safety Procedures (MSPs) for LVDC and SST operations.
- The impacted design and operation policies were identified with relevant sections should be updated to account for functionalities delivered by LV Engine solution.
- Trial of distribution transformers with on-load tap changer fitted have progressed:
  - Three sites have been selected for OLTC demonstration;
  - One site has been commissioned in Dec 2020 and the field data is now being collected;
  - A commissioning document that covers all the existing safety requirements was developed for the OLTC control system
- An initial report for SST modelling methodology in DIgSILENT was developed. This methodology will be further updated to include the manufacturing and field experience.

Work Package 7 (Dissemination and Knowledge sharing):

- The project has continued to go beyond its obligation for dissemination and knowledge sharing by sharing the project learning through a series of external presentations and published articles, material development and conference attendance.

The following sub sections provide more details on the work carried out in each key activity.

2.1.1 Work Package 2 – Partner Selection

2.1.1.1 Intelligent Control System partner selection

In order to improve the chance of LV Engine solution roll out, develop a holistic approach for control system and facilitate interoperability for integration future power electronic controllable devices, a collaboration was agreed between Angle-DC and LV Engine projects. Angle-DC demonstrates power electronic application in 33kV network for power flow and voltage control purposes. It is envisaged that both Angle-DC and LV Engine control system consists of central and local control component.

During Q4 of 2020, Nortech Management Limited was appointed as the Smart Control System project parent to build on the learning and key outputs of Angle-DC project and develop LV Engine control system. The first deliverable, due in Q1 2021, is the LV Engine control philosophy and required I/O schedule with a view for a holistic approach.

2.1.1.2 LV Automation equipment procurement

A short list of vendors was established, and a tender process initiated for the provision of controllable LV circuit breakers. These will be used at our Wrexham trial site. Prior to this we engaged extensively with manufacturers to ensure that LV automation scope of works could be delivered within the timescales of the project. The original intention was to incorporate controllable LV link box switches within underground linkboxes but it transpired that these could not be engineered and manufactured to our requirements within the project timescales. There were different issues with the different manufacturers' products, to summarise:

- The heat generated by the link box components with bell cover designs can cause water to evaporate and then condense onto the cold copper LV fuse stalks causing steam to be generated.

- Manufacturers seem keen to move away from traditional bell cover designs to hermetically sealed alternatives which effectively requires product re-engineering.
- Manufacturers are not currently receiving sufficient interest/demand in the market place which justify investment/allocation of engineering resource to develop the products.
- Communications to the link boxes via Power Line Carrier is problematic/intermittent particularly when distances exceed 100-200m between the substation and the link box (as measured along the route of the mains cable).

With the decision made to remove controllable LV link box switches from the design, the focus was on the controllable LV circuit breakers that would replace the fuses in the LV PENDAs, the communications gateway, the server requirements, and the signal list. After market engagement and developing business requirements, it was decided to appoint an LV automation supplier through a tender process, developing a fit for purpose scope for LV automation equipment and services including engineering services required by the vendor. All tender documents were submitted in Q4 2020, with the technical evaluation is currently ongoing.

2.1.1.3 LVDC Switchgear Market Research and Procurement

Scheme 4 and Scheme 5 trial site will require an LVDC switchboard in order to distribute supplies to customers from the LVDC output of the SST. In traditional AC secondary substations in Great Britain these switchboards comply with ENA TS 37-2[1]. These standards are not currently applicable to DC switchboards. The most applicable standard is IEC 61439-2[2]. Switchgear complying to this standard is typically used in the commercial and industrial sectors for supplying buildings and factories and tends to be physically larger and with a wider selection of design features than PENDAs to allow operation by personnel without the risk of inadvertent contact with live conductors, a risk which is present with the compact open type fuseboard PENDAs used in many DNO substations.

Most PENDAs in Great Britain are fitted with fuses on their outgoing ways. Fuse protection is unsuitable for LV Engine due to the low fault levels that the SST can provide. We require the use of DC Moulded Case Circuit Breakers (MCCBs) which can be tripped by protection schemes designed specifically for LV Engine. In order to de-risk the supply of these LVDC switchboards we have sought suppliers who can provide a complete solution i.e. the switchboard with their own brand MCCBs and isolators, such that an overall co-ordinated design can be achieved. We have been working with these suppliers to engineer a product which is small enough to be deployed in the LV Engine substation and has the necessary protection and control features required. This supplier engagement has also allowed us to develop a technical specification for LVDC switchgear.

2.1.2 Work Package 3 – Design and Manufacturing of SST

2.1.2.1 Detailed Design of SST

Following a competitive tender conducted in 2019, ERMCO-Gridbridge (EGB) was appointed as LV Engine SST manufacturing partner in November 2019. After staff mobilisation, EGB commenced the design process for both SST Topologies in early Q1 2020. The design process was initiated through the Project Inception phase, where regular detailed discussions with the SPEN team were held to translate each of the technical/functional requirements specified within the Smart Transformer Technical Specifications[3] (LV Engine's Deliverable #1) to an element of the

[1] Public Electricity Network Distribution Assemblies (PENDA) and IEC 61439-5 Low-voltage switchgear and controlgear assemblies (Part 5: Assemblies for power distribution in public networks)
[2] Low-voltage switchgear and controlgear assemblies. Power switchgear and controlgear assemblies
[3] https://www.spenergynetworks.co.uk/userfiles/file/LV_Engine_Deliverable1_Smart_Transformer_Technical_Specification_REDACTED.pdf

electrical, control and mechanical design. As part of the project initiation phase, EGB/SPEN team attended familiarisation sessions to review typical LV/HV operation practices in the UK and visit typical SPEN's secondary substations, see Figure 4. A summary of product development process for the two SST topologies is shown in Figure 5. It is planned that the Prototyping phase starts in December 2020.

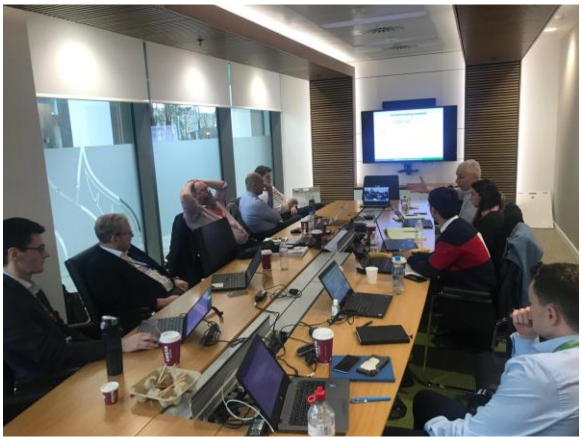

Figure 4 Network operation familiarisation and site visits took place with EGB team in February 2020

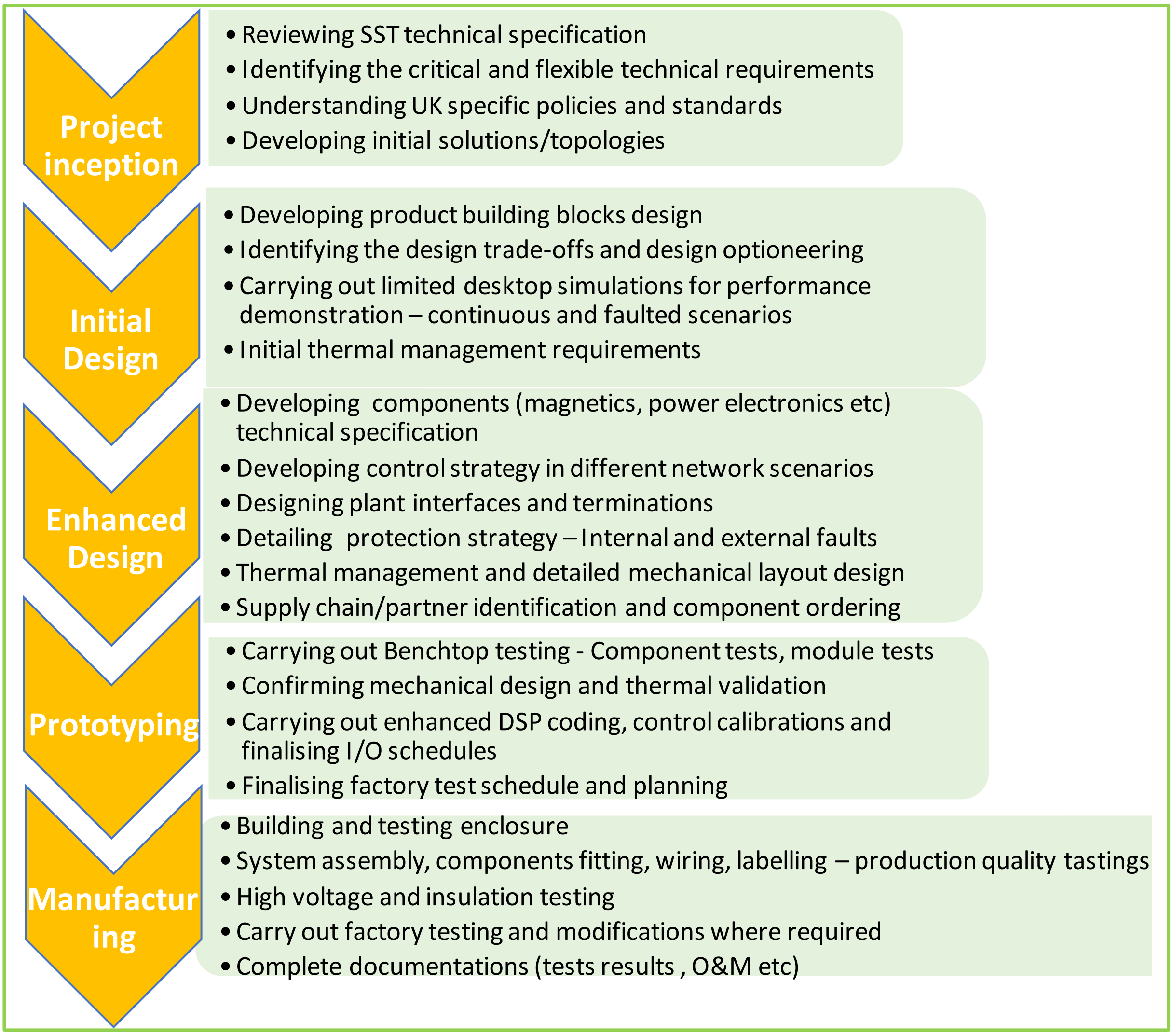

Figure 5 SST development process

SST Topology 1

Building block design

The high-level system architecture initially considered for SST Topology 1 is shown in Figure 6. The components inside of the grey box indicate the components that EGB are responsible to deliver. The dotted lines indicate isolation barriers.

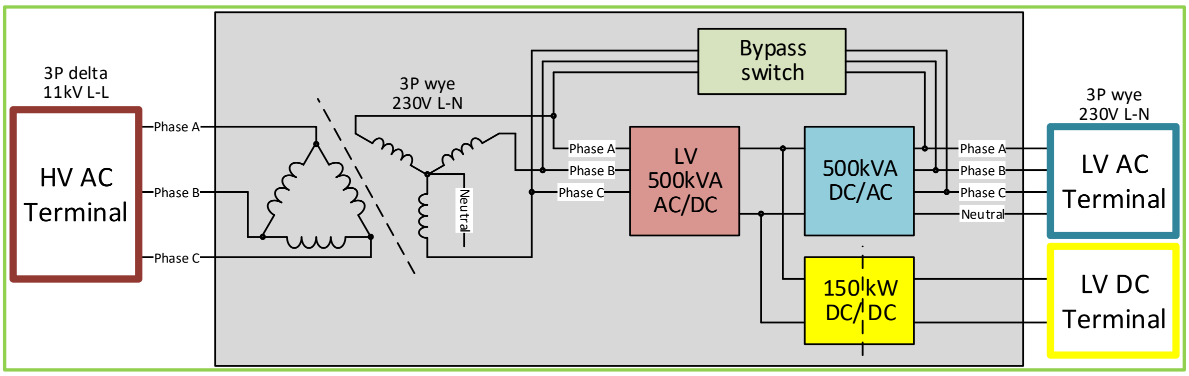

Figure 6 SST Topology 1 Block Diagram – Initial design considered

Nonetheless, following the detailed design analysis, performance evaluation and mechanical design of SST Topology 1, it was decided to consider Unified Power Flow Controller (UPFC) architecture for SST Topology 1 as shown in Figure 7. This decision was based on various product analysis carried out by EGB and SPEN team with the aim to improve the reliability and adaptability of the product for business as usual deployment. The main advantages of the UPFC (Figure 7) over the back to back conversion architecture (Figure 6) are as follows:

- **Improved performance during the fault –** Providing the same level of fault contribution to the faulted LV network as conventional transformer, eliminating the issue of low fault current provision by power electronics;
- **Improved efficiency –** The efficiency is expected to achieve 99% with the UPFC design as the power electronics do not need to supply all the LV demand and only operates to provide the system services. This will improve the efficiency and life-time losses significantly as the initial back to back design efficiency target was expected to be around 97%;
- **Smaller power electronics power rating –** For the same reason explained above, nominal power capability of the power electronics can be reduced significantly. This reduces the design complication and the overall system cost;
- **Bypass possibility –** The UPFC design allow fail-safe bypassing the power electronic unit when it is not needed or if there is any issue when power electronic components;
- **Smaller dimensions –** The lower power electronics power rating, higher efficiency and capability to bypass during the fault conditions contribute to a more compact physical layout design compared to back to back design;
- **Better reliabilities and building on previous EGB experience –** SST Topology 1 will be the first product of its type with no previous experience in the field, so the reliability of the product is yet to be seen in a live trial although reliability is evident in the design. EGB has existing 3 phase 150kW UPFC product which is currently commercially ready, however this product does not deliver all the functionalities required in LV Engine and is not designed to UK standards.

