SP ENERGY NETWORKS

LV ENGINE

Project Progress Report

Work carried out during 2022

Internal Use

About Report

Report Title	:	LV Engine Project Progress Report 2022
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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 currently due to conclude in December 2024.

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 fifth in the series of annual progress reports for the LV ENGINE project and covers the period January 2022 to January 2023, 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.

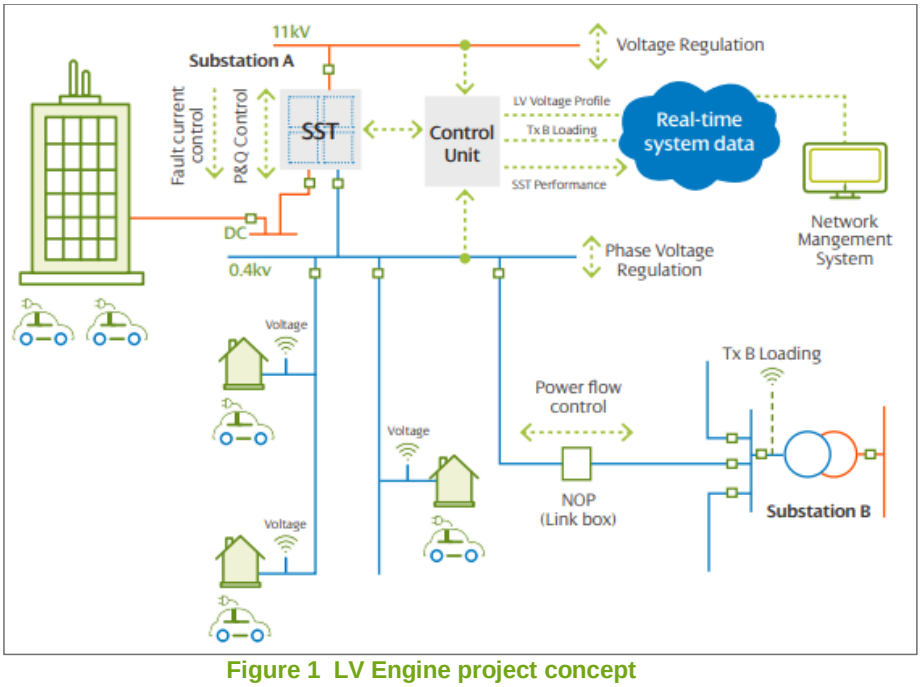


Figure 1 LV Engine project concept

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, there are different possible SST topologies which have been considered as part of LV engine to deliver the stated core functionalities. The two topologies considered are summarised below:

- ***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 electronics devices can be added to the existing distribution transformers to deliver the Core Functionalities of LV Engine. The aim is to enhance the Technology Readiness Level (TRL) of this product from 6 to 9.

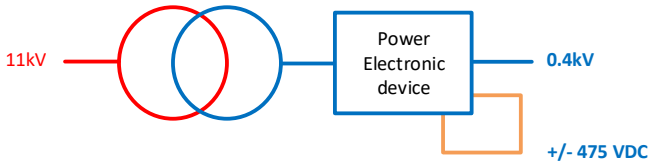


Figure 2 SST Topology 1

- ***Topology 2*** *- Topology using 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 the TRL of this product from 5 to 8.

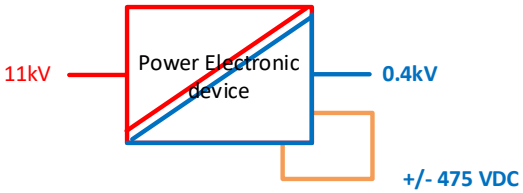


Figure 3 SST Topology 2

1.3 Project Highlights

The project is currently planned to be completed by Dec 2024 and the highlights in this reporting period are as follows:

- **SST Prototyping and testing (Deliverable #3) –** The main progress in 2022 was to build the final SST Topology 1 prototypes, carry out factory tests and improve the design/build where issues identified during the factory tests.

    - **SST Topology 1 -** Three 500kVA prototypes (engineering units) have now been built and factory tests at full power have been conducted. We encountered a number of issues during the tests, the two main issues being: i) thermal management issues at full power and ii) performance during the short circuit events. Solutions to those issues have now been developed, new components have now been delivered and we expect the factory tests on the prototypes to be completed before end of Q1 2023. In addition to those three prototypes, and based on learnings gathered through the prototyping, the first SPEN unit has been mostly

built. SPEN's technical team has also attended some of the factory tests at Ermco-Gridbridge factory in early January 2023.

- **SST Topology 2 –** The main progress on this topology was the work on the HV interface designs. The stackable HV modules (the modules which will be put in series to interface the HV network) have been built and passed some initial bench tests. In spite of this progress, based on learning gathered through various design alternatives, bench testing, and the status of supply chain, LV Engine team have concluded that SST Topology 2 is not a viable option to offer a commercially and technically justifiable solution. The team is committed to sharing these learnings in a dedicated report on this product before LV Engine project close-down. On that basis, we decided to stop the effort on this topology and focus on technology readiness elevation of SST Topology 1.

- **Trial site preparation and installation (Deliverable #5 and #6) –** Purchasing the equipment and site preparation have progressed further during 2022 to ensure all the equipment and necessary design are in place when SST is shipped to the UK.

  - **Wrexham Trial sites (AC schemes) –** The majority of civil work for the two substations in Wrexham were completed in previous reporting period, however, further substation wirings and equipment fitting conducted in 2022. Also, Kelvatek Weezap LV Circuit Breakers were installed and commissioned in one of substations following internal staff training and completion of business approval processes.

  - **Falkirk Trial site (DC Schemes) –**HV duct installed at the road crossing to reduce the risk of delay closer to the time of full substation installation. Also, we expect the LVDC switchboard designed for this substation is completely manufactured and tested before end of Q1 2023. DC EV chargers have been manufactured and are now enroute to Scotland.

- **Network Integration Testing (Deliverable #4) –** One of the key activities under this deliverable is to de-risk the customers security of supply and ensure there is no operation issue with LV Engine scheme by testing the performance of LV Engine solution in a controlled laboratory environment. For this purpose, Power Networks Demonstration Centre (PNDC) was appointed to conduct the tests prior to live trials. We have prepared a test plan document reflecting the test rig layout, components needed to be purchased for these tests and test schedule. All components are now ordered or delivered. We should be ready to start the tests very soon after SST is delivered to the UK. PNDC is currently booked for the test in early Q2 2023.

- **LV Engine system architecture and monitoring (Deliverable #5 and #6) –** Design and implementation of LV Engine system architecture have progressed significantly during this reporting period. After establishing the system architecture and use cases, we commissioned Avara to update the firmware of the router turning it to a smart hub at LV Engine substation. This router provides necessary communications with three devices (SST, LV CBs, Control unit) at the substations and reports to SPEN internal data historian and visualisation platforms. We expect the full end to end tests and commissioning to take place by mid Q2 2023.

- **UK Power Networks collaboration –** we continued collaboration with UK Power Networks by sharing the first-hand learnings between Active Response and LV Engine projects as agreed in the project full submission. For resourcing this collaboration, Ricardo was appointed to support identifying number of potential deployments of Active Response solutions in SPEN distribution networks. The work has progressed and we expect to complete the report by end of Q1 2023. As previously committed, we also plan to embark on a feasibility study to identify potential deployments of LV Engine solutions within UKPN licensed distribution networks. This activity is planned to start in July 2023.

- **Best Operational practices of SST (Deliverable #7)**
  In order to create the prospect of using the LV Engine solution within RIIO-ED2, we have started a number of detailed studies on selected LV networks, where reinforcement is required. These studies assess whether the LV Engine solution is a better option technically and commercially compared to conventional reinforcement. This activity is in-line with Deliverable #7 objective providing SPEN with LV Engine BaU adoption guidance and recommendations.

- **Disseminations**
  Similar to previous years, we continued to share the learnings of the project via different platforms and through different events. That includes submissions of technical papers to CIRED and IET AC/DC conferences, presentations at the SPEN stand in the Energy Innovation Summit, participation in Cenex event, drafting a white paper of market status of Solid- State-Transformers, and presenting in the PEMD event.

1.4 Project Issues

We encountered the following project issues in this reporting period that contributed to the overall delay of the project.

- SST Testing – We encountered a number of issues during the factory testing and one of them resulted in catastrophic failure during the test. This has been investigated to understand the cause and propose the remedy. Although we have built three prototypes so far to allow continuation of the factory tests on the remaining alternative units, the seriousness of this failure required further efforts for redesigning some key components.

- Covid-19 Pandemic – The post pandemic impact on supply chain remained an issue during this reporting period, as reported previously. Most manufacturers and suppliers experienced significant backlog as a result of supply chain and resource availability issues. This particularly affected three components in LV Engine: SST, DC ultra rapid EV charger and LVDC switchboard.

- SST Topology 2 manufacturing – After manufacturing HV modules of SST Topology 1 and passing initial factory tests, we came to the conclusion that building the SST Topology 2 cannot offer a technically and economically justifiable solution. The continuation of this product could have caused project further delay and overspend. Therefore, we decided to halt that development and instead focus on SST Topology 1 to ensure a commercially ready product will be available by project completion.

1.5 Key lessons learnt

- Based on the existing semiconductor technologies, learning generated from the design, manufacturing during LV Engine, and an independent assessment by a third party, the

project team came to the conclusion that LV Engine cannot elevate the SST Topology 2 technology to a reliable grid product within the project budget offering value to customers. Therefore, we have opted to halt efforts on manufacturing of this product and focus on SST Topology 1 product.

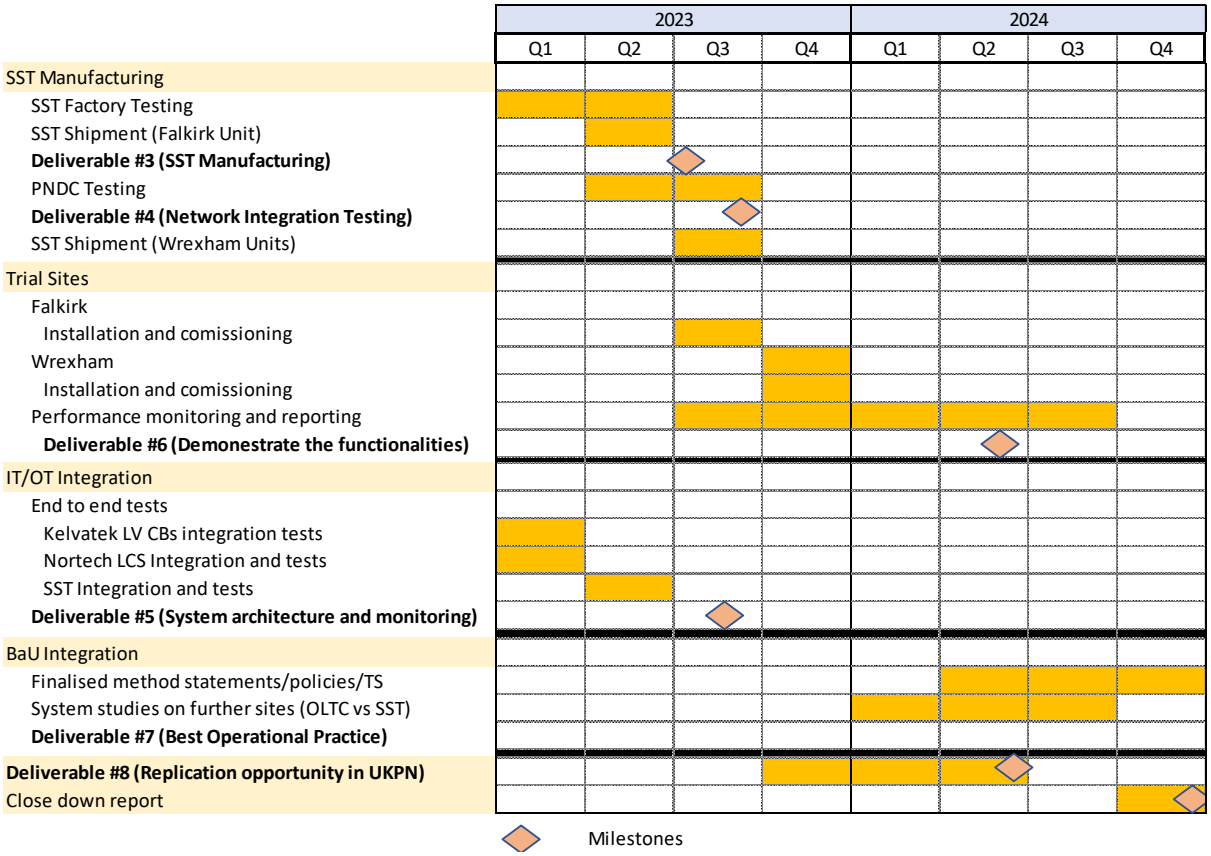
- Testing IT/OT system integration for the new devices manufactured by different suppliers located in different countries can be a very challenging task. End-to-end test can be mimicked by remote connecting to the devices at one end (while they are still with the manufacturers) to a non-DNO cloud environment and set SPEN as a listener at the other end.
- Manufacturing a number of full-size prototypes (Engineering units) can inform blue prints for the final assembly of the product, provides better flexibilities during the tests for parallel activities and also reduce risk of delay to the programme in case of catastrophic failure to any of the units during the test.