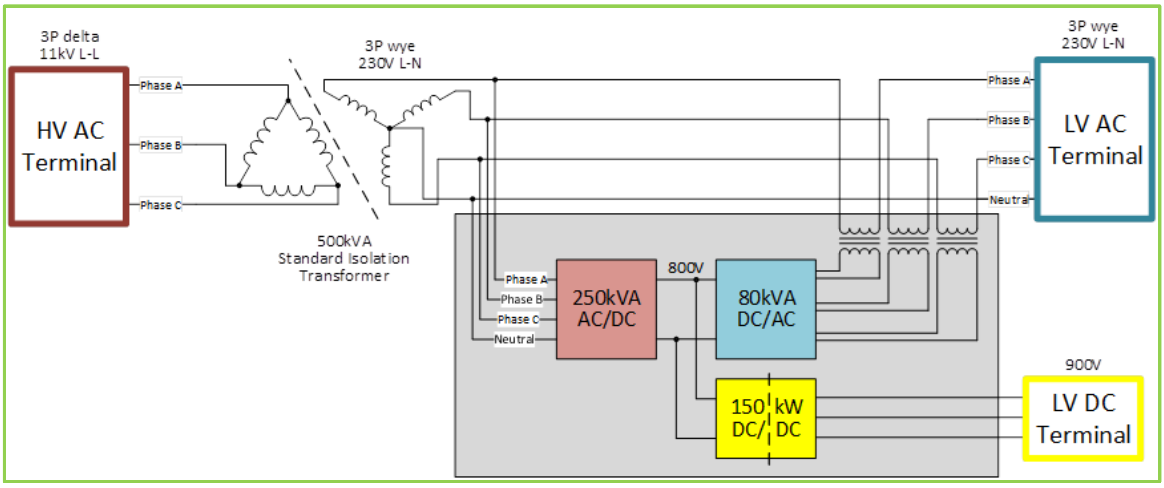

Figure 7 SST Topology 1, UPFC architecture

Control strategy

In order to deliver the LV Engine Core Functionalities, SST may operate in a radial or interconnected LV network arrangement. In an interconnected LV network, SST should be able to control the power flow within the interconnection following the control power command received from Smart Control System (SCS). An SST power flow control strategy has been developed to deliver the Core Functionalities while ensuring voltage stability and quality of supply to electricity customer stays within statutory limits. Extensive desktop studies were carried out to demonstrate the performance in radial and interconnected network arrangements.

Mechanical layout and local interface

The SST Topology 1 mechanical packaging will be confined to a (1.0m x 1.0m x 1.5m) overall envelope size (with ±10% variation) including all required cooling apparatus and cable boxes. This has been the target design and is being finalised with the aim to include the factory ordered optional 150kW DC Service Module in the target envelope size. The latest layout design is shown in Figure 8.

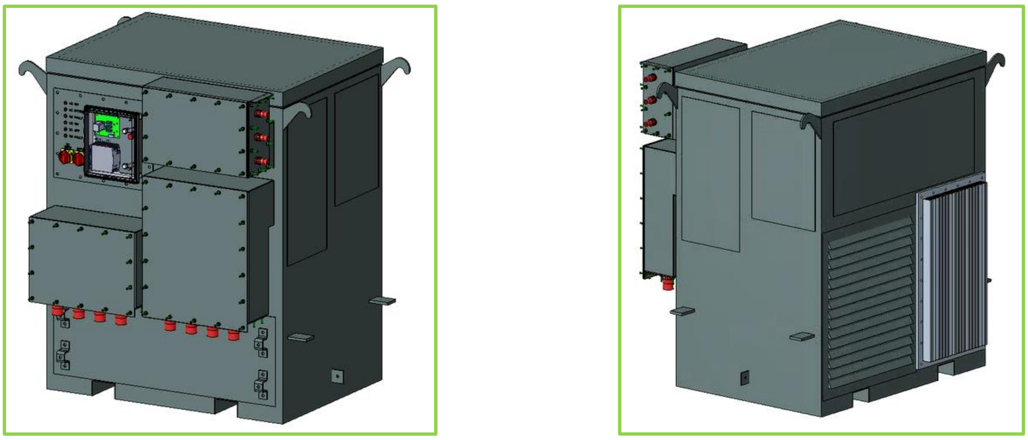

Figure 8 Physical layout of the SST Topology 1

The local interface design, shown in Figure 9, provides operation staff with the flexibility to switch off the power electronic and operate the unit in bypass mode. The following functions will be provided by the local interface:

- Providing indicators confirming the operation status;
- Access to switches providing the option for the local operation staff to switch off/on the power electronics that includes bypassing the AC services and coupling transformer, and switching off the DC operation;
- Connection to the Ethernet port for communication with SPEN telecoms/router with which communicating control commands, monitored parameters and remote access is facilitated;
- Access to auxiliary power supply providing 24DC for HV switchgear inter-tripping scheme and supply for the telecoms with secondary substation;
- Access to the contactor relay for connection of the 24VDC to HV switchgear's shunt trip coil;
- Provide a test point (via a multi-meter device) for the operation staff to ensure no internal capacitor charge exists before any work on the device.

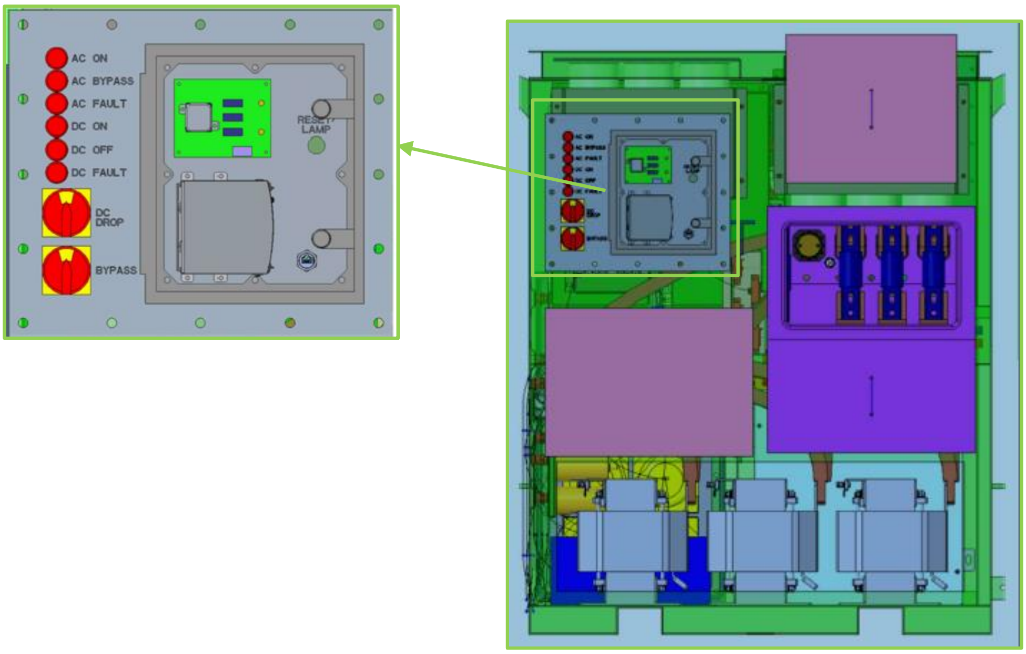

Figure 9 SST Topology 1, Local interface

Next step

The materials and components of the SST Topology 1 have now been ordered with expected delivery through late Q4 2020 into early Q1 2021. According to the design and manufacturing plan, prototyping and benchtop testing are the main activities, scheduled to start in Q1 2021. Manufacturing and Factory testing will commence in Q2 2021 with design changes and product manufacturing and testing completed in Q3 2021.

SST Topology 2

SST Topology 2 has represented a more onerous product development endeavour compared to SST Topology 1. As a result, the design progress is not as advanced as Topology 1 at the time of writing this report. Nonetheless, significant work has been carried out to detail the challenges, establish the topology and identify the requirements for operation under different network conditions. The detail design aspects developed to date have been documented in this report. The EGB team has been successfully engaging with both academic and industrial partners to adopt the solutions which have already been developed so that the design process for LV Engine product can be optimised.

Building block design

The overall building block of SST Topology 2 is shown in Figure 10. SST Topology 2 consist of three stages: the HV AC/DC stage, isolated DC/DC stage and DC/AC stage.

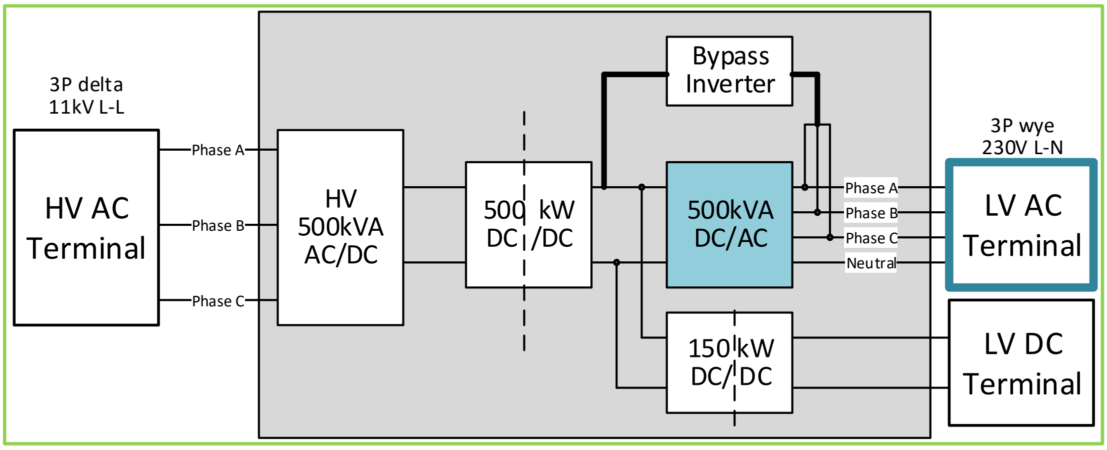

Figure 10 HV-SST 500kVA DC/AC Inverter feeds the LV-AC Terminal

There are several challenges in developing the SST Topology 2 rectifier stage and isolated DC/DC stage. There are ongoing works by EGB on strengthening University research relationships having a background in SST research to further improved simulation and investigate the topology and hardware options for the SST input power stages. As part of this, several options have been explored to narrow the focus, highlight key challenges, and underscore requirements over and above current research and previous experience of the EGB team. The focus is currently on the following challenges[1]:

1. Due to the vulnerability to overvoltage of the power semiconductor devices, proper protection methods should be taken to meet the isolation requirements. As specified by IEC 60076-3, SST Topology 1 should comply with the 75kV lightning impulse and 28kV withstand voltage;
2. The design of SST should leave sufficient margin for operational overvoltage up to 19.4kV peak;
3. Due to the limited overcurrent capacity of the power semiconductor devices, to handle the LV short circuit fault adequately to blow the downstream fuses, the power output of the HV stage should be oversized by 100% to about 1.0MVA for 3 seconds;
4. The utilisation of multi-level structure shown in Figure 11 due to the availability of HV commercial semiconductor devices increases the number of components and control complexity. In total there are 378 additional critical components required for the HV-LV conversion alone. This does not include the additional DSPs and Control Processors required to drive the 42 Si IGBTs and 84 SiC MOSFETs required.

The high voltage to low voltage conversion is accomplished via the 500kVA AC/DC high voltage rectifier and isolated DC/DC converter. The purpose of the HV 500kVA AC/DC rectifier is to take the three-phase high-voltage input and transform it to a cascaded medium voltage dc bus. The 500kW DC/DC then interfaces with the high voltage rectifier to provide isolation and control for the internal low voltage dc bus.

[1] In Nov 2020, EGB team informed SPEN that after extensive engagement with academic and industrial partners, they have concluded that they would use a new 2.0kV SiC modules from a Tier 1 power semiconductor supplier which will be commercially sampled for prototyping in Q1 2021. Using these modules will significantly reduce the number of components contributing to considerable improvement in size, reliability and overall cost of the unit.

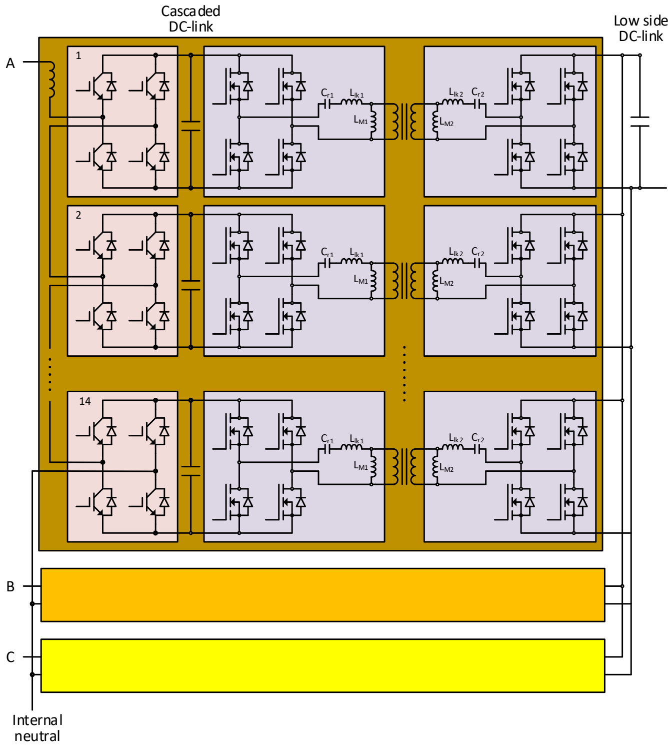

Figure 11 Input Rectifier and DC/DC Stage Possible Topology – 42 Stages Required

Academic and Industry engagement

To accelerate progress and break ground on the challenges, specifically the HV to Isolated DC conversion, EGB agreed to add additional qualified resources and/or key technology to the SPEN SST Topology 2 development program. EGB pursued noted power electronics programs at four universities where an existing relationship exists:

1. University of Texas, Austin: Semiconductor Power Electronics Center (SPEC) – Dr. Alex Q. Huang (SPEC Director)
2. North Carolina State University: NSF FREEDM Systems Center – Dr. Iqbal Hussain (FREEDM Director)
3. Virginia Tech: Future Energy Electronics Center (FEEC) – Dr. Jason Lai (FEEC Director)
4. University of Colorado, Boulder: Colorado Power Electronics Center (CoPEC) – Dr. Dragan Maksimovic

EGB evaluated the technology developments at SPEC (UT-A), FREEDM (NCSU) and FEEC (VT) for possible commercial advancement for use in the LV Engine application. After evaluation and further research, the detailed technology advancement focused on UT-A that revealed an unfolding Bridge & DAB topology using an experimental "SuperMOS" Cascade 7.2kV SiC module and experimental HV DAB Transformer[1]. This solution is currently an early single-phase lab prototype. After a series of detailed technical evaluations, risks/reward assessments and due diligence, EGB concluded that the UT-A prototype was not suitable for deployment within the LV Engine development.

EGB has also re-engaged Mitsubishi, Infineon & Wolfspeed for an update on their commercially available Si and SiC switching devices based on lessons learnt relating to topology, partitioning, modularity, reducing risk and best industry practice, coupled with commercial availability of the required supporting circuits (gate drive, power suppliesand sensors). The main output of this

[1] https://repository.lib.ncsu.edu/bitstream/handle/1840.20/34943/etd.pdf?sequence=1&isAllowed=y

engagement was to learn that 2.0kV SiC devices will be commercially available in Q2 2021 by Infineon with early access to market in Q1 2021. This can significantly reduce the overall SST Topology 2 cost, improve reliability, reduce cooling requirements, along with improved dimensions of the product developed for LV Engine.

Next Steps

EGB is currently validating the power and thermal simulation of the Infineon 2.0kV SiC modules. In anticipation of successful power & thermal simulation results with the 2.0kV SiC modules, EGB has agreed with Infineon to reserve parts for early benchtop prototype work in Q1 2021, ordering materials in Q2, the prototyping and manufacturing are scheduled in Q3 2021.

2.1.2.2 Life Cycle Assessment

As part of Deliverable #2, the project has committed to carrying out an LCA of the SST by using the detailed design produced within Work Package 3. The LCA demonstrates a move away from traditional specifications and a move towards performance and outcome specifications which include carbon emissions. The information from the study can be used to report more accurately on the proposed environmental benefits of the LV Engine use cases. This project also forms part of a wider ambition to understand and actively manage whole life carbon associated with SP Energy Networks operations in line with PAS2080 Carbon Management in Infrastructure.

The aim of LCA is to quantify the environmental impacts, in particular greenhouse gas (GHG) emissions, associated with the equipment manufacturing, installation, use and disposal that forms part of the LV Engine project. This report documents the approach taken for the LV Engine LCA, following the ISO14040[1] standard frameworks, as well as outlining data sources and assumptions, results and future recommendations. The software used for this LCA is SimaPro V9.0. SimaPro is an established software within the field of life cycle analyses and has been used in numerous studies across different industries. SimaPro software contains several databases of materials and processes commonly utilised within manufacturing.

2.1.3 Work Package 4 – Network Integration Testing

An initial report on Network integration testing specifications was finalised in Q1 2020. Since then, this document has been reviewed together with EGB, LV Engine SST Manufacturing partner, to ensure an optimum product test plan between factory acceptance tests and network integration tests. The aim is to assess the reliability on the products (both SST Topology 1 and SST Topology 2) and build confidence on performance before live trial.

We have also conducted a market engagement and research on potential testing facilities which are capable of delivering the requirements identified in the network integration testing specifications. The outcomes of this engagement are initial technical and commercial proposals will be further assessed in Q1 2021. The plan is to appoint a capable testing facility in Q2 2021.

2.1.4 Work Package 5 – Live Trial

Work Package 5 covers the demonstration of LV Engine in distribution network. We have focused on trial areas, namely Wrexham and Falkirk. The following sections summarise the key works associated with each of the sites.

2.1.4.1 Wrexham Trial site

Wrexham has been selected as the primary trial site for demonstration of LV Engine Schemes 1, 2 and 3. Voltage control, capacity sharing, power factor correction and LV imbalance load cancelations are the main functionalities which will be demonstrated in Wrexham.

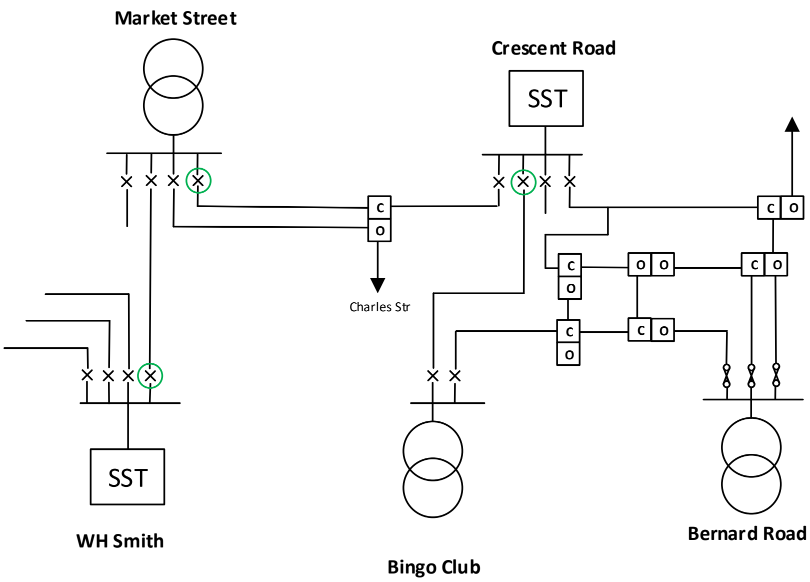

Figure 12 Wrexham Trial Site

Model Development

In order to create a platform for various desktop studies, we have enhanced the Werxham computer model which had been initially developed in previous reporting period (2019). The model was developed in DigSILENT and it includes the following details:

- LV network including all the LV main and service cables (for each phase);
- The number of customers at each load point;
- Detailed HV network up to the first primary substation;
- Automated scripts for allocating the monitored load at secondary substations to each customer connection point to create an imbalance loading arrangement as per monitored data;
- Linkboxes with ability to model open/close the interconnection between substations in the trial area.

Wrexham computer model has been used to conduct the following studies:

- Load flow studies to Identify the voltage and thermal stress in the network period of peak demand before and after LV Engine solution trial. Figure 13 and Figure 14 shows an example of the heatmaps generated to demonstrate the thermal and voltage stress, respectively.
- Quasi dynamic load flow studies accounting for load variations in 24 hours to demonstrate the power flow and voltages variations in different LV Engine schemes.
- Demonstrate initial control strategy for capacity sharing between neighbouring substations informing the LV Engie control philosophy.

Figure 15 shows the type of modelling results we were able to extract, using Scheme 1 as an example. The plots show the amount of active and reactive power flow that can be controlled down the feeder between Crescent Road and Bingo Club substation by adjusting the active power set points of the SST located at Crescent Road. The limitation occurs at active power set points above 100kW, where the Crescent Road LV busbar voltage starts to exceed the upper 10% statutory limit. Tapping the transformer at the Bingo Club to reduce the LV voltage by minus 2.5% can be used to increase this threshold to above 150kW. The SST can effectively control the loading of the Bingo Club transformer to between 20% and 60% demonstrating the capacity sharing.

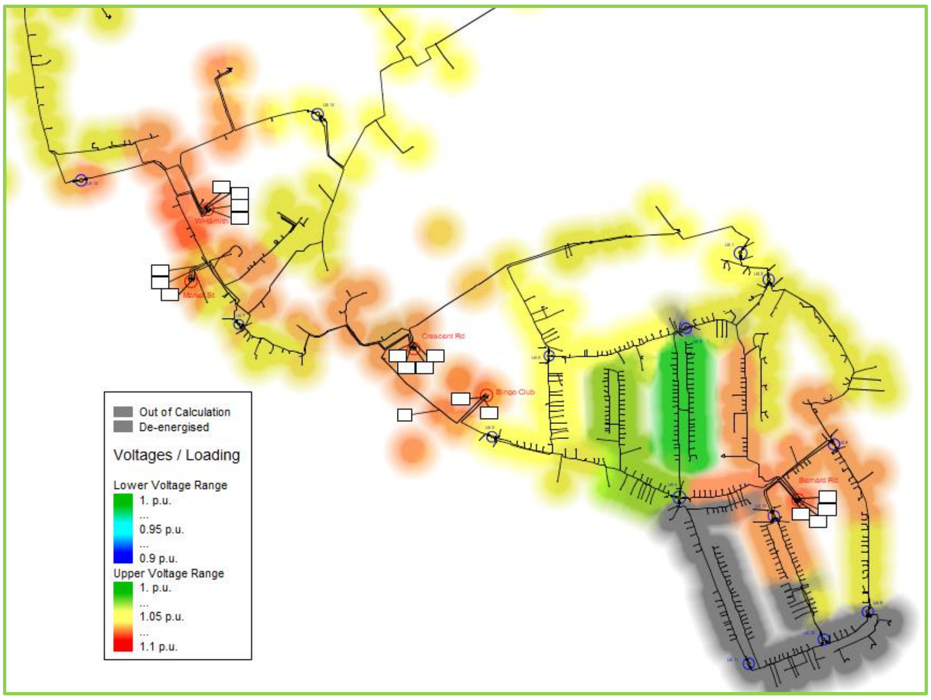

Figure 13 Voltage heatmap snapshot (at the period of Bingo Club substation maximum demand)

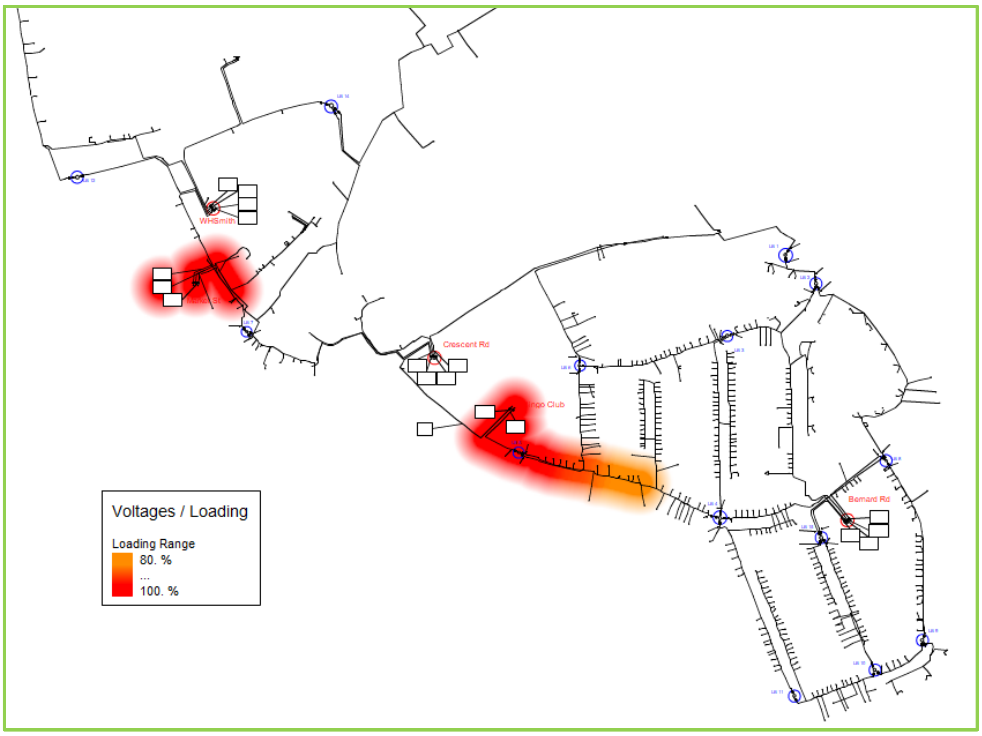

Figure 14 Cable loadings heat map (at the period of Bingo Street maximum demand)