1.6 Summary of key activity in next reporting period

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

- Finalise the factory acceptance test of SST Topology 1 and shipment to the UK;
- Complete testing the first SST Topology 1 at the Power Network Demonstrations Centre focusing on DC protection strategy;
- Install and commission the DC site at Falkirk Stadium;
- Progress in installation and commissioning the Wrexham trial site focusing on AC functionalities.
- Develop safety documents, operation and maintenance documents and deliver relevant training prior to any commissioning;
- Submit LV Engine Deliverables #3 and #4 and #5.

The latest project programme for the remaining years is as follows:



2 Project Manager's Report

This section provides an overview on the project progress made in this reporting period (15th January 2022 – 16th January 2023). The project's Work Packages were progressed in different aspects in this reporting period. The key project highlights are significant progress in completion of prototyping 3 x SST Topology 1 units and factory testing, also a number of other devices required for LV Engine solution have been manufactured and tested. The following section elaborates on progress and shares some of the learnings captured during this reporting period.

2.1 SST Design and Manufacturing

The main focus in 2022 was to complete SST Topology 1 prototyping and carry out factory tests. We also progressed on design and building modules of SST Topology 2 although as explained further below we concluded that Technology Readiness Level (TRL) elevation expected at the start of project cannot be achieved during LV Engine and therefore it is better to focus resources on delivery and TRL elevation of SST Topology 1.

SST Topology 1 – Three prototypes of SST Topology 1 have been built. These full-size prototypes were mainly built for initial factory tests and also prepare blueprints for the final product assembly.

Ermco-Gridbridge, SST manufacturing partner, operate in two locations:

i) Raleigh – focusing on power electronics technology and control system
ii) Dyersburg – focusing on manufacturing, assembly and tests

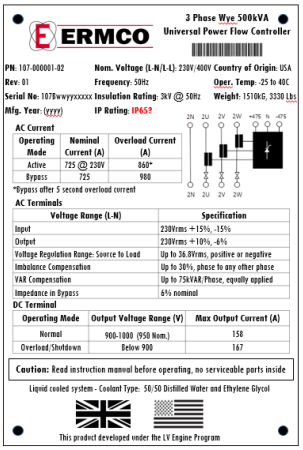
Manufacturing three prototypes before assembly of final products provided a great flexibility for parallel activities in the two aforementioned locations and also contingency in case of damage to any of these units during the test. Figure 4 shows one of the prototypes and nameplate design for SST Topology 1. The following key tests successfully completed for SST Topology 1 during this reporting period:

- Operation in full power – After a series of testing in different power level and conditions, units were also tested in continuous nominal rating (725A) and temporary overloading conditions. Further tests are scheduled in Q1 2023 for full power operation for a long period to capture any thermal issue if there is any.

- Short Circuit Test – Safe operation of the unit under network fault conditions (~15kA rms) has been a challenging requirement. A special Solid State Relay (SSR) has been built and tested for bypassing the power electronic units in case of network faults. The operation of SST under short circuit condition and it ability to withstand against the fault was tested in an independent short circuit facility.

- High potential tests – Dielectric tests for up to 3kV were successfully passed and confirm the adequacy of insulation design.

Figure 5 shows the units under various tests. SPEN technical team attended Ermco-Gridbrige facilities in both locations (Raleigh and Dyersburg) to witness the tests and carry out overall Ermco-Gridbrige factory inspection.



(a) (b)

Figure 4 (a) SST Topology 1 Prototype (b) Nameplate designed for this device

(a) (b)

Figure 5 (a) SST Topology 1 prototype under various tests in Ermco-Gridbridge facility (b) SST Topology 1 under short circuit tests in KEMA facility

In addition to the significant progress on the tests, the following key activities were also completed:

- Developed and tested the graphic user interface application that will be used to configure the device and allow troubleshooting locally;
- Drafted operation and maintenance manual detailing installation, commissioning and operation of the device;
- Completed DNP3 profile documents and tested all the DNP3 data points.

Due to number of technical and market issues (see section 2.8 for more details), we experienced a delay in our programme reported previously that aimed to complete the factory tests in 2022. Therefore, we expect the following progress in the next reporting period specifically related to SST Topology 1:

- Completion of Factory tests and shipment of the first unit to the UK in early Q2 2023;
- Manufacturing and shipment of remaining 2 units to the UK by Sep 2023.

SST Topology 2 – The design, build and benchtop testing of SST Topology 2 was progressed although we opted to bring the majority of Ermco-Gridbrige resources onto SST Topology 1 development. A summary of the progress made is provided below:

- Stackable High Voltage Modules (SHVM) were built and successfully bench tested, see Figure 6. We decided to use hard duty transparent enclosures to allow visual inspection during the test.

- HV cabinet design was finalised. Team decided to use have a cable connection arrangement between the HV cabinet and LV cabinet. This provided better flexibility within the substation depending on the dimensions of the substation and space available. See Figure 7 the overall design and dimensions of the HV cabinet.

Figure 6 Stackable High Voltage Unit

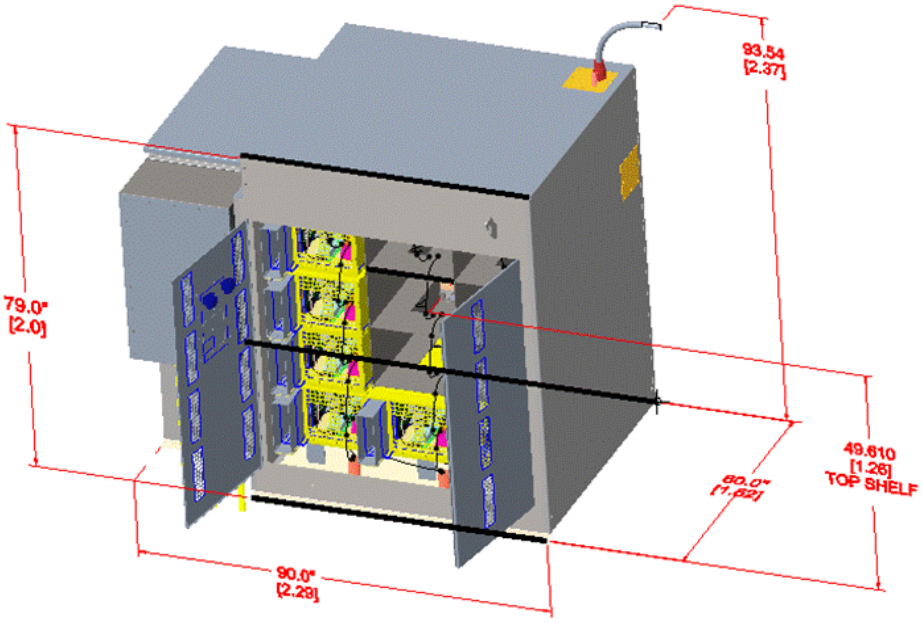


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Figure 7 HV Cabinet for SST Topology 2

In spite of the progress made during 2022, the LV Engine team have come to the conclusion that further effort to manufacture and trial SST Topology 2 is very unlikely to result in a high TRL (~8) product as initially expected. On that basis and in order to avoid project overspent and further delay to the project, we have opted to stop the effort on this development. Considering our commitment to disseminate transparent learnings, SPEN will provide a separate report, before project completion, detailing out learnings and recommendations for future efforts to build a full power

electronic transformer. It should be mentioned that the decision to halt manufacturing SST Topology 2 will not impact any of the LV Engine schemes initially planned to be trialled nor any of the learnings expected to be generated from the project.

2.2 Trial site preparation

The majority of site preparation work was carried out during 2021, however, there have been a number of site developments and equipment procurement activities during 2022.

2.2.1 Wrexham

As reported previously, all civil works and LV cabling were completed in 2021. The main progress in Wrexham was the commissioning of Kelvatek LVCBs in Crescent Road substation. These circuit breakers will provide monitoring capability (transient and average), automation for closing the LV interconnection and also flexibility for adjusting protection settings when we use power electronic equipment (if required). The commissioning was carried out after a training session delivered by Kelvatek to our operation staff. Figure 8 shows a picture of the commissioning day.

Figure 8 SPEN Wrexham operation team commissioning Kelvatek LVCBs

2.2.2 Falkirk

Falkirk stadium will host the first UK LV DC substation aimed to be delivered by LV Engine. All the legal, wayleaves and connection agreements have been finalised. All the equipment is either delivered or delivery is imminent. For this reporting period, the progress highlights are summarised below:

- Schneider Electric was appointed, through a competitive tender process, for design, build and delivery of the LV DC switchboard. This switchboard has now been designed and built. The factory test plan is currently under review with the aim to complete all the factory tests in March 2023. Figure 9 shows the LVDC switchgear designed for LV Engine DC scheme.

- The HV cable route for Falkirk substation needs to cross the road at the entrance to the Falkirk stadium car park. Considering that the Stadium usually has a busy event calendar, we decided to complete the HV ducting for the two road crossings to de-risk

any project delay that may happen due to the stadium's busy calendar in the future, see Figure 10.

- Two Tritium ultra-rapid 150kW DC fed EV chargers have now been delivered, one to PNDC and one to Falkirk Council. The PNDC charger will be used only for testing the scheme performance and protection strategy prior to installation work in Falkirk.

- The unit Transformer+ Ring Main Unit for Falkirk has now been built and shunt trip coil fitted and tested by Schneider Electric. They are now stored in our depot ready for commissioning day.