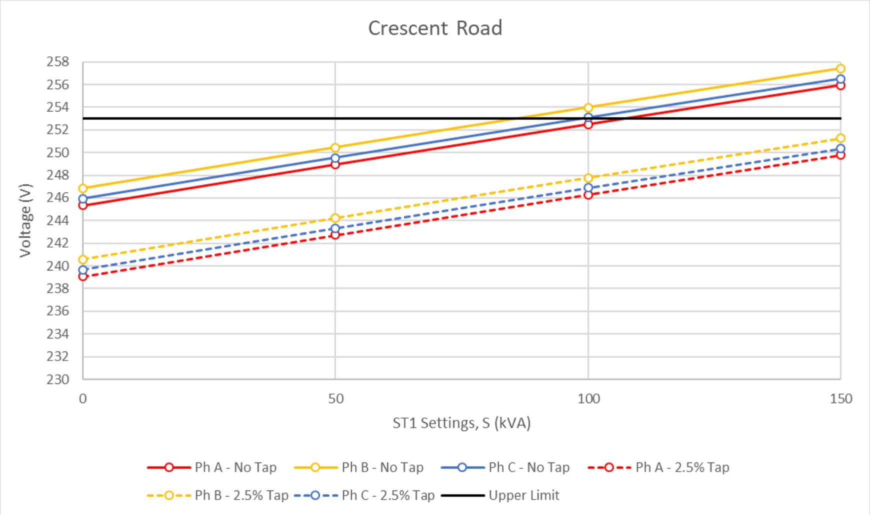

Figure 15- Increase in power transfer between two neighbouring substations in Wrexham with -2.5% tap at conventional substation

*Wrexham – **C**ontrol **S**ystem **D**evelopment*

Several control methodologies for capacity sharing between SST and a conventional transformer which are located at two neighbouring substations (as shown in Figure 16) were developed and tested on the Wrexham model. The control methodologies demonstrated in various network conditions over a 24-hour period using the load data monitored for individual feeders in Wrexham. A script was set up to run through a 24-hour load profile with load flows being conducted at each hour (quasi-dynamic simulation). Figure 17 shows a flowchart for one of the control methodologies which has been developed and is currently being assessed.

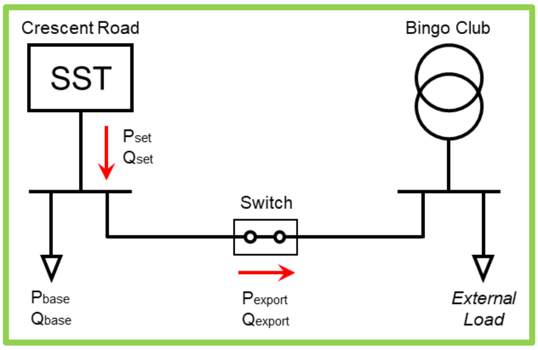

Figure 16 Capacity sharing between two neighbouring substations

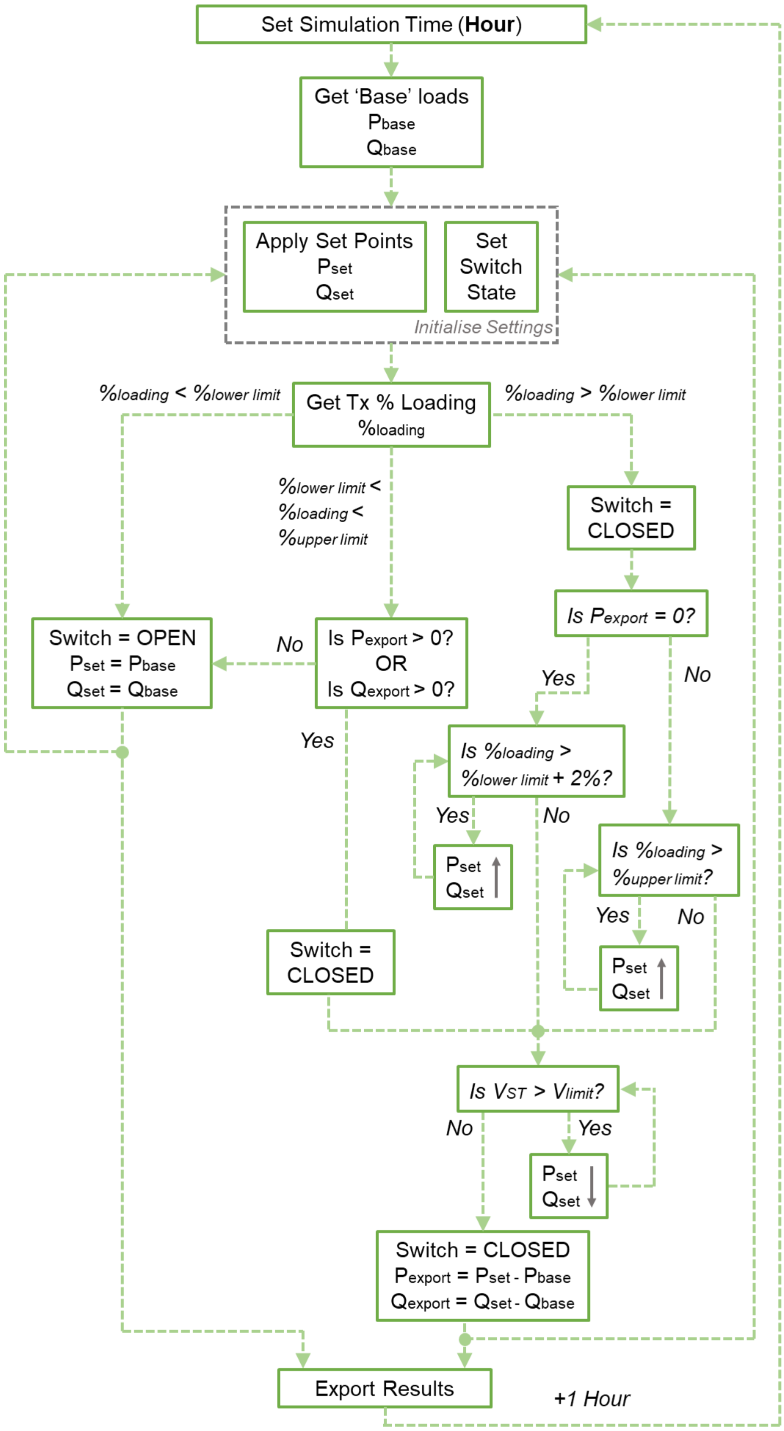

Figure 17 An example of capacity sharing algorithm developed and tested on Wrexham network model

Wrexham Site Layout

The design and layout planning in Wrexham substations have been progressed as planned during 2020. Introduction of a new plant to a typical secondary substation required careful layout planning to ensure adequate spaces considered for, installation, typical operation practices and escape routes. Different layout design options were prepared and assessed with operation and delivery staff to ensure the optimum design can be achieved. The design package for each substation is now currently being prepared that includes:

- Plants technical specifications – completed

- Plants layout, electrical design and cabling – completed
- Civil design, ventilation and access - ongoing
- Communications, control and protection – ongoing

Figure 18 shows the final design prepared for one of the substations in Wrexham. Although the LVDC supply is yet to be confirmed in Wrexham, as a result of ongoing engagement with Wrexham Council, LVDC board have also been considered in the design to allow for potential LVDC demonstration. 3D models of the substations have also been prepared for better understating the final layout design and demonstration, see Figure 19.

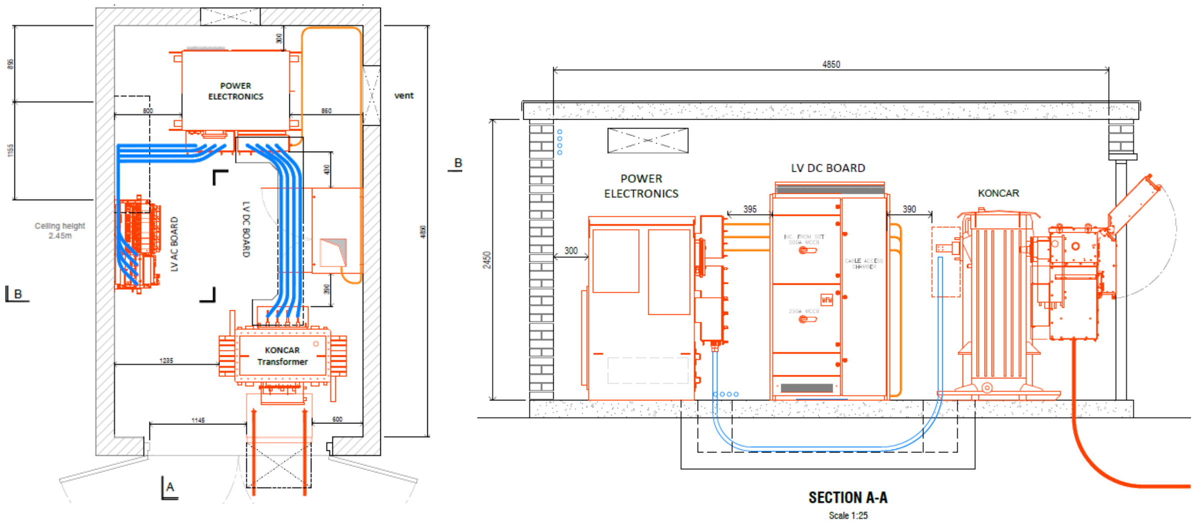

Figure 18 LV Engine Design – one of the Wrexham substations

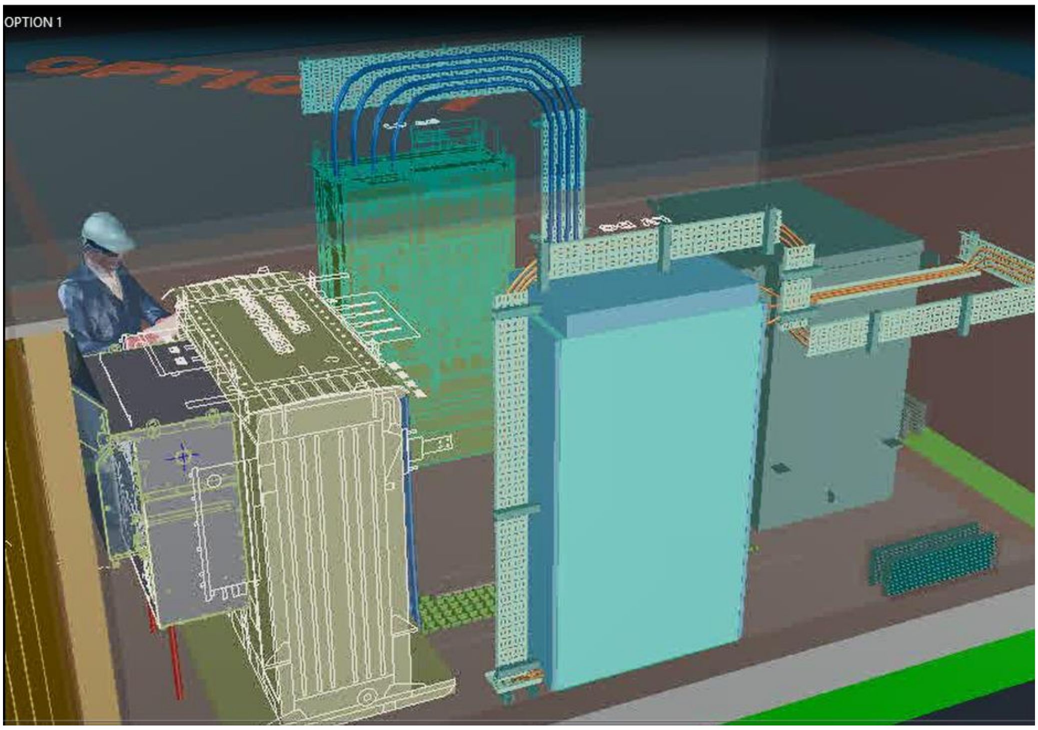

Figure 19 3D model of LV Engine substation

Wrexham LV Automation – LV Protection

Detailed protection and grading studies have been conducted for Wrexham network where the conventional 315A fuses will be replaced with LV CBs. The LV CBs will provide capability to close /open the LV interconnections following a command from Smart Control System. LV CBs will also provide monitored capability (voltage and current) for each phase at each feeder separately. This work focused on a number network scenarios (over 130 cases) to understand the impact of deploying SSTs (both topologies) on the performance of the AC network protection. The outcomes of the study have been documented and the report will be made available on the LV Engine website. The following information will be available in the report:

- Methodology, assumptions and network scenarios considered for protection grading studies;
- Fit-for-purpose SST modelling methodology used for protection studies;
- The coordination between HV protection (at the upstream primary substation) and the LV network;
- The expected clearance time when SST deployed in different LV Engine scheme and comparison with the based case scenario (existing network)
- The protection coordination between fuses and LV CBs in those network arrangements where combination of fuses and LV CBs exists.

Communication requirements

It is planned to utilise a SPEN's approved 4G router for communication in secondary substation. A 4G router that incorporates a DNP3 to IEC 60870-5-101 protocol convertor will be utilised. A schedule listing all the communications signals required between the SST, Local Smart Control System, Regional Smart Control System and the corporate PI system has been developed.