- As part of our DC protection strategy informed by various system studies and design, we identified the need for deploying an Earth Leakage Relay. Following the market research conducted in previous reporting period, we carried out short circuit withstand tests in PNDC on those relays short listed and which complied with our requirements. Following our tests in PNDC, Bender RCMB 301 passed all the test and chosen to be used for LV Engine project. See Figure 11 the test set up in PNDC.

- In order to de-risk the protection strategy, also informing the LVDC protection solutions beyond LV Engine, we developed a protection logic controller design that can detect the transient DC fault behaviours and discriminate the faulted feeder among multiple feeders. This logic can be a replacement to over current protection solutions and can be flexibly retrofitted to DC switchboards. The design is now complete, and we are planning to build and test this solution by end of Q2 2023.

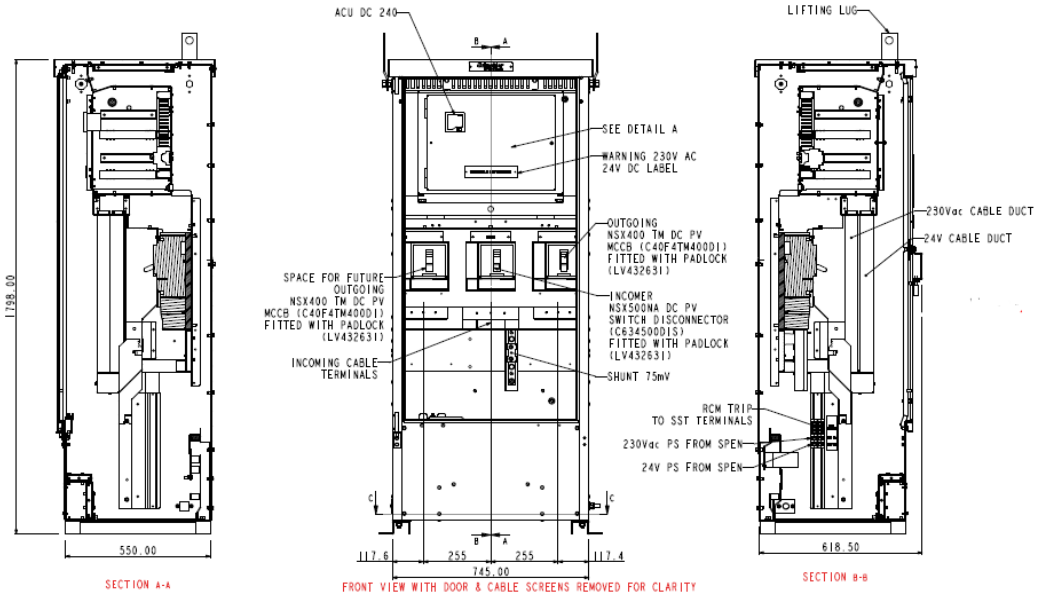

Figure 9 – LVDC switchboard designed for Falkirk

Figure 10 HV duct road crossing for Falkirk Stadium

Figure 11 Short circuit withstand tests for earth leakage relays in PNDC

2.3 Monitoring and system integration

In line with LV Engine Deliverable #5, Establish the system architecture of LV Engine schemes, we progressed significantly on LV Engine system architecture and integration of monitored data into our IT system. We have aligned LV Engine with the overall SPEN RIIO-ED2 strategy to ensure a better value for money and more enduring solution.

A summary of progress highlights in this reporting period is provided below:

- I/O schedule – A complete I/O schedule has been reviewed and confirmed by all vendors and SPEN has developed and established it.

- 4G Router firmware upgrade – the router's firmware update progressed significantly and has been tested for delivery of various functions including interface with LV Engine equipment (in total equipment from three different vendors, averaging functions, protocol conversion from DNP3 to IoT, IP allocation etc). This 4G router acts as a smart hub in the secondary substation reporting performances
- Field Online development - This system will be used to publish key events from the field, which are of interest to internal IT/OT systems. The development of this system and tests are now complete.
- System testing – LV Engine equipment will be supplied by different vendors located in different countries. It was important for the team to test the communication between each equipment and the router prior to any site commissioning. In order to facilitate an initial test, we established VPN channels from vendors' offices to router supplier offices to allow live communication of the devices with the router. SPEN will be using an Azure environment for data handling, SPEN's Azure settings and proxies were mimicked by the router vendor. SPEN was a listener via service bus client to receive the data for final checks and interfaces with internal platforms. This test has now successfully been carried out de-risking the final field implementation when all devices are in the substation.

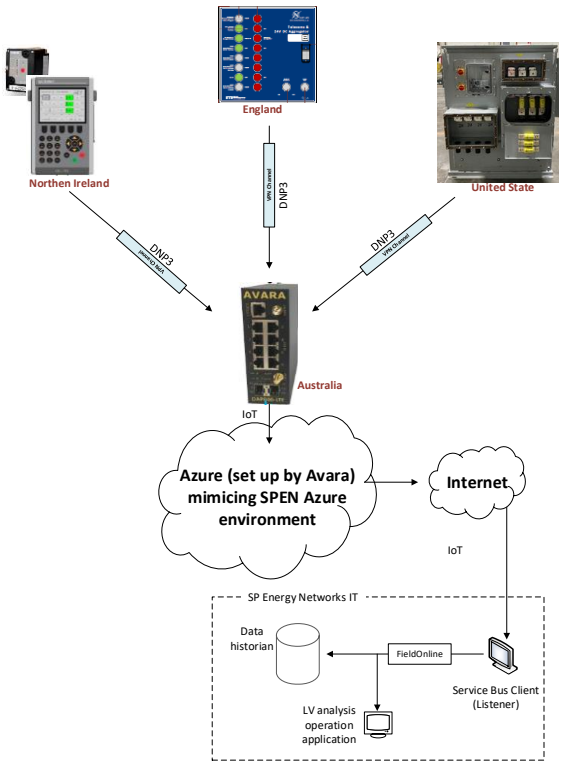

Figure 12 Simplified LV Engine system architecture

LV Engine system architecture, use cases, data flows and details of system integration requirements will be published in LV Engine Deliverable #5 which is currently drafted.

2.4 Network Integration Testing

In preparation for network integration testing (Deliverable #4), Power Network Demonstration Centre (PNDC) were awarded to work closely with SPEN and other LV Engine partners on the preparation of the test plan and test execution. Our initial aim is to test our LVDC protection strategy

as we currently see it as the main risk to our schemes 4 and 5. The following work was carried out in this reporting period:

- All the equipment required for this test has been purchased and layout of the equipment in PNDC LV bay has been agreed. We have all the equipment delivered to PNDC except SST which is due for delivery before mid May.
- A detailed test plan has been prepared and documented based on a number of workshop and technical discussions held between SPEN and PNDC.
- Safety requirements have been reviewed and agreed.

A simplified schematic diagram showing the set up and measurement points for the LVDC system testing is shown in Figure 13.

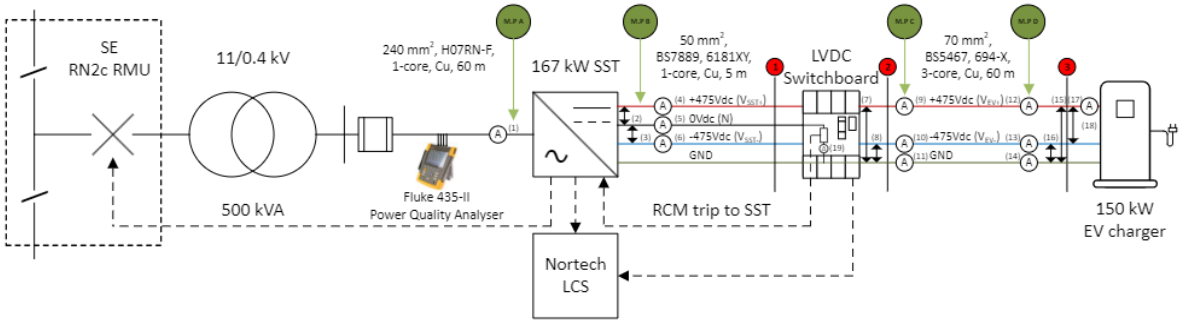

Figure 13 schematic showing the LVDC testing setup in PNDC

2.5 BaU integration

The LV Engine team has committed to consider the BaU integration of the solution and pave the way for technology adoption before project completion. We have started to run a number of system studies to show the impact of the LV Engine solution on a number of LV networks. The aim is to produce techno-economical procedures and criteria for the design engineers to use when they consider LV Engine solution. We have already identified potential sites where the LV Engine solution can be deployed to alleviate thermal and voltage issues in LV networks. This work will contribute directly to LV Engine Deliverable #7. Figure 14 shows an example of this study where a network with thermal and voltage issues could be improved by using LV Engine solution.

Figure 14 LV network with thermal and voltage issues (left) could be improved by using LV Engine solution and network reconfiguration (right)

2.6 Disseminations

Knowledge sharing continues to be a core element of LV Engine's activities to ensure our internal and external stakeholders are aware of project progress, project learnings and challenges. Key highlights on dissemination activities during this reporting period are as follows:

EIS – We had the opportunity to present the latest project learnings and some technical challenges during Energy Innovation Summit in 2022.

CIRED WG – We continued to provide inputs to LV DC distribution networks CIRED working group based on learnings from LV Engine.

SST market research white paper – We commissioned the Compound Semiconductor Applications (CSA) Catapult to have a fresh look into the status of the power electronics market and the challenges in supply chain for manufacturing power electronic transformers. The learnings from that work will be published in form a white paper on LV Engine website.

IET AC/DC conference – The learnings captured from technical studies carried out for our LVDC protection strategy were presented in IET AC/DC conference 2023.

Internal staff awareness – We continue 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 and voltage regulation distribution transformer technologies.

Participation in Cenex event – The Cenex event focusing on e-mobility was an appropriate platform for LV Engine team to disseminate the LVDC technology for ultra-rapid charger and the scheme we plan to demonstrate.

IET PEMD presentation – The LV Engine team was invited as the one of the key speakers in IET Power Electronics, Drive and Machine conference in Newcastle. We had the opportunity to promote LV Engine technology and learnings generated from the project to industry and academic parties.

2.7 Project reports and materials

During the reporting period the following reports and materials have been generated to document the learnings generated within the project to date:

Document	Summary
Protection Study for LV DC multiple feeders	This report considers the potential solutions for protecting a substation with multiple outgoing LVDC feeders while the total load is very close to the source (DC/DC converter) ratings.
Network Integration Test Plan (This will be part of **Deliverable #4** submission)	This report provides the test schedule and requirements for testing LV Engine schemes which will be carried out in PNDC.
Operation and Maintenance Manual of SST (this will be part of **Deliverable #3** submission)	This is the O&M document comprising installation, commissioning and operation of the SST. An important document produced for the first time for this product designed and manufactured in LV Engine.
Initial power system studies for SST deployment (Beyond LV Engine)	This document shows the studies carried out for number of LV networks within SPD and SPM licence areas for effectiveness of SST and its potential benefits.
Market Assessment of Full Power Electronic SST (Topology 2)	A fresh market assessment providing insight into the status of power electronic supply chain and impact of that on future manufacturing of SSTs especially SST topology 2.
Test result report on Earth Leakage Relay	Outcomes of Earth Leakage Relay testing carried out in PNDC which results in qualifying one of the relays for LV Engine trial sites.
LV Engine monitoring and performance document (This will be part of **Deliverable #5** submission, in draft currently and under review)	This report reflects the work carried out for data integration of LV Engine schemes within our IT system.
Design for LVDC protection logic solution	This report provides detailed design of the LVDC logic protection developed through the project. We have used this design to progress into prototyping phase.
O&M manual for Local Control System	This report provides the operation and maintenance manual for the local control system built and tested by Nortech.