Wrexham Council Engagement

The project team have engaged with Wrexham Council to raise awareness about LV Engine and the trial of innovation technologies in Wrexham. Delivery of the UK's zero carbon target requires involvement and awareness of all stakeholders, and we recognise the local authorities as a key stakeholder. There are ongoing discussions with Wrexham council for their involvement in trial of LV DC network in line with the council's plan for facilitating the uptake of low carbon technologies.

2.1.4.2 Falkirk trial site

We have successfully secured our LVDC trial site at Falkirk stadium and progressed with the site design during 2020. We have established a close collaboration with Falkirk Council in line with their ambition to create charge place hubs along the route of the A9, contributing to "Electric A9" plan. The existing charging hub at Falkirk stadium is shown in Figure 20. As part of our collaboration, LV Engine will supply an ultra rapid EV charger (150 kW) using ±475V DC connection.

Figure 20 Electric A9 – Falkirk Stadium Charging Hub

To the best of our knowledge, this is a unique LV DC supply arrangement that has not been undertaken by any network operator to date. This arrangement introduces several design and operation challenges which the LV Engine team have been progressing to address, including:

- Establishing an unconventional connection agreement with the customer for an LVDC supply;
- Health and Safety requirements for installation and operation of LVDC equipment;
- The LV DC protection strategy and suitable LVDC switchgears;
- Maintenance requirements and spare parts
- The earthing arrangement for the DC network;
- Establishing a plug and play arrangement for the DC EV charger with no communication requirement with the LV Engine substation i.e. SPEN assets.

Falkirk Connection Offer

Throughout 2020, Falkirk Council were issued with a connection offer to facilitate a form of contract between parties for provision of the new substation. The connection offer was accepted in Q4 2020 which established the commitment from both parties for the delivery of LV Engine LV DC trial site. The LV Engine connection offer is different in some respects from a business-as-usual connection offer as follows:

- Specific reference to ESQCR Paragraph 27 as this is a non-standard supply;
- Inclusion of bespoke earthing diagram;
- Emphasis on innovation nature of project and risk associated with trial of new technology;
- The cost of substation installation and associated HV connection will be covered by LV Engine rather than Falkirk Council.

An extract of this connection offer is shown in Figure 21.

Re: Falkirk Stadium, Stadium Way Falkirk FK2 9EE – LV Engine Scheme 4 (DC Only)

Thank you for your enquiry, which we received on 01.08.2020 regarding LV Engine – Scheme 4 works at the above address. We have pleasure in submitting this Offer Letter for your consideration.

Connection Charge:
The cost for this work will be £1.00 (exclusive of VAT)
VAT will be charged at £0.20
This equates to a total cost of £1.20 (inclusive of VAT)

Charge breakdown (exclusive of VAT):

Charge Description	Connection	Diversion	Reinforcement
Electrical Substation Works	1.00	0.00	0.00
High Voltage Overhead Line Works	0.00	0.00	0.00
Primary Substation System SP	0.00	0.00	0.00
High Voltage Underground Main Works	0.00	0.00	0.00

The Connection Charge is payable in full prior to the commencement of any of Our Works.

A summary of our works:

As part of the LV Engine innovation project (funded via the Network Innovation Competition (NIC) from Ofgem), we have outlined that Falkirk Stadium is intended to be the site for a Topology 2 Type B (DC Only) Solid-state Transformer (SST) demonstration. This SST will be enabled to provide a LV DC supply so to directly connect to ultra-fast EV chargers (DC connected 150kW). As LV Engine is a novel solution, SP Energy Networks cannot guarantee the reliability of LVDC supply and would stipulate that the provided LV DC supply must only be used to supply the EV chargers provided as part of the project.

Figure 21 Extract from Connection Offer for Falkirk Council

Falkirk DC load - EV charging developments

Following an extensive market research conducted in 2019, the project team established a collaboration with Tritium, EV charger manufacturer based in Australia, which has DC EV charger product in the pipeline with the timeline matching the LV Engine developments. There have been regular engagement with Tritium to specify the technical requirements such as unit protection, earthing, supply, voltage limits requirements etc.

Tritium is designing and manufacturing 75kW and 150kW DC supplied EV chargers as part of their product development strategy. The team will publish further information on technical specifications of the charging units in the next reporting period as the design in progress and some aspects of the design is confidential at this stage until the final product is ready.

Falkirk Wayleaves and Planning Permission

As physical plant details were finalised, this allowed for SPEN to approach Falkirk Council for the legal rights required to maintain and operate the plant, which will loop into an existing HV circuit from Earls Road 33/11kV Primary substation. The rights of the cable have now been concluded, with the final substation lease currently being finalised. The legal rights need to cater for both the match day use of the stadium and the normal day to day use by Falkirk Council.

Details of the lease and servitude requirements for the substation and cables are demonstrated in Figure 22.

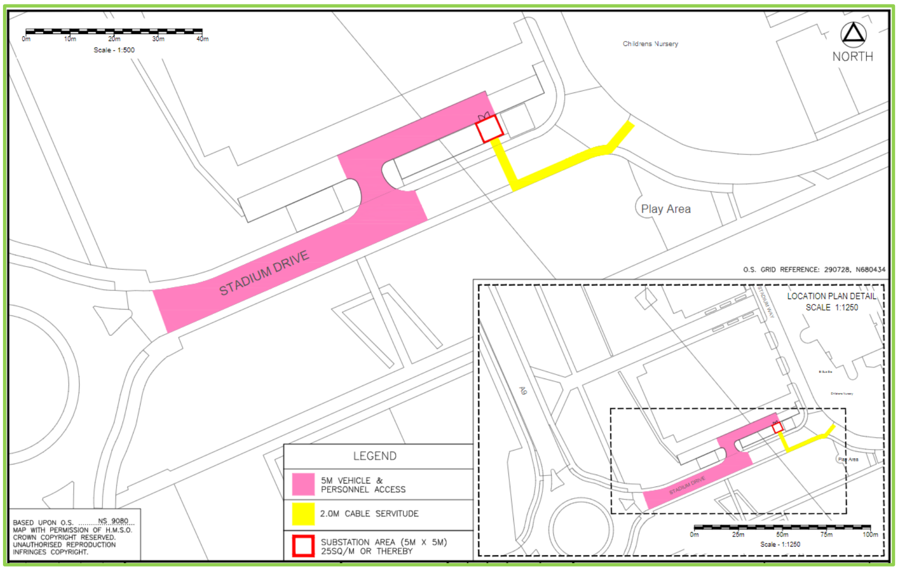

Figure 22 LV Engine – Falkirk Lease plan

Falkirk Substation layout and civil design

The team are currently in a process of finalising the lease agreement for the LV Engine substation that is planned to be installed at a maintenance vehicle parking bay shown Figure 23.

Similar to the work carried out in Wrexham, substation layout design and plant interfaces have been finalised for Falkirk, see Figure 24 the section view of the substation layout within the enclosure. The traditional secondary substation GRP type enclosure serves to provide an extended asset life for plant designed for outdoor use. The trial of the SST requires an enclosure which can accommodate both traditional outdoor kit and provide a suitable environment for the SST. As such a hybrid is required which draws on key elements of the enclosures used at GSP or Primary substations alongside the basic GRP unit deployed at secondary substations. An enclosure brief is being finalised within the team ahead of a procurement exercise in 2021.

Figure 23 LV Engine Substation location at Falkirk

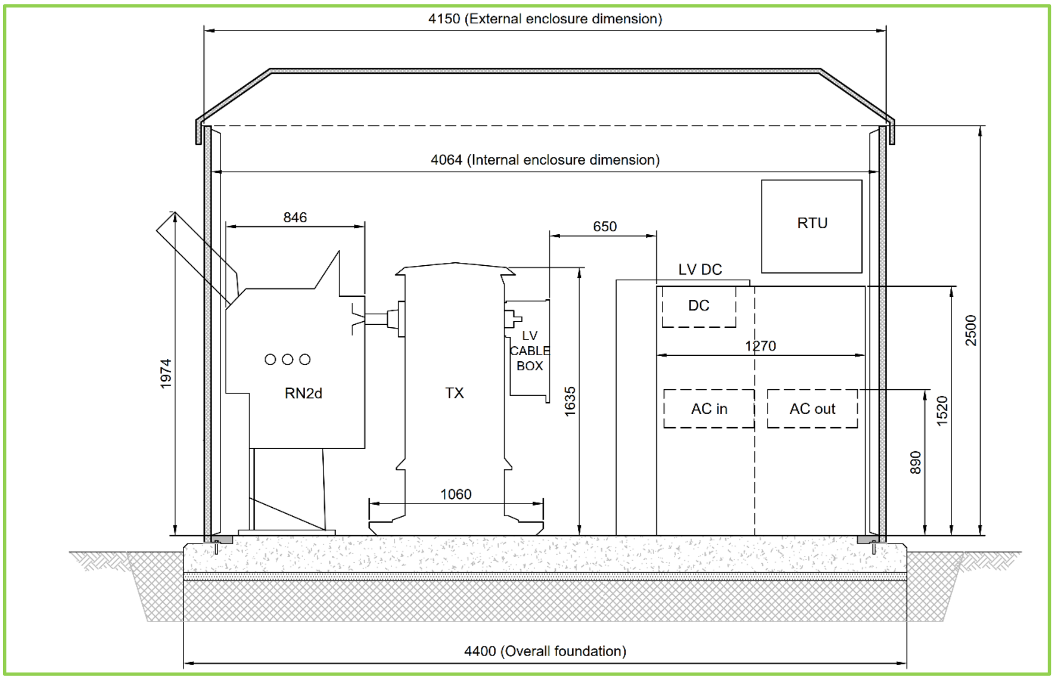

Figure 24 Falkirk Substation Electrical Layout and Section

We have also commissioned the civil and structural design work associated with the substation. The design outcome is currently under review which covers:

- Reinforced concrete foundation design,
- Substation building general arrangement drawings,
- Internal cable ducting and trench route general arrangement drawings.

Falkirk Detailed Electrical Design

An electrical schematic for the substation is shown in Figure 25. We have considered trial of SST Topology 1 for Falkirk to reduce any impact on the customer as we believe that a higher technology readiness level (>=8) compared to SST Topology 2 can be achieved. The SST will be supplied by a conventional RMU with a transformer feeder circuit breaker fitted with overcurrent and earth fault protection. The circuit breaker can also be tripped by protective circuits from within the SST. The SST will provide a 24VDC supply which can be used for protection, control and telecoms systems. A 24V battery will be included in the design for continuity of supply under an outage. Substation lighting will be provided by 24V DC LED. No heating will be provided in the substation. The substation will not have any 230V AC supplies. The LVDC switchboard will have one incoming switch-disconnector and one outgoing MCCB. The outgoing way will be fitted with a DC meter for information purposes only. The customer interface will be at the cable termination of the outgoing way. The customer will be required to supply a five-core cable to connect their EV charging head to the substation switchboard. The EV charging head is rated at 150kW.

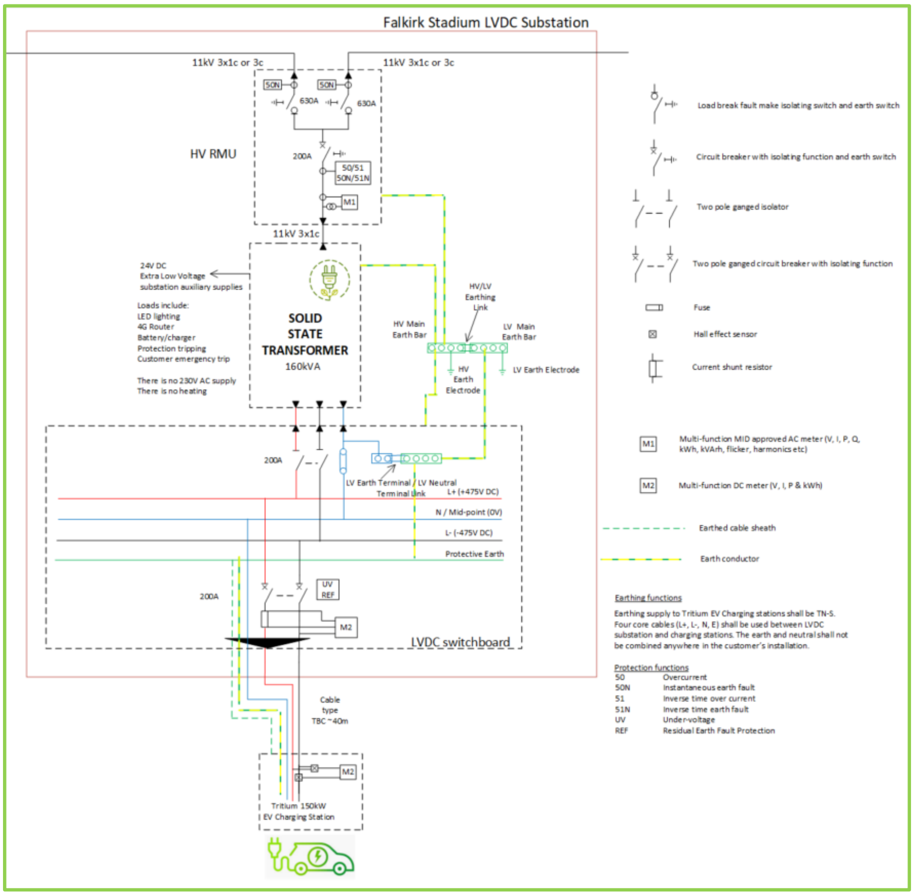

Figure 25 Falkirk Substation LVDC Substation Schematic

Falkirk Earthing Design

We have commissioned a capable consultant to conduct the earthing study in Q4 2021. That includes the soil resistivity and earth resistance measurements at Falkirk, calculating the earth potential rise (EPR) at the site and provide recommendation on the suitable earthing arrangement for DC and hybrid AC/DC networks. The site measurements have successfully completed in Q4 and initial earthing study suggested that Falkirk will not be a high EPR which will results in less complicated earthing design arrangement.