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

2.8 Project Issues

We have encountered the following project issues in this reporting period which are the main causes of the delay in the project to date:

SST Manufacturing and testing issues – The major full power tests, thermal tests and short circuit tests conducted in this reporting period. While most of the tests passed the requirements, we encountered number of issues that contributed to project delay during this reporting period:

- Bypass system – As stated in the previous reporting period, the solid state relay (SSR) designed to bypass the device did not fulfil the initial factory tests. Consequently, Ermco-Gridbridge team redesigned it, built the new SSR and tested in various stages. The second prototype also did not pass the tests due to higher speed of processing required to detect the overload conditions activating SSR. However, the third attempt for the design was successful and final build was established.
- Thermal issue – The operation of SST under full load resulted in an uncontrolled temperature rise in the isolation transformer in the DC/DC converter. Therefore, a new engagement with the DC/DC transformer supplier started in parallel with new market research for similar transformers. Eventually, a new design for transformer with extra cooling pipes was agreed with the original supplier. They have now provided their prototype for testing. The initial tests confirmed the new design is expected to fulfil the thermal requirements. The final product is expected to be shipped to EGB in March 2023 to be fitted in the final SST product.
- DC-link failure – during various factory tests, DC capacitors forming the internal DC-link, failed. The diagnosis was that the presence of excessive DC ripples resulted in extra thermal stress on the capacitor and consequently failure. A new type of capacitor with better specifications was identified and purchased. The capacitors have a cubical shape whereas the original capacitors were cylinder shape, therefore, a new arrangement for fitting in the enclosure was also developed.
- SST Topology 2 manufacturing and design – Although HV modules for SST Topology 2 were designed, built and tested. After further work on the design of the product, we came to the conclusion that the existing semiconductor technologies will not result in a product that can be replicated for roll out. The highest voltage rating for Sic IGBTs that are currently commercially available are around 2.0kV, that requires at least 4 modules to stack up in each phase for 11kV network interface. We spent significant time designing and testing the HV SST layout and practicalities in terms of installations on site. The final dimensions of this product and process required for site installation did not offer a solution that we can replicate after project completion. We believe higher voltage Sic IGBTs will be available soon to the market that fundamentally change the design and size of this product. Therefore, to avoid any extra effort that will result in project overspend and delay, we decided to stop development of SST Topology 2. This decision does not have impact on the Core Functionality intended to be delivered by LV Engine solution.

Post pandemic challenges - Delays to supply chains and difficulty to secure resources have been challenges globally which affected LV Engine too. Although we had ordered/received the majority of materials, ordering new materials, which needed to address the issues we encountered during the factory test, has been a challenge with long lead times offered by the suppliers.

2.9 Outlook to the next reporting period

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

- Finalise factory acceptance test of SST Topology 1 and ship the first unit to the UK;
- Test the first SST Topology 1 at the PNDC centre focusing on DC protection strategy;
- Instal and commission the DC site at Falkirk Stadium;
- Develop safety documents, operation and maintenance documents and deliver relevant training prior to any commissioning;
- Submit LV Engine Deliverables #3, #4 and #5;
- Manufacture and ship the remaining 2 units of SST Topology 1 to the UK.

The following progress is planned in the next reporting period under specific work packages:

Work Package 3 – Design and Manufacturing of SST

- Manufacture all the three SST Topology 1 units and ship to the UK.
- Finalise and submit LV Engine Deliverable #3.
- Prepare detailed report on learnings gathered specially for SST Topology 2 manufacturing stop.

Work Package 4 – Network Integration testing

- Complete 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:
  - Install civil, HV connections and enclosure.
  - Install all the switchgear, cablings and wiring.
  - Finalise and approve internally the commissioning method statement
  - Carry out site acceptance tests and commissioning.
- Progress on Wrexham site preparation and commissioning:
  - Progress on installation the first SST Topology 1 in Wrexham.
- Commission telecoms and monitoring devices to allow remote performance monitoring of the device

Work Package 6 – Novel approach for transformer selection

- Finalise the safety documents required for commissioning and operation of LV DC and SST.
- Deliver necessary training to delivery and operation staff to adopt new technology.
- Prepare SST performance report contributing directly to Deliverable #6.

Work Package 7 – Dissemination

- Organise and hold UK DNO workshop to share lessons learnt.
- Produce 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. We aim to have a fresh business case developed after reviewing the performance of LV Engine solution in the live trial. The updated business case will be reported in project close down report after project completion

4 Progress against plan

4.1 Key Achievements and project highlights

4.1.1 SST prototyping and manufacturing

Project successfully progressed on the SST manufacturing and factory testing. The following key highlights have been achieved:

- 3 x full-size SST prototypes were manufactured and type tests significantly progressed.
- Short circuit withstand test was carried out in an independent laboratory test.
- Software and graphic user interface for configuration of SST were developed and tested.
- Stackable high voltage modules designed for SST Topology 2 were built and passed bench tests.

4.1.2 Trial Site Developments

- DC chargers for the pre-trial tests at PNDC and also installation in Falkirk substation have been delivered;
- LVDC switchboard design and manufacturing have been completed, factory tests are in progress;
- HV cable ducting for the road crossings was installed for our LVDC trial site (Falkirk);
- LV CBs were installed and commissioned in Falkirk.

4.1.3 Pre-trial network integration testing

The PNDC was appointed to support the pre-trial testing in its facilities. All the equipment required for this test is now purchased and a detailed test plan has been developed and documented ready for the test to start in around mid Q2 2023.

4.1.4 IT/OT integration

We significantly progressed on the design and testing of the LV Engine solution system architecture enabling us to monitor the performance of LV Engine solution. We are currently in final stages of our end to end tests.