Falkirk DC Switchboard

In order to develop a Technical Specification, the market availability and needs for product development were established via Market Research. This allowed the team to understand the existing market for LVDC switchboards and appreciate where there may need to be a steer for product development or a combination of technologies. This exercise allowed the development of a detailed Technical Specification for LVDC Distribution Board which will be published on LV Engine website when it is internally approved. It has been structured to accommodate the needs of the LVDC supply at Falkirk along with a future proofed BaU offering for use beyond the trial.

Market engagement has facilitated high-level designs which have resulted in a number of switchboard styles, Figure 26**Error! Reference source not found.** shows potential designs which are considered for trial in LV Engine project. The final design and project award for manufacturing the LVDC board will be concluded in Q1 2021.

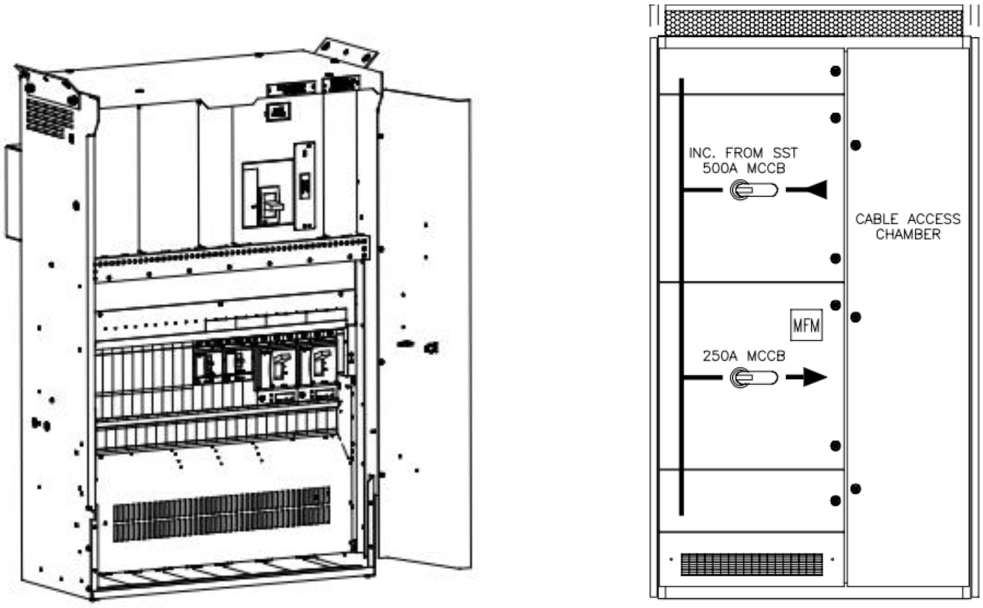

Figure 26 Styles of LVDC switchgear

Falkirk LVDC Protection

Protection of conventional LVAC distribution systems is either with fuses or by MCCBs or ACBs fitted with electronic trip units providing over current and earth fault protection with programmable or selectable trip curves. As the SST cannot provide a fault current in excess of the SST's full load current, neither fuse protection nor conventional overcurrent protection will work. We are looking to implement a protection mechanism on the outgoing MCCBs which use an under-voltage shunt trip release coil. When the SST detects a fault on the LVDC network it will temporarily shut off its LVDC output causing this trip coil to release and trip the MCCB. The overall protection control strategy has been agreed between SPEN, EGB (SST Manufacturer) and Tritium (EV charger manufacturer). We are commissioning a protection study to demonstrate the feasibility of an overall protection strategy that can provide appropriate primary and backup protection and considers the behaviour of the SST and the EV charging head under all fault scenarios.

Falkirk DC Metering

As reported in the previous reporting period, the need to facilitate DC metering as part of the DC customer connections creates a number of challenges. The works from the last period are currently being updated in liaison with suppliers, meter operators and the wider commercial team who consider Use of System charges within SPEN. The deployment of a Topology 1 solution at Falkirk provides LVAC access for metering reference and the impact of this is part of that review.

2.1.5 Work Package 6 –Development of Novel Approach for Transformer Selection

In order to ensure that LV Engine solution can be deployed by the business, different SPEN staff with planning, delivery and operation roles have been involved in the project. We have progressed in the following aspects in 2020:

- Identifying the impact on existing policy documents when introducing LV Engine solution;
- Identifying the safety document and training materials should be developed to cover the installation and operation of LV Engine solution;
- Installation and commissioning distribution transformers with on-load tap changers fitted for comparison with LV Engine solution and informing novel approach for transformer selection.

2.1.5.1 Operational Implementation works

In order to facilitate the trials being energised, with operational staff available to work on the equipment safely an updated suite of documents are required to support/complement existing safety documentation. This documentation will also provide the basis of operational training for staff who are likely to encounter the LV Engine substations.

The hierarchy of operational documents which are relevant to deployment of LV Engine are:

- **Power System Safety Instruction (PSSI)** - these contribute to make collectively the Safety Rules. The Safety Rules are the control measures to manage the risks to persons working or testing on, or near to, the Company's electrical and mechanical Systems.
- **Management Safety Procedures (MSP)**, Energy Networks MSPs have been introduced to detail the manner in which the objectives, responsibilities and requirements of the Safety Rules shall be met, and to ensure that they are applied in a consistent manner.
- **Approved Equipment Register** – this is a listing of the Equipment which is approved in accordance with PowerSystems documents for use or installation on the Company network.

To deliver an operationally compliant trial, SPEN's Safety and Compliance representatives have been working with LV Engine core team. We have identified the following documents required under each of the headings above.

Table 1 – LV Engine Operational Documents Required

Operational Document Set	Document Title
PSSI	Safety Instruction to apply the principles established by the ScottishPower Safety Rules (Electrical and Mechanical) and the Company Safety Instructions to establish Safety from the System for personnel working on or testing of SSTs and LVDC Plant and Apparatus.
MSP	LVDC Switchboard – this will include the following: • General requirements for work or testing on LVDC equipment supplying customers • Procedure for work or testing on the LVDC switchboard • Precautions for working on the unit • Precautions for working on the LVDC customer interface circuit breaker Topology 1 SST – this includes the following: • General requirements for work or testing on SST Topology 1 • Procedure for work or testing on the L SST Topology 1

		• Precautions for working on the unit, including the protective by-pass and intertrip signalling • Performing Capacitor measurements Topology 2 SST – this will mirror SST Topology 1, but will include the associated HV precautions.
Approved Register	Equipment	Updates to the Approved Equipment Register Supporting Approval Documentation

The first of these documents has been drafted and is currently progressing internal reviews.

2.1.5.2 Application of voltage regulating distribution transformer

LV Engine will provide a novel approach for transformer selection at secondary substations to allow network planners benefit from toolbox for selecting a technology which offers the best value for money. Voltage regulating distribution transformers (VRDT) which are similar to conventional distribution transformers but fitted with on-load tap changers will be assessed as an alternative to conventional transformer and SS. In order to provide adequate leanings for VRDT deployments and collect performance data for comparison with SST, we plan to install and monitor 3 VRDT. To do this, following work has undertaken by LV Engine team and SPEN district teams:

- Conducted site selection exercise and shortlisted three trial sites in Glasgow, Edinburgh and Dumfries where high uptake of photovoltaic has taken place;
- Provided training staff on delivery, operation and maintenance of the unit.
- Developed a method statement for commissioning the VRDT at secondary substation with emphasis on safety requirement;
- Conducted the site design for the three selected sites
- Commissioned the first VRDT substation in Glasgow in Q4 2020. The two remaining sites are planned to be commissioned in Q1 2021.
- Installed monitoring equipment to collect the voltage variation and loading of the transformer for further analysis and desktop studies.

Figure 27 First VRDT commissioning in Glasgow

2.1.6 Work Package 7 – Dissemination and knowledge sharing

Project team has conducted internal and external dissemination activities, a summary of these activities are as follows:

- **Knowledge sharing at ENIC** where the project was shared with a wider range of interested parties, with the aim of sharing lessons learned in 2020 and identifying new stakeholders. We also had the opportunity to build on our collaboration with UK Power Networks and deliver a live session on power electronic application challenges.

- **Linking into the power electronic forums** –In line with the commitment made at the proposal submission, we have been collaborating closely with Power Electronics UK and Compound Semiconductor Application (CSA) Catapult to stimulate the UK power electronic industry for grid application products. LV Engine team worked with the CSA Catapult to publish a position paper[1] on opportunities for the UK power electronic manufacturers. We also contributed to a webinar delivered on the 16th of September to engaged directly with UK power electronic community.

- **CIRED** – Two papers on LV Engine were presented as posters at CIRED Workshops in 2020. "An approach to assessing the effective integration of solid-state transformers in LV networks" was presented at a Workshop in January[2] and "Communication requirements for future secondary substation to enable DSO functions" in September 2020[3].

- **Internal staff awareness** – The project team has continued to share the project progress and lessons learnt with stakeholders within SPEN through various webinar events, raising awareness and preparing the business for the Smart Transformer technology. The team have also installed and commenced the trial of On Load Tap Changer transformer (OLTC).

- **IEEE Webinar** – LV Engine team submitted a paper to IEEE on "grid applications of smart transformers" in collaboration with Kiel University and Karlsruhe Institute of Technology[4].

- **IEEE Journal** – We have also submitted a journal paper to the IEEE Transactions on Smart Grid which is now under the review after response to the initial comments from reviewers.

- **LV Engine website** – We continue to update the LV Engine[5] website regularly with the materials developed by the project team and have passed our internal approval process.

- **ENA Working groups** – LV Engine team in collaboration with Active Response project team (managed by UK Power Networks) proposed a new working group to Energy Networks Associate to develop guidance on testing the power electronic devices. The proposal was accepted, and the first draft of the technical guidance is due to be published in early Q1 2021.

[1] https://csa.catapult.org.uk/events/power-electronics-in-electricity-networks-applications-opportunities-and-challenges/
[2] https://app.oxfordabstracts.com/events/1162/program-app/submission/156905
[3] https://app.oxfordabstracts.com/events/1162/program-app/submission/156850
[4] https://resourcecenter.ieee-pes.org/education/webinars/PES_Ed_web_LVEngine_022020.html
[5] https://www.spenergynetworks.co.uk/pages/lv_engine.aspx

2.2 Lessons learnt

In addition to the detailed analysis and technical knowledge presented in the reports produced during this reporting period (see section 2.3), the following summarises some of the learning made during the reporting period from each of the active work packages.

2.2.1 Work Package 2

Market Research on LV CBs and Linkbox Switches

- Problems with heat and condensation can occur in some controllable link box switch designs. This was found during previous NIC projects, but technical details were not reported in their dissemination reports. This is an on-going problem leading to plans by one manufacturer to completely re-engineer their controllable link box switch design. These re-designed controllable link box switches will not be ready within the LV Engine project timescales.
- There are reliability problems with Power Line Carrier communication which one manufacturer uses in their controllable link box switch design.
- The technology readiness level of controllable link box switches available on the market are not at a stage where the project feels they can be reliably used. The project has decided to remove controllable link box switches from its LV automation solution.

2.2.2 Work Package 3

SST Design

- The Strathclyde University earthing report recommended that the SST tank may not solidly earthed due to potential DC leakage current leading to corrosion. However, under ESQCR the SST tank will have to be solidly earthed. The SST manufacturer has confirmed that no adverse DC leakage current or corrosion problems will occur.
- Smaller size bushings and cable boxes may be used to reduce the overall dimensions of the SST. The initial specifications for bushings are those for transformers which can be relaxed for the SST (Topology 1) unit.
- Protection of the SST Topology 1 is required by fuses at the entry terminal to comply with the 25MVA fault level design at LV. Fuses need to be serviceable in case of any fault within the cable connected zone between the SST Topology 1 and the LV board.
- To allow the DC protection strategy relying on undervoltage relay, SST Topology 1 DC supply needs to be stable during transient HV voltage depressions to prevent undervoltage protection tripping on the outgoing MCCB on the LVDC switchboard.
- The SST design shall consider jack and rail handling in the substation + lifting points in the corners.
- The SPM 33kV network interconnection within a group may be changed which can impact fault levels, this should be considered in the protection grading studies.
- The UPFC design is preferable over the back to back (AC/DC/AC) design for SST Topology 1 solution. As the UPFC design offers a more efficient, smaller footprint, more reliable and less expensive solution than the back to back design. In addition, UPFC does not limit the fault current to the LV network whereas back to back arrangement does have this limitation;
- The status of LV network (radial or interconnected) may not be available to SST (or a local smart control system) in a real-time basis, therefore the control strategy for delivery of SST services (e.g. voltage control or power flow control) should not rely on the real-time information from network;
- The voltage at SST LV terminal should remain stable in the event of sudden change in demand to ensure the quality of supply to the customers is not affected. For that reason,

SST control strategy in response to active (P) and reactive power (Q) setpoints is to revert to voltage control mode after achieving the setpoint. In another words, SST will not lock to the P&Q set points after achieving them but will lock to the resultant voltage after achieving P&Q set points;

- The services expected from SST (e.g. voltage control, imbalance cancelation, power factor correction etc) at full rating may not be required at the same time. Designing SST for provision of all services concurrently at full rating leads to unnecessarily overdesigning the product. Instead, priority of services can be considered so that some of the services may gracefully degraded if SST reaches its thermal ratings;
- For devices connected to the HV network, the insulation requirements are to pass the impulse lightening voltage of 75kV and withstand voltage of 28kV in compliance with IEC 60076-3. In SST Topology 2 will have power electronic modules connected directly to the HV network. Although the bushing and insulation to the enclosure can be designed to satisfy IEC 60076-3 power electronic devices are very susceptible to excessive overvoltage condition. Therefore, some specific design considerations should be considered to protect the power electronic modules in overvoltage conditions. LV Engine's existing design is to stack up extra power electronic modules at HV to build the tolerance against 28kV however further design options to meet the 75kV lightening impulse are being assessed.
- The safety policy for working around grid connected capacitor devices should be considered for power electronic devices too. Capacitors may be used in the design of a power electronic device, for example SST requires an internal DC link which is constructed by series of capacitors. In order to avoid any capacitor charge shock to operation staff, SST should be fitted with a discharging mechanism. Also, operation staff should be able to test internal charges using multi-meters and test points available on SST local interface before conducting any work on SST (e.g. replacing the fuses).
- SST design for LV Engine will provide 24V DC supply through the local interface. This can be used for any telecommunication supply with no need for extra auxiliary supply in the substation. SST will be also able to issue 24V DC inter-tripping voltage to the ring main unit (shunt trip coil) which will be used in overall protection strategy.
- The spare parts required for SST should be available in the substation to ensure operation staff can have immediate access to spare parts in case of failure. SST designed in LV Engine has an allocated compartment for the spare parts especially 800A fuses.
- Power electronic devices may have limited capability in temporary overloading and adequate fault current contribution to allow operation of protection devices based on existing operation practices. More innovative solutions for fault identification and protection should be developed if power electronics are to be effectively deployed in both AC and DC distribution networks.
- From the review of previous literature, the life cycle analysis of similar SST technology has been assessed which showed that the environmental impact is worse for an SST when compared to a conventional transformer. The information gained from previous literature will be used in further analysis and comparison of the derived environmental benefits of the live trials of the SST within Work Packages 5 and 6.
- The ISO 14040 standard was used directly within this study, with no alterations or deviations made. This standard can be used for studies of electrical equipment and the wider electricity network. An LCA study can be facilitated through the use of an established software providing a standardised approach and a broad range of material/component information.
- The majority of carbon emissions associated with the SST came from power losses. Equipment utilising more power electronic devices on the electricity network will increase losses and associated carbon emissions. Improving efficiency of power electronic devices should be a priority as more are introduced onto the network.

- The second largest contributing area to carbon emissions from the SST was manufacturing and assembly. This is again due to the use of power electronic devices. These devices require more rare earth minerals to be extracted and processed which have higher associated carbon emissions and other environmental impacts. Reducing the carbon emissions from these processes should be a continuing focus of research and development within power electronics. Alternatively, power electronic devices which utilise materials that have lower associated carbon emissions should be selected for use in equipment, if technical requirements can be satisfied.
- Other environmental impacts, such as human health and ecosystem quality, were shown to be impacted by the SST mainly through losses and manufacturing. These areas should be carefully considered within the lifecycle of new and existing equipment. While focusing on reducing carbon emissions these other environmental categories must not be overlooked when making decisions on materials, design or use cases.
- This study will form learning for managing whole life carbon associated with SP Energy Networks operations in line with PAS2080 Carbon Management in Infrastructure. The results from the study, the process used, and these learnings will be disseminated to the project partners and the wider industry.
- The transition between the fault operation and the post-fault operation of the SST will lead to a high voltage variation. The soft-switching of operation modes is proposed to limit or even avoid the transition.

Smart Control System

- Different objective functions were considered for the SCS in order to deliver the maximum benefit to SPEN's customers:
    - In radial operation the objective function is to minimize feeder loading (using the conservation voltage reduction (CVR) principle of operation for constant impedance loads and inferred V/kW, V/kVAr relationships for constant power loads;
    - In meshed (interconnected) operation, the objective function is to match the SST set point to the local active power load and share reactive power with other transformers to offset their reactive power requirement.
    - The constraints associated with any objective functions will be assets thermal rating and configurable voltage limits ensuring compliance with statutory limits.
- In situations where the open/closed status of a linkbox is not monitored, sensitivity studies (sensitivity of load variation to voltage variation) can be used as an alternative method for determining whether or not two substations are interconnected;
- At present, LV Substation and Smart Meter data is recorded with 1-hour averages. Whilst this is appropriate for initial studies, finer granularity data is required to understand, design and test the control system dynamics;
- Taking into account practicalities of data flows and latencies, the SCS will be designed to operate based on real-time knowledge of power flows and voltages at the distribution substations, real-time smart meter voltage excursion alarms and forecast voltages at strategy points along LV feeders based on machine learning techniques and utilizing 24-hour data roll-ups from the previous day's operation together with historical data sets.
- Provision of a specific set points for power flow control may not be an optimum solution, instead a range of active and reactive powers may be considered to avoid frequent change in set points and control complication. This is to be considered in the control strategy for both the SST and local smart control system.
- The voltage dependency of loads must be included in studies, and the overarching control philosophy, to determining the optimal running arrangements for the network.

- A fit-for-purpose model for SST to represent their behaviour and allow for the full range of control variables to be developed, tested and utilised in the control system algorithm.
- Consideration was given to future disruptive loads such as EVs. The SCS control philosophy needs careful consideration and refinement when a future large update of EVs becomes prevalent within LV distribution networks. This is because EVs are constant power loads and the use of CVR is no longer appropriate as this will cause an increase in currents and an increase in network losses.

2.2.3 Work Package 5

- Working in power control mode during interconnected operation may cause some rapid voltage rise or voltage drop if the LV interconnection is opened unexpectedly. Voltage capping as a secondary control loop will be considered, and also we are doing further work to finalise the control strategy.
- Using the LVDC supply by DNOs can reduce the cost of EV chargers significantly. This is a strong enabler for the uptake of EVs.
- Prolonged outage of scheme 4 (DC only substation) There will be no heating in the substation without an auxiliary 230V AC supply. This could lead to varying temperatures, humidity, and condensation on the SST components. Corrosion of expensive SST parts could occur if condensation is not controlled during prolonged outage.
- Network outage scenarios can result in very long fault clearance times due to reduce fault infeed. However, LVCBs tend to perform better than gU fuses (of an equivalent rating) due to a thermal overload characteristic (60s to 1hr).
- There will be no 230V AC supply at the Scheme 4 trial site (Falkirk). Normally a secondary substation has a 230V AC 13A socket available. However, to provide this from the +/-475V DC LV supply would require a circa 3-4kVA DC/AC inverter which would be physically large and expensive, so is not going to be provided.
- LVCBs operate faster than the gU fuses of the same rating. This can cause coordination issues between LV feeders with a mix of LV CBs and gU fuses depending on substation interconnection.
- Interconnected LV networks introduce challenges with of the co-ordination of LV fuses and LV circuit breakers. All outage and network rearrangement scenarios shall be considered in protection grading studies
- Low fault levels from the SST will mean conventional overcurrent and earth fault protection will not work on feeder circuit breakers.
- Faults applied at three phase customer premises located at the end of long feeders have shown, in initial studies, that potential lack of coordination can occur where upstream substation protection (315A LVCB curve) operates faster than a customer fuse due to the combined load and fault currents seen at the substation. Further investigation into the impact of load modelling (i.e. voltage insensitive load) on this is required. Moreover, service cables may burn out prior to upstream LVCB operation regardless but requires service cable damage curves to verify.
- There are no specified margins related to coordination between LV protection (i.e. customer fuse and upstream fuse/LVCB). Grading of curves where overlap is avoided seems to be a good rule of thumb to ensure sufficient coordination. Compare this with 400ms coordination margin with 11kV protection. Protection grading curves will be used to ensure coordination is achieved between LV protection devices.
- The asymmetrical fault current contribution of SST direct model in DIgSILENT depends on the settings of additional zero-sequence and negative sequence impedance that used to represent the converter controller status. The initial assumptions have been given.

Modelling possibilities are limited in DIgSILENT. More precise parameterisation would improve accuracy. There is an inherent limitation in the direct model when compared to the dynamic model.

- The static loading (pre-fault) of the network can have an impact on the overall thermal capability of the SST during the fault. This can be significant if the SST supplies constant power loads. Consideration for future deployment and further investigation into the ZIP load combinations in the residential and commercial areas in the UK is required.
- For the LVDC earthing design, previous learning has been primarily taken from the rail industry where return conductor rails are not always properly insulated from earth. Experience has proven that no damage occurs to tracks over a period of 25 years if the average stray current per unit length does not exceed 2.5mA/m, (average stray current per unit length of track).
- Under the Electricity, Supply, Quality and Continuity Regulations (2002) (ESQCR), which all DNOs must by law adhere to, this would not be allowed by regulation 8(3) which requires that a generator or distributor shall ensure that no impedance is inserted in any connection with earth of a low voltage network which he owns or operates. In order to reduce the risk of stray DC currents to earth we have proposed the use of TN-S earthing as opposed to TN-C or TT earthing. Out of these three systems, TN-S would result in the least amount of stray current being produced in the protective earth or surrounding soil.
- LVDC switchboard for Falkirk – DNO LVAC switchboards used in GB secondary substations are typically based on ENA TS 37-2 (PENDA1) which in turn references IEC 61439-5 (PENDA). These specifications and standards are not currently applicable to DC switchboards. LVDC switchboard manufacturers are currently quoting us switchboard designs based on IEC 61439-2 which is the standard in common use in the industrial and commercial standard. We are developing our own technical specification which will reference and be in-line with IEC 61439-2. However, if there is to be a nationwide rollout of LVDC switchboards, then it might be better to revise ENA TS 37-2 and IEC 61439-5 so that they are applicable for DC applications.
- Our initial work on LVDC earthing recommended that LVDC mid-point/neutral is not solidly earthed due to potential DC leakage currents leading to corrosion. However, under ESQCR the neutral is required to be solidly earthed. As our LVDC network is small (~40m of cable) there should not be a risk of corrosion due to DC leakage currents. However, if an extensive rollout of LVDC networks is to take place in GB the problems of leakage currents and earthing needs quantifying. It may require changes to ESQCR to allow unearthed DC networks to be operated or allow protection devices (which only operate under fault conditions) to be inserted between the neutral and earth in DC networks.

2.2.4 Work Package 6

- One of the safety requirements identified for the application of VRDT at the secondary substation is to avoid any tapping (automatic or manual) when operation staff are conducting any switching operation. This can be allowed by isolating the power supply to the local control unit
- Safety documents for operation and installation of the SST and LVDC should be completed, approved and understood by operation and delivery staff before commissioning day. Due to very innovative nature of the project, relevant operation and delivery staff should be involved in document development.

2.2.5 Work Package 7

- Through the interaction with UK power electronics community, we learnt there is a strong capability in the UK in design and manufacturing power electronics and control system

[1] Public Electricity Network Distribution Assemblies

products. However, the automotive and aerospace industry mainly attracts this capability with little presence in grid application products.

- The limitations for physical attendance in the events during Covid-19 has provided opportunity for the team to reach out to a wider audience through webinars. We plan to build up on that experience and conduct more webinars (but interactive sessions) during LV Engine project.

2.3 Project reports and materials

During the reporting period the following reports have been generated to document the learning made within the project to date:

Document	Summary
LVDC Switchgear Technical Specification	Requirements for the supply and delivery of Low Voltage Direct Current (LVDC) switchgear for use in power distribution at the LV Engine trial site.
Enclosure Technical Specification	A specification for the LVDC substation enclosure at Falkirk.
OLTC commissioning method statement	safety procedures and methods statements for installing and commissioning secondary substation transformers fitted with on-load tap changers
Deliverable 2 Report (LCA & detailed design)	The Life Cycle Assessment part compares the environmental costs of manufacturing, delivering, installing, operating and disposing of the SST versus a conventional oil filled transformer. The detailed design part describes the design of the SST power electronic devices, internal layout, topology and the control strategy.
Wrexham protection study	A protection co-ordination / grading study for the Wrexham site. Deals with the challenges of how to co-ordinate the LV circuit breakers at the substations with service fuses at properties under the lower system fault levels due to the use of SSTs. Looks at all the possible network running arrangements and fault levels.
Wrexham system studies report	Described the modelling work carried out at the Wrexham trial site. Produced graphs showing relationships between voltage set points, active power flows, reactive power flows and resultant system voltages and thermal loadings. Produced heat maps showing areas of thermal and voltage stress. Modelled power flows under different operating and developed high-level SST and LV automation control strategies for Scheme 1, Scheme 2 and Scheme 3.
UoK smart oversizing SST	provides recommendations for the SST topology 2 design (100% power electronics). Looks into over-sizing the SST components to deliver increased fault levels to allow protection systems to operate. Considers whether some or all of the three power electronic stages in the SST require over-sizing.