4.2 Project issues

Delay in Deliverable #3 and #4 due to delay in manufacturing and testing of SST. These issues were reported in detail in Section 2.8.

4.3 Key activities planned for upcoming reporting period (2023/24)

As summarised in Section 2.9, the key activities in the next reporting period are planned to achieve the following:

- Deliver all three SST Topology 1 units to the UK with all the necessary tests passed;
- Commission DC trial site at Falkirk Stadium;
- Complete the network integration testing;
- Progress on installation and commissioning in Wrexham site;
- Submit deliverables #3 and #4 and #5 of LV Engine.

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

Table 3 LV Engine project deliverables

	Project Deliverable	Initial target delivery date	Status	Expected delivery date
1	Technical specification of SST and functional specification of the LV Engine schemes' including relevant control algorithms	10/12/18	**Completed**	-
2	Detailed technical design of SST by the manufacturer and life cycle assessment	22/12/19	**Completed**	-
3	Manufacture SSTs for LV Engine schemes	11/01/21	**Delayed- In Progress**	07/07/2023
4	Complete network integration tests	28/09/20	**Delayed – In progress**	15/09/2023
5	Establish the system architecture of LV Engine schemes	20/06/21	**Delayed- In Progress**	18/08/2023
6	Demonstrate the functionalities of SST	20/06/22	**Not Started**	24/05/2024
7	Best operational practices of SSTs	07/11/22	**In Progress**	26/07/2024
8	Identify a trial site for replicating LV Engine solution within UK Power Networks	26/09/22	**Not Started**	22/04/2024
N/A	Comply with knowledge transfer requirements of the Governance Document.	End of project	**Not Started**	15/12/2024

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: https://www.spenergynetworks.co.uk/pages/data_sharing_policy.aspx. LV Engine website is accessible via: 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 that will be reported in the final project close down report.

10 Risk Management [CONFIDENTIAL]

The summary of key risks and mitigation plans which are currently monitored in the project

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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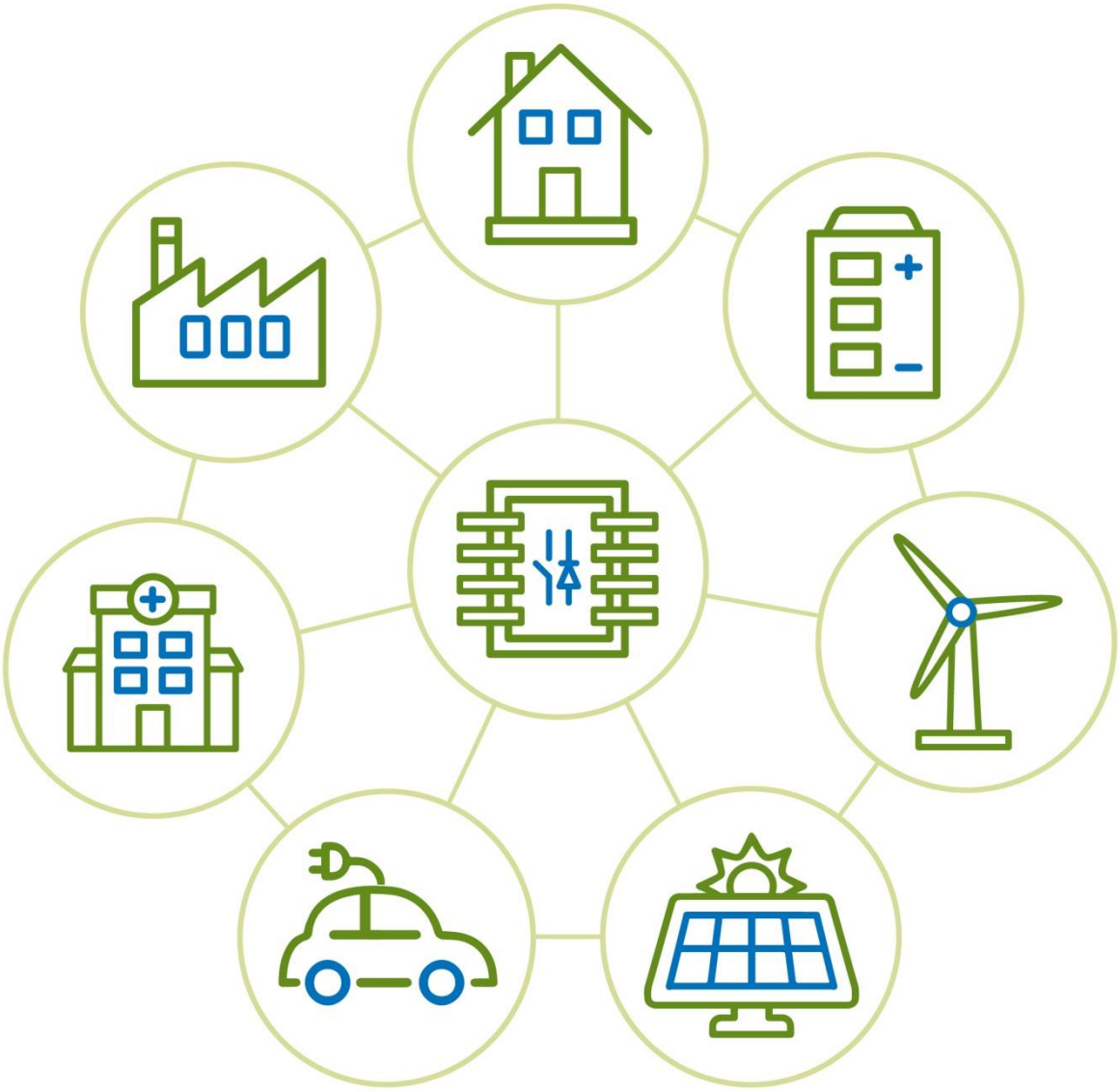

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