These documents can be made available to interested parties upon request, in line with SP Energy Networks Data Sharing Policy.

2.4 Project Issues

We have encountered the following project issues in this reporting period, nonetheless there is no material change to be reported at this stage:

- Covid-19 Pandemic – The risk of pandemic and its impact worldwide was not expected during LV Engine programme development. The recent pandemic has introduced a number of issues to the project, nonetheless, we have been working to find alternative solutions and reduce the impacts where possible. At this stage we are not expecting any material change to be reported as a result of the Covid-19 pandemic. The issues and the solutions are as follows:
    - Supply chain – The lead times for procuring some of the components have been longer than initially expected. In some cases, the suppliers temporarily suspended all or part of the orders due to shortage of raw materials. That specially became an issue for the components required for manufacturing SSTs. EGB have reported several of the issues, however, they actively change the suppliers with larger stock availability and also ordered materials/components more than the volume needed for LV Engine to make the order more attractive to the suppliers.
    - Business priority – LV Engine relies heavily on SPEN's design, operation and delivery staff whose core responsibility is to ensure the continuity and quality of the electricity supply to our customers. Electricity network is a critical infrastructure, new working arrangements needed to be in place to ensure health and availability of personnel. For example, site activities were prioritised or some of the staff had to participate as backup in critical operation activities. LV Engine team needed to adapt the working arrangement accordingly and delay some of the site works, site visits and face-to-face activities.
- Delay in SST Topology 2 design – We encountered some challenges in developing SST Topology 2 , especially for the design of power electronic modules interfacing the HV network. 1.2kV Sic modules, which are commercially available in the market, were initially considered for manufacturing the HV stage of SST Topology 2. However, after several design optioneering and thermal studies, it appeared that size and reliability of the SST may not be realistic/acceptable for grid application in the secondary substations. Following these findings, EGB team carried out extensive fresh market engagement and it appeared that we could rely on 2.0kV Sic modules which will be commercially available in Q1 2021 with the early product release can be used by EGB team in late Q4 2020. Deploying the 2.0kV Sic modules can significantly reduce the size and design complexity of the SST Topology 2. This change in strategy to achieve a better product has delayed the completion the SST Topology 2 design for around four months compared to the initial plan which was completion by end of 2020. EGB has now validated the thermal behaviour of the 2.0kV units and we are certain that we can go ahead with this product. At this stage, we do not envisage any material change to manufacturing SST Topology 2, however, any new update will be reported in the next reporting period.

2.5 Outlook to the next reporting period

In the next reporting period, the project critical path will be:

- Completion of manufacturing and factory acceptance test of SST Topology 1;
- Completion of design and manufacturing SST Topology 2;
- Installation and commissioning the DC site at Falkirk Stadium;
- Progress on installation and commissioning trial sites in Wrexham
- Development of safety documents, operation and manual documents and deliver relevant training prior to any commissioning.

Furthermore, the following progress is planned in the next reporting period under different work packages:

Work Package 3 – Design and Manufacturing of SST

- Complete and approve the benchtop testing for SST Topology 1
- Complete the detailed factory test schedule and agreed between SPEN and EGB
- Complete manufacturing SST Topology 1 with FAT passed and approved
- Finalise design for SST Topology 2, progress on prototyping and manufacturing
- Finalise the LV Engine control philosophy,
- finalise the software and hardware of local control system
- Progress on LV Engine/Holistic central control system with inclusion of smart meter data in the control system
- Prepare and submit LV Engine Deliverable #3

Work Package 4 – Network Integration testing

- Finalise the testing schedule for SST Topology 1
- Progress on the testing schedule for SST Topology 2
- Appoint the network integration testing facility
- Progress on testing SST Topology 1 in network integration testing facility
- Prepare a submit LV Engine Deliverable #4

Work Package 5 – Live Trials

- Install and commission Falkirk DC trial site
    - Finalise Civil and electrical design
    - Ordering DC and HV AC switchgears
    - Finalise and implement the protection strategy
    - Establish Telecom and monitoring equipment
    - Carry out site acceptance tests and commissioning
- Progress on Wrexham site preparation and commissioning
    - Finalise Civil and electrical design
    - Integrate the LV CBs into SPEN IT/OT systems
    - Complete Civil works at two secondary substations

  - Order all the LV and HV switchgears
  - Continue engagement with Wrexham Council for opportunity to trial LV DC in Wrexham

Work Package 6 – Novel approach for transformer selection

- Finalise the safety documents required for commissioning and operation of LV DC and SST
- Deliver necessary trainings to delivery and operation staff to adopt new technology
- Install and commission two more VRDT as planned in Dumfries and Edinburgh
- Collect the monitored data from VRDT operation

Work Package 7 – Dissemination

- Organise and hold UK DNO workshop to share lessons learnt
- Technical papers for relevant conferences and articles
- Share lessons learnt at ENIC (or similar event/conference)
- Continue to share project progress and lessons learnt with stakeholders within SPEN
- Update the LV Engine website with the new document created by the project team

3 Business Case Update

There has been no reported change to the Business Case submitted in the Full Submission Proposal (FSP) during the reporting period.

4 Progress against plan

4.1 Key Achievements and project highlights

4.1.1 SST Design

Project successfully progressed on the SST design. The following key highlights have been achieved:

- Design completion of SST Topology 1 and ensuring the mechanical design and interfaces are suitable for integration to secondary substations;
- Securing materials required for manufacturing SST Topology 1 and reducing the impact of Covid 19 on supply chain. EGB is now receiving the materials and the benchtop testing has now started;
- Confirming the 2.0kV Sic modules can be used for the HV stage of SST Topology 2 which will significantly reduce the size of the unit and improve the unit overall reliability;
- Completion and submission LV Engine Deliverable #2 which consists of two reports covering the SST detailed design and also the life cycle assessment of the SST;
- Smart Control System manufacturer project partner has been appointed.

4.1.2 Trial Site Developments

- DC trial site for LV Engine have been secured with a connection agreement and wayleaves are now in place with the DC customer (Falkirk Council);
- Considerable progress on civil and electrical design of Falkirk site;
- Considerable progress on electrical design of Wrexham site.

4.2 Project issues

As reported in Section 2.4 the SST Topology 2 design is expected to finish with four months delay compared to the plan provided in the last reporting period. No material change to any of the LV Engine deliverables is expected at this stage.

4.3 Key activities planned for upcoming reporting period (2021/22)

As summarised in Section 2.5, the key activities in the next reporting period are planned to achieve the following:

- Manufacture SST Topology 1 with all the necessary tests passed;
- Commission DC trial site at Falkirk Stadium;
- Conduct the network integration testing;
- Commission at least one of the substations in Wrexham;
- Submit deliverable #3 and #4 of LV Engine.

4.4 Dissemination

The project team has a planned dissemination programme, aligning with UKPN's Active Response project. Key dissemination events include:

- Share lessons learned at ENIC and other relevant events;
- Submitting papers within academic forums;
- Holding DNO workshop to share lessons learned and obtain feedback.

5 Progress against budget [CONFIDENTIAL]

6 Project Bank Account [Confidential]

7 Project Deliverables

The project deliverables set out in the Project Direction links with the Project Milestones and the identified targets directly. This project deliverables can be used to check the progress of the project delivery and position the progress against the original proposal.

Table 3 shows a summary of the LV Engine deliverables defined in the Project Direction.

Table 3: LV Engine project deliverables

Reference	Project Deliverable	Deadline	Comment
1	Technical specification of SST and functional specification of the LV Engine schemes' including relevant control algorithms	10/12/18	**Completed** - This deliverable is now completed and submitted to Ofgem within deadline
2	Detailed technical design of SST by the manufacturer and life cycle assessment	22/12/19	**Completed** – This deliverable is now completed and submitted to Ofgem. Deliverable was delayed by 12 months.
3	Manufacture SSTs for LV Engine schemes	11/01/21	**In Progress** – This deliverable will be prepared in collaboration with SST manufacturing partner
4	Complete network integration tests	28/09/20	**In progress** – This deliverable will be prepared in collaboration with Network Integration Test Facility provider
5	Establish the system architecture of LV Engine schemes	20/06/21	**In Progress** – This deliverable will be prepared in collaboration with Intelligent and control system partner and internal SPEN IT & real-time system team
6	Demonstrate the functionalities of SST	20/06/22	**Not Started**
7	Best operational practices of SSTs	07/11/22	**In Progress**
8	Identify a trial site for replicating LV Engine solution within UK Power Networks	26/09/22	**Not Started**
N/A	Comply with knowledge transfer requirements of the Governance Document.	End of project	**Not Started**

SPEN confirm that adequate resources for project management and project delivery have been planned for upcoming deliverables. Resources are available internally in different parts of SPEN organisation and also additional supports will be provided by our project partners.

8 Data access details

The Publicly Available Data Sharing Policy is available via SPEN's website: www.spenergynetworks.co.uk/pages/lvengine.aspx

9 IPR

LV Engine complies with the Ofgem default position regarding the IPR ownership and no further IPR is to report at this stage. However, we are working with project partners to finalise the list of IPRs and the type of IPRs generated in LV Engine. This list will be ready and reported in the next reporting period.

10 Risk Management [CONFIDENTIAL]

11 Accuracy Assurance Statement

I therefore confirm that processes in place and steps taken to prepare the PPR are sufficiently robust and that the information provided is accurate and complete.

Signature: ____________________

Name (Print): ____________________

Title: ____________________

Date: ____________________

Signature: ____________________

Name (Print): ____________________

Title: ____________________

Date: ____________________

12 Material Change Information

None to report

13 Other

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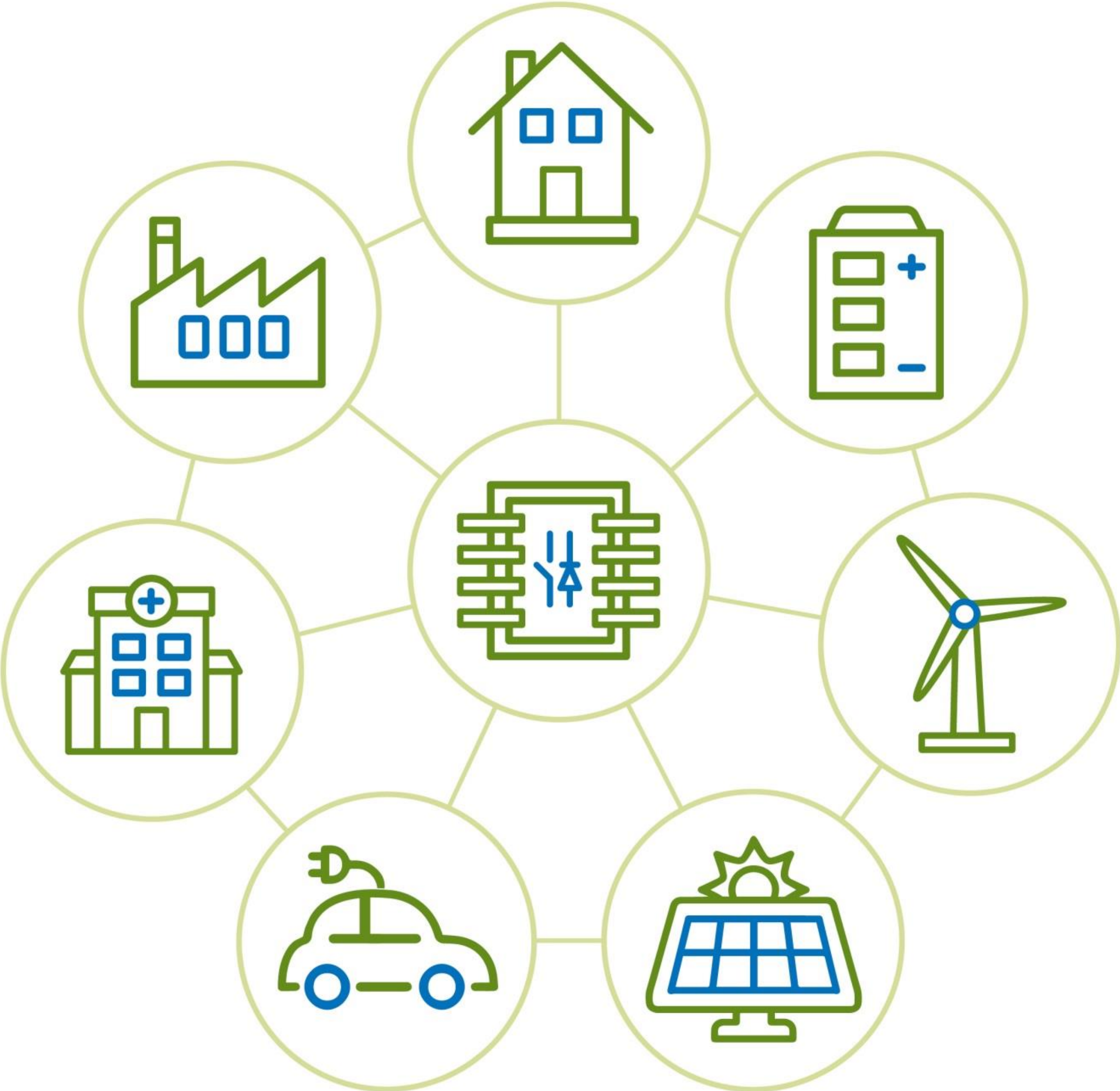

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